PLASTICS MATERIALS AND PROCESSES

A Concise Encyclopedia

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PREFACE

Plastics Materials and Processes: A Concise Encyclopedia defines the important concepts of the plastics industry in a single-volume encyclopedia. Materials, processes, properties, test methods, and other information that is used commonly throughout the industry are defined without great involvement in detail and in a manner that is straightforward and efficient. This book is aimed at meeting the needs of general managers, executives, purchasing and manufacturing personnel, supervisors, engineers, students, and all others that are working in the field of plastics or have interest in these important materials. It is expected that in today's robust working environment the time burdens on these individuals are greater than ever. When this limited time frame is coupled with the universe of exploding polymer technology, the resulting pressures may make it difficult to maintain an overall grasp of the information required to efficiently perform.

The selection of information provided in this book has been made with a view toward giving the reader an efficient, intelligent overall insight without having to wade through voluminous texts or handbooks in specific areas. It is not the purpose of the book to provide an exhaustive treatise on any subject, as it is assumed that the reader will consult more comprehensive and detailed texts, journals, and even the producers of materials and processing equipment for such specific and in-depth information. However, this book should make the journey to acquire such information easier and more efficient.

As the goal of this book is to provide a sourcebook of practical information for all ranges of interest, its organization is aimed primarily at reader convenience. The main body, therefore, consists of a concise encyclopedia of knowledge useful in today's plastics industry. It contains an extensive array of materials information and property and performance data presented in an alphabetical format. In addition, it presents all-important application guidelines, process method trade-offs, and design, finishing, and performance criteria. It also summarizes chemical, structural, and other basic polymer considerations.

This main body of information is preceded by a brief introduction to polymers and plastics that may be used to provide the reader with a "glue" to hold the individual snippets of information together. This initial section covers the nature of polymers, and it offers an introduction to the material and process descriptions that follow.

After the encyclopedia, are several appendices containing valuable property data and other detailed information. Here plastics and other materials commonly used in the industry are compared to one another, and guidance is offered regarding their processing methods and final applications. Finally, there is a completely cross-referenced and easy-to-use index that is provided as a road map for the preceding information and as a method of linking subjects and information together.

The result of this compilation is a concise, yet valuable reference to the broad amount of information required to function in the plastics industry. It will be a useful first-source to anyone involved in all aspects of product design, development, application, manufacturing, marketing, or other peripheral function in the plastics industry. The authors hope that this book will be the most worn book in the reader's reference library as a result of being the first choice for information.

CHARLES A. HARPER
EDWARD M. PETRIE

ACKNOWLEDGMENTS

This book is dedicated to my father, Edward J. Petrie, who has provided me with the materials and processes for everything that I do and, most importantly, the will to succeed.

—EDWARD M. PETRIE

INTRODUCTION

THE NATURE OF PLASTICS

Practically stated, a plastic is an organic polymer, available in some resin form or some form derived from the basic polymerized resin. These forms can be liquid or pastelike resins for embedding, coating, and adhesive bonding, or they can be molded, laminated, or formed shapes, including sheet, film, or larger-mass bulk shapes.

The number of basic plastic materials is large, and the list is increasing. In addition, the number of variations and modifications to these plastic materials is also quite large. The methods by which these materials are processed, finished, and prepared for final use is also immense. Together, the resultant quantity of materials and processes available is just too large to be completely understood and correctly applied by anyone other than those whose day-to-day work puts them in direct contact with a diverse selection of materials. The practice of mixing brand names, tradenames, and chemical names of various plastics only makes the problem of understanding these materials more troublesome.

Although there are numerous minor classification schemes for polymers, depending on how one wishes to categorize them, nearly all polymers can be placed in one of two major classifications—thermosetting materials (or thermosets) and thermoplastic materials. Likewise, foams, adhesives, embedding resins, elastomers, and so on, can be subdivided into thermoplastic and thermosetting classifications.

THERMOSETTING PLASTICS

As the name implies, thermosetting plastics or thermosets are cured, set, or hardened into a permanent shape. Curing is an irreversible chemical reaction known as cross-linking, which usually occurs under heat. For some thermosetting materials, curing is initiated or completed at room temperature. Even here, however, it is often the heat of the reaction or the exotherm that actually cures the plastic material. Such is the case, for instance, with a room-temperature-curing epoxy or polyester compound.

The cross-linking that occurs in the curing reaction is brought about by the linking of atoms between or across two linear polymers, resulting in a three-dimensional rigidized chemical structure. One such reaction is shown in Fig. IN.1. Although the cured thermoset part can be softened by heat, it cannot be remelted or restored to the

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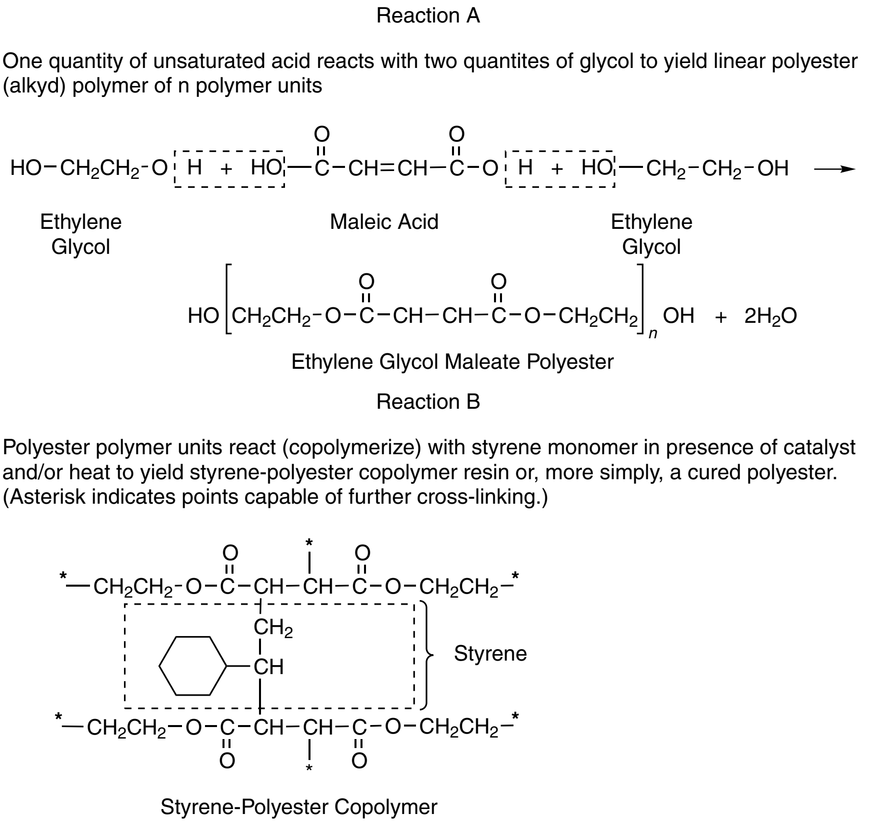

Reaction A

One quantity of unsaturated acid reacts with two quantites of glycol to yield linear polyester (alkyd) polymer of n polymer units

Reaction B

Polyester polymer units react (copolymerize) with styrene monomer in presence of catalyst and/or heat to yield styrene-polyester copolymer resin or, more simply, a cured polyester. (Asterisk indicates points capable of further cross-linking.)

Figure IN.1 Simplified diagrams showing how crosslinking reactions produce polyester resin (styrene-polyester copolymer resin) from basic chemicals.

flowable state that existed before curing. Continued heating for long times leads to degradation or decomposition.

In general, unfilled thermosetting plastics tend to be harder, more brittle, and not as tough as thermoplastics. Thus it is common practice to add filler to thermosetting materials. A wide variety of fillers can be used for varying product properties. For molded products, usually compression or transfer molding, mineral or cellulose fillers are often used as lower-cost, general-purpose filler and glass fiber fillers are often used or optimum strength or dimensional stability. There are also many product and processing trade-offs, but a general guide to the application of filler can be found in several major texts on the subject. It should be added that filler form and filler surface treatment could also be major variables. Thus it is important to consider fillers along with the thermosetting material, especially for molded products. Other product forms may be filled or unfilled, depending on requirements.

Table IN.1 Typical Tradenames and Suppliers of Thermosetting Plastics (Note: these are but a few, see Appendix N for an expanded listing.)

Plastic	Typical trade names and suppliers
Alkyd	Plaskon (Allied Chemical)
	Durez (Hooker Chemical)
	Glaskyd (American Cyanamid)
Diallyl phthalates	Dapon (FMC)
	Diall (Allied Chemical)
	Durez (Hooker Chemical)
Epoxies	Epon (Shell Chemical)
	Epi-Rez (Celanese)
	D.E.R. (Dow Chemical)
	Araldite (Ciba)
	ERL (Union Carbide)
Melamines	Cymel (American Cyanamid)
	Plaskon (Allied Chemical)
Phenolics	Bakelite (Union Carbide)
	Durez (Hooker Chemical)
	Genal (General Electric)
Polybutadienes	Dienite (Firestone)
	Ricon (Colorado Chemical Specialties)
Polyesters	Laminac (American Cyanamid)
	Paraplex (Rohm and Haas)
	Selectron (PPG)
Silicones	DC (Dow Corning)
Ureas	Plaskon (Allied Chemical)
	Beetle (American Cyanamid)

Plastic materials included in the thermosetting plastic category and discussed separately in the following sections of this book include alkyds, diallyl phthlate, epoxies, melamines, phenolics, polyesters, silicones, and ureas. A list of typical tradenames and suppliers of the more common plastics is given in Table IN.1.

THERMOPLASTICS

Thermoplastics differ from thermosets in that they do not cure or set under heat as do thermosets. Thermoplastics merely soften or melt when heated to a flowable state, and under pressure they can be forced or transferred from a heated cavity into a cool mold. On cooling in a mold, thermoplastics harden and take the shape of the mold. Because thermoplastics do not cure or set, they can be remelted and then rehardened by cooling. Thermal aging, brought about by repeated exposure to high temperatures required for melting, causes eventual

Table IN.2 Typical Tradenames and Suppliers of Thermoplastics (Note: these are but a few, see Appendix N for an expanded listing.)

Thermoplastic	Typical trade names and suppliers
ABS	Marbon Cycolac (Borg-Warner) Abson (B. F. Goodrich Lustran (Monsanto)
Acetals	Delrin (E. I. du Pont) Celcon (Celanese)
Acrylics	Plexiglas (Rohm and Haas) Lucite (E. I. du Pont)
Aramids	Nomex (E. I. du Pont)
Cellulosics	Tenite (Eastman Chemical) Ethocel (Dow Chemical) Forticel (Celanese)
Ionomers	Surlyn A (E. I. du Pont) Bakelite (Union Carbide)
Low-permeability thermoplastics	Barex (Vistron/Sohio) NR-16 (E. I. du Pont) LPT (Imperial Chemical Industries)
Nylons (see also Aramids)	Zytel (E. I. du Pont) Plaskon (Allied Chemical) Bakelite (Union Carbide)
Parylenes	Parylene (Union Carbide)
Polyaryl ether	Arylon T (Uniroyal)
Polyaryl sulfone	Astrel (3M)
Polycarbonates	Lexan (General Electric) Merlon (Mobay Chemical)
Polyesters	Valox (General Electric) Celanex (Celanese) Celanar Film (Celanese) Mylar Film (E. I. du Pont) Tenite (Eastman Chemical)
Polyethersulfone	Polyethersulphone (Imperial Chemical Industries)
Polyethylenes, polypropylenes, and polyallomers	Alathon Polyethylene (E. I. du Pont) Petrothene Polyethene (U.S.I.) Hi-Fax Polyethylene (Hercules) Pro-Fax Polypropylene (Hercules) Bakelite Polyethylene and Polypropylene (Union Carbide) Tenite Polyethylene and Polypropylene (Eastman) Irradiated Polyolefin (Raychem)
Polyimides and polyamide-imides	Vespel SP Polyimides (E. I. du Pont) Kapton Film (E. I. du Pont) Pyralin Laminates (E. I. du Pont) Keramid/Kinel (Rhodia) P13N (Ciba-Geigy) Torlon Polyamide-Imide (Amoco)
Polymethyl pentene	TPX (Imperial Chemical Industries)

Table IN.2 (*Continued*)

Thermoplastic	Typical trade names and suppliers
Polyphenylene oxides	Noryl (General Electric)
Polyphenylene sulfides	Ryton (Phillips Petroleum)
Polystyrenes	Styron (Dow Chemical) Lustrex (Monsanto) Dylene (Koppers) Rexolite (American Enka)
Polysulfones	Ucardel (Union Carbide)
Vinyls	Pliovic (Goodyear Chemical) Diamond PVC (Diamond Alkali) Geon (B. F. Goodrich) Bakelite (Union Carbide)

degradation of the materials and so limits the number of reheat cycles. Most of the common thermoplastics materials are discussed in detail in the following section.

Specific data on a variety of thermoplastics can be found in the following sections of this book. In general, thermoplastic materials tend to be tougher and less brittle than thermosets so that they can be applied without the use of filler. However, although some are very tough, others do tend to craze or crack easily, so each case must be considered on its individual merits. Traditionally by virtue of the basic polymer structure, thermoplastics have been much less dimensionally and thermally stable than thermosetting plastics. Hence, thermosets have offered a performance advantage, although the lower processing costs for thermoplastics have given the latter a cost advantage. However, three major trends put both thermoplastics and thermosets on a competitive performance consideration basis.

1. Much has been done in the development of reinforced, fiber-filled thermoplastics, greatly increasing stability in many areas.
2. Much has been achieved in the development of so-called engineering thermoplastics, or high-stability, higher-performance plastics, that can also be reinforced with fiber or fillers to increase their stability further.
3. Lower-cost processing methods for thermosetting plastics have been developed, especially the screw-injection molding technology.

All of these options should be considered in optimizing the design, fabrication, and performance of plastic parts.

A list of typical tradenames and suppliers of the more common thermoplastics is given in Table IN.2, and a list of so-called advanced thermoplastic materials is

Table IN.3 Advanced Thermoplastic Materials

Matrix systems	Abbreviation	Trade names and suppliers
Polyphenylene sulfide	PPS	Ryton (Phillips Petroleum)
Polysulfone	PSF	Udel (Union Carbide)
Polyetheretherketone	PEEK	APC (Imperial Chemical Industries)
Polyethersulfone	PES	Victrex (Imperial Chemical Industries)
Polyetherimide	PEI	Ultem (General Electric)
Polyamide-imide	PAI	Torlon (Amoco)
Polyetherketone	PEK	(Imperial Chemical Industries)
Polyamide	PA	J-2 (E. I. du Pont)
Polyimide	PI	K-III (E. I. du Pont)
Polyarylene sulfide	PAS	PAS-2 (Phillips Petroleum)
Polyarylene ketone	—	HTA (Imperial Chemical Industries)
Polyetherketoneketone	PEKK	(E. I. du Pont)

presented in Table IN.3. Specific data and information for a variety of thermoplastics are given in the main body of this book.

Glass Fiber-Reinforced Thermoplastics

Basically, thermoplastic molding materials are developed and can be used without filler, as opposed to thermosetting molding material, which are more commonly used with filler incorporated into the compound. This is primarily because shrinkage, hardness, brittleness, and other important processing and use properties necessitate the use of filler in thermosets. Thermoplastics, on the other hand, do not suffer from the same shortcomings as the thermosets and hence can be used as molded products without fillers. However, thermoplastics do suffer from creep and dimensional stability problems, especially under elevated temperature and load conditions. Because of this shortcoming, most designers find it difficult to match the techniques of classical stress-strain analysis with the nonlinear, time-dependent, strength modulus properties of thermoplastics. Glass fiber-reinforced thermoplastics (FRTPs) help to simplify these problems. For instance, 40 percent glass fiber-reinforced nylon outperforms its unreinforced version by exhibiting 2-$^1/_2$ times greater tensile and Izod impact strengths, 4 times greater flexural modulus and only 1/5 of the tensile creep.

Thus FRTPs fill a major materials gap in providing plastic materials that can be reliably used for strength purpose and which in fact can compete with metal die castings. Strength is increased with glass fiber reinforcement, as are stiffness and dimensional stability. The thermal expansion of FRTPs is reduced, creep is substantially reduced, and molding precision is much greater.

The dimensional stability of glass-reinforced polymer is invariably better than that of the nonreinforced materials. Mold shrinkages of only a few mils per inch are characteristic of these products. Low moisture absorption of reinforced plastics ensures that parts will not suffer dimensional increase under high-humidity conditions. Also, the characteristic low coefficient of thermal expansion is close enough to metals, such as zinc, aluminum, and magnesium, that it is possible to design composite assemblies without fear that they will warp or buckle when cycled over temperature extremes. In applications where part geometry limits maximum wall thickness, reinforced plastics almost always afford economies for similar strength or stiffness over their unreinforced equivalent. A comparison of some important properties for unfilled and glass-filled thermoplastics is given in the Appendices.

Chemical resistance is essentially unchanged, except that environmental stress crack resistance of such polymers as polycarbonate and polyethylene is markedly increased by glass reinforcement.

Plastic Films, Tapes, and Fibers

Films are thin sections of the same polymers described previously. Most films are thermoplastic in nature because of the great flexibility of this class of resins. Films can be made from most thermoplastics. Films are generally made from thermoplastic resins by extrusion, casting, calendering, and skiving. The films are sold in thicknesses from 0.5 to 10 mil. Thickness in excess of 10 mil is more properly called sheets. Tapes are films slit from film to some acceptable width and are frequently coated with adhesives.

Films differ from similar polymers in other forms in several key properties but are identical in all others. The most important features of common films are summarized in Table IN.4. Films differ from other polymers chiefly in improved electric strength and flexibility. Both of these properties vary inversely with the film thickness. Electric strength is also related to the method of manufacture. Cast and extruded films have higher electric strength than skived films. This is caused by the greater incidence of holes in the latter films. Some films can be oriented, which improves their physical properties substantially. Orienting is a process of selectively stretching the films, thereby reducing the thickness and causing changes in the crystallinity of the polymer. This process is usually accomplished under conditions of elevated temperature, and the benefits are lost if the processing temperatures are exceeded during service.

Certain polymeric materials are also available in fiber form. These are generally thermoplastic materials. Synthetic polymeric fibers are used significantly in the garment industry. They are also being used increasingly in the design and manufacture of reinforced composites. Like other forms of polymers, fibers offer properties that can vary significantly based on the base material, fillers and modifiers, and the processing methods chosen.

Table IN.4 Film Selection Chart

Film	Cost	Thermal Stability	Dielectric Constant	Dissipation Factor	Strength	Electric Strength	Water Absorption	Folding Endurance
Cellulose	Low	Low	Medium	Medium	High	Medium	High	Low
FEP fluorocarbon	High	High	Low	Low	Low	High	Very low	Medium
Polyamide	Medium	Medium	Medium	Medium	High	Low	High	Very high
PTFE polytetrafluoroethylene	High	High	Low	Low	Low	Low	Very low	Medium
Acrylic	Medium	Low	Medium	Medium	Medium	Low	Medium	Medium
Polyethylene	Low	Low	Low	Low	Low	Low	Low	High
Polypropylene	Low	Medium	Low	Low	Low	Medium	Low	High
Polyvinyl fluoride	High	High	High	High	High	Medium	Low	High
Polyester	Medium	Medium	Medium	Low	High	High	Low	Very high
Polytrifluorochloroethylene	High	High	Low	Low	Medium	Medium	Very low	Medium
Polycarbonate	Medium	Medium	Medium	Medium	Medium	Low	Medium	Low
Polyimide	Very high	High	Medium	Low	High	High	High	Medium

POLYMER STRUCTURE

All polymers are formed by the creation of chemical linkages between relatively small molecules, or monomers, to form very large molecules, or polymers. As mentioned, if the chemical linkages form a rigid, cross-linked molecular structure, a thermosetting plastic results. If a somewhat flexible molecular structure is formed, either linear or branched, a thermoplastic results. Illustrations of these molecular structures are presented in Fig. IN.2.

Many carbon-hydrogen chain elements tend to gather and behave in basic groups. The hydrogen in a basic group could be substituted by some other element or group to form a new group. These basic groups could then react with each other in a head-to-tail fashion to make large molecules and larger macromolecules. Also, a group can react with a different group to form a new larger group, which can then react with itself in a head-to-tail fashion to produce the desired new macromolecule. These basic groups are

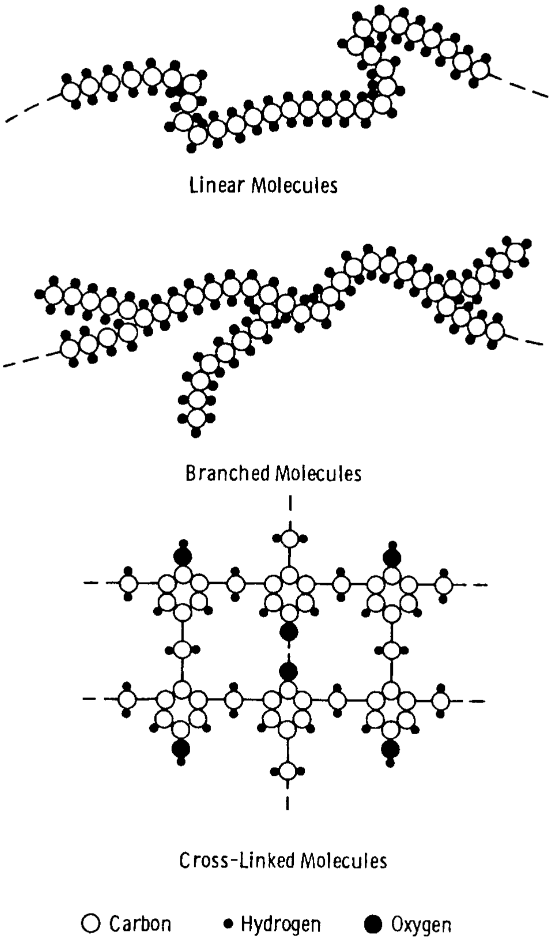

Figure IN.2 Some possible molecular structures in polymers.

called monomers; and when they are head to tail or polymerized into long chains, they form polymers. The reaction between different basic groups to form a new basic recurring group is called copolymerization. These copolymers can also recur in a head-to-tail fashion to form long-chain molecules. The basic monomers are usually gases or very light liquids; and, as polymerization continues, the molecular weight and viscosity both increase until solidification and formation of the gum or solid production results.

The degree of polymerization can be controlled so that the end product has the desired processing properties but lacks the final properties for engineering use. The long chains in this state have a great deal of mobility between them, which also varies greatly with slight changes in temperature. Some such materials are useable as thermoplastic materials. These long chains can react further with themselves or with other chemicals.

The general principles relating mechanical properties of polymers to structures have been known for many years. Rubbers, plastics, and fibers, for example, are not intrinsically different materials. Their differences are a matter of degree rather than kind. If the forces of attraction between the molecular chains are small, and the chains do not fit readily into a geometric pattern, lattice, or network, the normal thermal motion of the atoms tends to cause the chains to assume a random, more or less coiled arrangement. These conditions lead to a rubberlike character.

In practical rubbers, a few cross-links are added to prevent slippage of the molecular chains and permanent deformation under tension (or flow). With such polymers, when the stress is released, the normal thermal motion of the atoms causes them to return to a random-coiled arrangement. If the forces between the chains are strong and the chains fit easily into a regular geometric pattern, the material is a typical fiber. In cases where the forces are moderate and the tendency to form a regular lattice is also moderate, the result is a typical plastic.

Some polymers are made and used as three different materials: rubber, plastic, and fiber. Polyethylene, for example, is used as a substitute for natural rubber in wire covering, as a plastic in low-loss stand-off insulators and insulation films, and as a fiber in acid-resistant filter cloths where high fiber strength is not as important as chemical resistance.

PLASTIC PROCESSING METHODS AND DESIGN GUIDELINES

Although many users of plastics buy parts from plastic processors, they should still have some knowledge of plastic processing, as such information can often be helpful in optimizing product design. Also, an increasing number of user companies are doing some in-house processing. For these reasons, some guideline information in plastic processing and some guidelines for the design of plastic parts are presented in the following section.

It should be mentioned that the information presented at this point applies broadly to all classes of plastics and types of processing. Most plastic suppliers will provide very specific data and guidelines for their individual production. This invaluable source of guidance is too-often unused. It is strongly recommended that plastic suppliers be more fully utilized for product design guidance. However, the information presented at this point will be valuable for making initial design and process decisions.

Table IN.5 explains the major ways in which plastic materials can be formed into parts and the advantages, limitation, and relative cost of each processing

Table IN.5 Descriptions and Guidelines for Plastic Processing Methods (Ref: Hauck, J. E., “Engineer’s Guide to Plastics”, *Materials Engineering*, February 1967)

Process	Description	Key advantages	Notable limitations	Cost factor*
Blow molding	An extruded tube (parison) of heated thermoplastic is placed between two halves of an open split mold and expanded against the sides of the closed mold by air pressure. The mold is open, and the part is ejected	Low tool and die costs; rapid production rates; ability to mold relatively complex hollow shapes in one piece	Limited to hollow or tubular parts; wall thickness and tolerances often hard to control	1.5–5, 2–3
Calendering	Doughlike thermoplastic mass is worked into a sheet of uniform thickness by passing it through and over a series of heated or cooled rolls. Calenders also are used to apply plastic covering to the back of other materials	Low cost; sheet materials are virtually free of molded-in stresses; i.e., they are isotropic	Limited to sheet materials; very thin films not possible	1.5–3, 2–5.5
Casting	Liquid plastic (usually thermoset except for acrylics) is poured into a mold (without pressure), cured, and removed from the mold. Cast thermoplastic films are made by depositing the material, either in solution or in hot-melt form, against a highly polished supporting surface	Low mold cost; ability to produce large parts with thick cross sections; good surface finish; suitable to low-volume production	Limited to relatively simple shapes; except for cast films, becomes uneconomical at high-volume production most thermoplastics levels; not suitable	1.5–3, 2–2.5
Compression molding	A thermoplastic or partially polymerized thermo-setting resin compound, usually preformed, is placed in a heated mold cavity; the mold is closed, heat and pressure are applied, and the material flows and fills the mold cavity. Heat completes polymerization, and the mold is opened to remove the part. The process is sometimes used for thermoplastics, e.g., vinyl phonograph records	Little waste of material and low finishing costs; large, bulky parts are possible	Extremely intricate parts involving undercuts, side draws, small holes, delicate inserts, etc., not practical; very close tolerances difficult to produce	2–10, 1.5–3

Table IN.5 (*Continued*)

Process	Description	Key advantages	Notable limitations	Cost factor*
Cold forming	Similar to compression molding in that material is charged into split mold; it differs in that it uses no heat—only pressure. Parts are cured in a separate operation. Some thermoplastic sheet material and billets are cold-formed in process similar to drop hammer-die forming of metals. Shotgun shells are made in this manner from polyethylene billets	Ability to form heavy or tough-to-mold materials; simple; inexpensive; often has rapid production rate	Limited to relatively simple shapes; few materials can be processed in this manner	
Extrusion	Thermoplastic or thermoset molding compound is fed from a hopper to a screw and barrel where it is heated to plasticity and then forwarded, usually by a rotating screw, through a nozzle having the desired cross-section configuration	Low tool cost; great many complex profile shapes possible; very rapid production rates; can apply coatings or jacketing to core materials, such as wire	Limited to sections of uniform cross section	2–5, 3–4
Filament winding	Continuous filaments, usually glass, in form of rovings are saturated with resin and machine-wound onto mandrels having shape of desired finished part. Once winding is completed, part and mandrel are placed in oven for curing. Mandrel is then removed through porthole at end of wound part	High-strength fiber reinforcements are oriented precisely in direction where strength is needed; exceptional strength/weight ratio; good uniformity of resin distribution in finished part	Limited to shapes of positive curvature; openings and holes reduce strength	5–10, 6–8

Injection molding	Thermoplastic or thermoset molding compound is heated to plasticity in cylinder at controlled temperature; then forced under pressure through a nozzle into sprues, runners, gates, and cavities of mold. The resin solidifies rapidly, the mold is opened and the part(s) ejected. In modified version of process —-runnerless molding—the runners are part of mold cavity	Extremely rapid production rates, hence low cost per part; little finishing required; good dimensional accuracy; ability to produce relatively large, complex shapes; very good surface finish	High initial tool and die costs; not practical for small runs	1.5–5, 2–3
Laminating, high pressure	Material, usually in form of reinforcing cloth, paper, foil, etc., preimpregnated or coated with thermoset resin (sometimes a thermoplastic), is molded under pressure greater than 1,000 lb/in^2 into sheet, rod, tube, or other simple shape	Excellent dimensional stability of finished product; very economical in large production of parts	High tool and die costs; limited to simple shapes and cross-section profiles	2-5, 3-4
Matched-die molding	A variation of conventional compression molding, this process uses two metal molds having a close-fitting, telescoping area to seal in the plastic compound being molded and to trim the reinforcement. The reinforcement usually mat or preform, is positioned in the mold, and the mold is closed and heated (pressures generally vary between 150 and 400 lb/in^2). Mold is then opened and part lifted out	Rapid production rates; good quality and reproducibility of parts	High mold and equipment costs; parts often require extensive surface finishing, e.g., sanding	2–5, 3–4

Table IN.5 (*Continued*)

Process	Description	Key advantages	Notable limitations	Cost factor*
Rotational molding	A predetermined amount of powdered or liquid thermoplastic or thermoset material is poured into mold. Mold is closed, heated, and rotated in the axis of two planes unitl contents have fused to inner walls of mold. The mold is opened and part removed	Low mold cost; large hollow parts in one piece can be produced; molded parts are essentially isotropic in nature	Limited to hollow parts; in general, production rates are slow	1.5–5, 2–3
Slush molding	Powdered or liquid thermoplastic material is poured into a mold to capacity. Mold is closed and heated for a predetermined time to achieve a specified buildup of partially cured material on mold walls Mold is opened, and unpolymerized material is poured out. Semifused part is removed from mold and fully polymerized in oven	Very low mold costs; very economical for small -production runs	Limited to hollow parts; production rates are very slow; limited choice of materials that can be processed	1.5–4, 2–3
Thermoforming	Heat-softened thermoplastic sheet is placed over male or female mold. Air is evacuated from between sheet and mold, causing sheet to conform to contour of mold. There are many variations, including vacuum snapback, plug assist, drape forming, etc.	Tooling costs generally are low; produces large parts with thin sections; often economical for limited production of parts	In general, limited to parts of simple configuration; limited number of materials to choose from; high scrap	2–10, 3–5

Transfer molding	Thermoset molding compound is fed from hopper into a transfer chamber where it is heated to plasticity. It is then fed by means of a plunger through sprues, runners, and gates of closed mold into mold cavity. Mold is opened and the part ejected	Good dimensional accuracy; rapid production rate; very intricate parts can be produced	Molds are expensive; high material loss in sprues and runners; size of parts is somewhat limited	1.5–5, 2–3
Wet lay-up or contact molding	Number of layers, consisting of a mixture of reinforcement (usually glass cloth) and resin (thermosetting), are placed in mold and contoured by roller to mold's shape. Assembly is allowed to cure (usually in an oven) without application of pressure. In modification of process, called spray molding, resin systems and chopped fibers are sprayed simultaneously from spray gun against mold surface; roller assist also is used. Wet lay-up parts sometimes are cured under pressure, using vacuum bag, pressure bag, or auto-clave	Very low cost; large parts can be produced; suitable for low-volume production of parts	Not economical for large-volume production; uniformity of resin distribution very difficult to control; mainly limited to simple shapes	1.5–4, 2–3

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*Material cost × factor = purchase price of a part: top figure is overall range, bottom is probable average cost.

Table IN.6 Guidelines on Part Design for Plastic Processing Methods

					Reinforced plastic molding						
Design rules	Blow molding	Casting	Compression molding	Extrusion	Injection molding	Wet lay-up (contact molding)	Matched die molding	Filament winding	Rotational molding	Thermo-forming	Transfer molding
Major shape characteristics	Hollow bodies	Simple configurations	Moldable in one plane	Constant cross-section profile	Few limitations	Moldable in one plane	Moldable in one plane	Structure with surfaces of revolution	Hollow bodies	Moldable in one plane	Simple configurations
Limiting size factor	M	M	ME	M	ME	MS	ME	WE	M	M	ME
Min inside radius, in	0.125	0.01–0.125	0.125	0.01–0.125	0.01–0.125	0.25	0.06	0.125	0.01–0.125	0.125	0.01–0.125
Undercuts	Yes	Yes[a]	NR[b]	Yes	Yes[a]	Yes	NR	NR	Yes[c]	Yes[a]	NR
Min draft, degrees	0	0–1	>1	NA[b]	<1	0	1	2–3	1		1
Min thickness, in	0.01	0.01–0.125	0.01–0.125	0.001	0.015	0.06	0.03	0.015	0.02	0.002	0.01–0.125
Max thickness, in	>0.25	None	0.5	6	1	0.5	1	3	0.5	3	1
Max thickness buildup, in	NA	2–1	2–1	NA	2–1	2–1	2–1[d]	NR	NA	NA	2–1
Inserts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NR	Yes
Built-up cores	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Molded-in holes	Yes	Yes	Yes	Yes[e]	Yes	Yes	Yes	Yes	Yes	No	Yes
Bosses	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Fins or ribs	Yes	Yes	Yes	Yes	Yes	Yes	No[f]	No[g]	Yes	Yes	Yes
Molded-in designs and nos.	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Overall dimensional tolerance, in./in.	±0.01	±0.001	±0.001	±0.005	±0.001	±0.02	±0.005	±0.005	±0.01	±0.01	±0.001
Surface finish[h]	1–2	2	1–2	1–2	1	4–5	4–5	5	2–3	1–3	1–2
Threads	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes

M = material. ME = molding equipment. MS = mold size. WE = winding equipment.

[a] Special molds required.

[b] NR—not recommended; NA—not applicable.

[c] Only with flexible materials.

[d] Using premix: as desired.

[e] Only in direction of extrusion.

[f] Using premix: yes.

[g] Possible using special techniques.

[h] Rated 1 to 5:1 = very smooth, 5 = rough.

method. In general, a plastic part is produced by a combination of cooling, heating, flowing, deformation, and chemical reaction. As noted previously, the processes differ depending on whether the material is a thermoplastic or a thermoset.

The usual sequence of processing a thermoplastic is to heat the material so that it softens and flows, force the materials into the desired shape through a die or in a mold, and chill the melt to its final shape. By comparison, a thermoset is typically processed by starting out with partially polymerized material, which is softened and activated by heating (either in or out of a mold), forcing it into the desired shape by pressure, and holding it at the curing temperature until final polymerization reaches the point where the part hardens and stiffens sufficiently to keep its shape when demolded.

The cost of the finished part depends on the material and the process used. A very rough estimate of the finished cost of a part can be obtained by multiplying the materials cost by a factor ranging from 1.5 to 10.

Table IN.6 gives guidelines on part design for the various plastic processing methods listed in Table IN.5. The design of a part frequently depends on the processing method selected to make the part. Also, of course, selection of the best processing method frequently is a function of the part design. Major plastic processing methods and their respective design capabilities such as minimum section thickness and radii and overall dimensional tolerance are listed in Table IN.6. The basic purpose of this guide is to show the fundamental design limits of the many plastic processing methods.

There are many plastic fabrication processes, and a wide variety of plastics can be processed by each of the processes or method. Fabrication processes can be broadly divided into pressure processes and pressureless or low-pressure processes. Pressureless or low-pressure processes such as potting, casting, impregnating, encapsulating, and coating are often used with thermosetting materials. Pressure processes are usually either thermoplastic materials processes, such as injection molding, extrusion, and thermoforming, or thermosetting processes, such as compression molding, transfer molding, and laminating. However, there are exceptions to each.

PLASTIC FINISHING

The following sections will also provide practical information and guidance on several important plastic processes that occur only *after* the part is formed. Although sometimes referred to as postprocessing operations or secondary processes, the common operations listed below are essential to producing practical commercial products from plastic materials:

- Machining and finishing
- Assembly
- Decorating

Fortunately, many of the processes and tools satisfactory for working with metals, wood, and other common engineering materials also apply to plastics. Although there are similarities in these processes, there are also some critical differences that must be considered because of the unique nature of polymeric materials. The material properties of the polymeric resins will dictate many of the processing parameters. There are also certain assembly and finishing opportunities that are available for the designer because the material is a polymer. It is these unique differences that must occupy the designer's early attention.

The reader should consider the individual plastic supplier as an excellent source of information on fabricating and finishing processes for specific types of plastic materials. Generally, this information is readily available because the plastic resin producers benefit by providing the most complete and up-to-date information on how their materials can reliably and economically produce commercial products.

Because of the tremendous number of plastic materials available, their many forms, and the possible finishing and fabrication processes, it would be difficult to include in this book comprehensive information covering all product possibilities and all possible needs of the reader. However, this book will define the basic terms and concepts that are used in the industry, and, although additional information is required, this will help efficiently direct and guide the reader to more complete information.

PLASTIC PROPERTIES

The various properties of polymeric materials are also defined in this book, as are the methods used to test for those properties. It is important to compare properties of various materials and the properties that result from different processing methods in order to select the correct material/process combination for the intended product. Information regarding how the properties of the product will change with service is also important because all polymeric materials will generally "age" in some form because of their operating environment.

Much work has been done on the standardization of the measurement for properties of plastics and the analysis of plastic properties. An understanding of plastic performance as indicated by standard tests is especially important to the large percentage of non-chemically trained users of plastic material.

Standard Tests and Their Significance

Among the most widely used test procedures are those developed by the American Society for Testing and Materials (ASTM). These test procedures, divided into categories of performance (chemical, mechanical, thermal, analytical, optical, and electrical) are listed in Table IN.7. A cross-reference of some important ASTM tests and Federal test methods is presented in Table IN.8.

Table IN.7 Widely Used ASTM Tests for Plastics

- Performance tests
  - D1693, environmental stress cracking
  - G23 (formerly E42), accelerated weathering
  - Pipe tests (Commercial Standard CS 255-63)
  - D794, permanent effect of heat
  - D1435, outdoor weathering
  - Weight loss on heating (D706, specification for cellulose acetate molding compounds)
  - D570, water absorption
- Chemical tests
  - C619, chemical resistance of asbestos-fiber-reinforced thermosetting resins
  - C581, chemical resistance of thermosetting resins of color in CIE 1931 system
- Mechanical tests
  - D790, flexural properties
  - D1822, tensile impact
  - D747, stiffness in flexure
  - D256, Izod impact
  - D638, tensile properties
  - D785, Rockwell hardness
  - D621, deformation under load
  - D695, compressive properties of rigid plastics
  - D732, shear strength
- Thermal tests
  - D648, deflection temperature
  - D635, flammability (for self-supporting materials)
  - D1238, flow rate (melt index) by extrusion plastometer
  - D569, flow properties
  - D1525, Vicat softening point
  - D746, brittleness temperature
- Analytical tests
  - D792, specific gravity and density
  - D1505, density by density-gradient technique
- Optical tests
  - E308, spectrophotometry and description
  - D1003, haze
- Electrical tests
  - D618, conditioning procedures
  - D495, arc resistance
  - D149, dielectric strength
  - D150, dielectric constant and dissipation factor
  - D257, tests for electrical resistance, insulation resistance, volume resistivity, volume resistance

Table IN.8 Cross-Referenced ASTM and Federal Tests

Test method	Federal Standard Method No.	ASTM No.
Abrasion wear (loss in weight)	1091	
Accelerated service tests (temperature and humidity extremes)	6011	D 756-56
Acetone extraction test for degree of cure of phenolics	7021	D 494-46
Arc resistance	4011	D 495-61
Bearing strength	1051	D 953-54, Method A
Bonding strength	1111	D 229-63T, pars 40-43
Brittleness temperature of plastics by impact	2051	D 746-64T
Compressive properties of rigid plastics	1021	D 695-63T
Constant-strain flexural fatigue strength	1061	
Constant-stress flexural fatigue strength	1062	
Deflection temperature under load	2011	D 648-56, Procedure 6(*a*)
Deformation under load	1101	D 621-64, Method A
Dielectric breakdown voltage and dielectric strength	4031	D 149-64
Dissipation factor and dielectric constant	4021	D 150-64T
Drying test (for weight loss)	7041	
Effect of hot hydrocarbons on surface stability	6062	
Electrical insulation resistance of plastic films and sheets	4052	
Electrical resistance (insulation, volume, surface)	4041	D 257-61
Falling-ball impact	1074	
Flame resistance	2023	
Flammability of plastics 0.050 in. and under in thickness	2022	D 568-61
Flammability of plastics over 0.050 in. in thickness	2021	D 635-63
Flexural properties of plastics	1031	D 790-63
Indentation hardness of rigid plastics by means of a durometer	1083	D 1706-61
Interlaminar and secondary bond shear strength of structural plastic laminates	1042	
Internal stress in plastic sheets	6052	
Izod impact strength	1071	D 256-56, Method A
Linear thermal expansion (fused-quartz tube method)	2031	D 696-44
Machinability	5041	
Mar resistance	1093	D 673-44
Mildew resistance of plastics, mixed culture method, agar medium	6091	
Porosity	5021	
Punching quality of phenolic laminated sheets	5031	D 617-44

Table IN.8 (*Continued*)

Test method	Federal Standard Method No.	ASTM No.
Resistance of plastics to artificial weathering using fluorescent sunlamp and fog chamber	6024	D 1501-57T
Resistance of plastics to chemical reagents	7011	D 543-60T
Rockwell indentation hardness test	1081	D 785-62, Method A
Salt-spray test	6071	
Shear strength (double shear)	1041	
Shockproofness	1072	
Specific gravity by displacement of water	5011	
Specific gravity from weight and volume measurements	5012	
Surface abrasion	1092	D 1044-56
Tear resistance of film and sheeting	1121	D 1004-61
Tensile properties of plastics	1011	D 638-64T
Tensile properties of thin plastic sheets and films	1013	D 882-64T
Tensile strength of molded electrical insulating materials	1012	D 651-48
Tensile time—-fracture and creep	1063	
Thermal-expansion test (strip method)	2032	
Warpage of sheet plastics	6054	D 1181-56
Water absorption of plastics	7031	D 570-63

Rating of Plastics by Property Comparisons

The Appendices of this book contain data on plastics as a function of the most important variables. It is frequently useful to compare or rate plastics for a given property or characteristic. Any such data must be considered approximate, of course, because of the many possible variables involved. Some such comparative data are presented in the Appendices and the main section of this book.

ELASTOMERS

ASTM D1566 defines elastomers as “macromolecular materials that return rapidly to approximately the initial dimensions and shape after substantial deformation by a weak stress and release of the stress.” It also defines rubber as “material that is capable of recovering from large deformation quickly and forcibly, and can be, or already is, modified to a state in which it is essentially insoluble (but can swell) in solvent, such as benzene, methyl ethyl ketone, and ethanol toluene azeotrope.”

A rubber in its modified state, free of diluents, retracts within 1 min to less than 1.5 times its original length after being stretched at room temperature to twice its length and held for 1 min before release. More specifically, an elastomer is a rubberlike material that can be or already is modified to a state exhibiting little plastic flow and quick and nearly complete recovery from an extending force. Such material before modification is called, in most instances, a raw or crude rubber or a basic high polymer and by appropriate processes may be converted into a finished product.

When the base high polymer is converted (without the addition of plasticizers or other diluents) by appropriate means to an essentially nonplastic state, it must meet the following requirements when tested at room temperature:

1. It is capable of being stretched 100%.
2. After being stretched 100%, held for 5 min, and then released, it is capable of retracting to within 10% of its original length within 5 min after release.

The rubber definition with its swelling test certainly limits it to only the natural latex tree sources, whereas the elastomer definition is more in line with modern new synthetics.

Elastomers, when compared with other engineering materials, are characterized by large deformability, lack of rigidity, large energy storage capacity, nonlinear stress-strain curves, high hysteresis, large variations in the stiffness, temperature, and rate of loading, and compressibility of the same order of magnitude as most liquids. Certain of the elastomeric materials possess additional useful characteristics to a relative degree, such as corrosive chemical resistance, oil resistance, ozone resistance, temperature resistance, and resistance to other environmental conditions.

The nomenclature for elastomers, common names, ASTM designations, relative costs, and general characteristics are summarized in Appendix C. Further discussion of these commercially available elastomers can be found in the following sections under their specific names.

The proper selection and application of elastomers are difficult for design engineers in many instances because engineering terms in conventional usage have different meanings when applied to rubber properties. Elastomers are organic materials and react in a completely different manner from metals. For this reason some of the more common definitions are presented in the following section.

A

A-stage The A-stage is the earliest stage in the reaction of a thermosetting resin in which the materials are still soluble in certain solvents and fusible. It is often the stage in which the resin, the hardener, and all other components are present and mixed together, yet no or very little crosslinking has taken place. In the A-stage the resin formulation is generally a thick liquid or flowable paste, but all the constituents are present to fully cure the resin.

Later stages of reaction are termed *B-stage* (partially cured or advanced to a relatively dry state but still flowable under heat and pressure conditions) and *C-stage* (fully cured to a nonflowable thermoset plastic).

abhesive An abhesive is a material, such as a film or coating, that is applied to a surface to prevent adhesion or sticking of other substances. Mold release agents, release films, graffiti-resistant paints, and ice are examples of abhesive materials. Generally, the opposite of an *ab*hesive is an *ad*hesive.

ablative plastic An ablative plastic is one that absorbs heat and generally protects other parts from the effects of the heat. The ablative plastic will absorb heat while it decomposes. The decomposition process is termed *pyrolysis*. Ablation takes place in the near surface layer exposed to the heat. The degraded outer surfaces will break away when decomposed and expose a new surface to the heat.

Phenolics are good ablative plastics in that, when exposed briefly to very high temperatures, they undergo rapid decomposition to gases and form a porous char,

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thereby dissipating heat and leaving a protective thermal barrier on the substrate. This sacrificial loss of material accompanied by the transfer of energy is known as *ablation*.

In addition to providing for high heat absorption and heat dissipation per unit mass expended, ablative materials are used because they provide an automatic control of surface temperatures by self-regulating ablative degradation; excellent thermal insulation; tailored performance by varying the individual material components and composition of the ablative system; design simplicity and ease of fabrication; and lightweight and low-cost materials.

An example of an application for an ablative plastic is the outer skin of a spacecraft where the plastic is used as a heat shield. Ablative polymers are also often used as fire protection in cable runs, electrical equipment, fire barriers in buildings, etc. Some ablative polymers are known as fire-stop materials.

The following polymeric materials have been used as ablative materials for specific applications: phenolics, phenyl silanes, nitrile phenolics, nitrile rubber, silicones, epoxy polyamide, and novolac epoxies. Fillers and reinforcements are used in ablative formulations to improve performance and reduce thermal conductivity. Common ablative fillers are glass, silica, and quartz cloth; carbon and graphite cloth; microbubbles (phenolic, silica, and glass); and asbestos fiber.

See also pyrolysis.

abrasion and abrasion resistance Abrasion may be defined as the loss of material from a surface through wearing away by frictional forces. The terms abrasion and at times wear are used synonymously. However, the term wear is usually used to describe progressive damage at the interface of two sliding surfaces. Severe wear is sometimes considered abrasion. The term abrasion is normally used to characterize the rapid removal of matter from a surface through the action of a strongly abrading element.

Abrasion is a difficult property to define as well as to measure. It is normally accepted that abrasion depends on the polymer's hardness and resilience, frictional forces, load, and actual area of contact. Generally, hard and rigid plastics have better abrasion resistance than tough, flexible plastics. *Friction*, *hardness*, *wear*, and *abrasion resistance* are related closely to the viscoelastic properties of the polymer.

Abrasion resistance is the resistance of a plastic surface to a constant source of abrasion. Abrasion resistance in plastics is usually measured by a scratch test, in which the material is subjected to many scratches, usually from contact with an abrasive wheel or a stream of falling abrasive material. The degree of abrasion can be determined by loss of weight for severe damage, but it is more usually measured by evidence of surface marring, such as loss of gloss or development of haze for transparent specimens.

There are many types of abrasion resistance tests for specific forms of abrasive materials and for specific applications and materials. The abrasives used in these tests include loose particle abrasives (ASTM D673 and D1242), abrasives bonded on cloth or paper (ASTM D1242), and standard abrasive wheels (ASTM D1044). ASTM D1044 evaluates the resistance of transparent plastics to surface abrasion by measuring its effect on the transmission of light. Another test method to evaluate abrasion resistance, ASTM D1242, measures the volume lost by two different types of abrasion processes, loose abrasion and bonded abrasion. Test methods for the abrasion resistance of rubber are given in ASTM D1630 and D2228. Abrasion in connection with textile materials is defined in ASTM D123.

See also wear.

abrasive An abrasive is a material used for the surfacing and finishing of other materials by an abrasive action. Abrasives are often used to smooth and flare plastic surfaces; prepare surfaces for painting or adhesive bonding; and remove flash, molding gates, and other unwanted materials from plastic parts.

Natural abrasives can be sand, walnut shells, etc. Artificial abrasives include silicon carbide, aluminum oxide, boron carbide, and boron nitride. Artificial abrasives are generally superior in uniformity to naturally occurring abrasives and provide more consistent abrasive finishing processes.

abrasive finishing Abrasive finishing is a process by which a plastic part is given a certain surface appearance through the application of abrasive particles. Abrasive finishing can be used to remove imperfections from a plastic part or to smooth and polish a part's surface. It can also be used to provide a certain surface texture.

Often abrasive finishing is used to pretreat a plastic part before adhesive bonding or coating. The abrasive finishing process removes contaminants from the surface and provides a rough surface that the adhesive or coating material can lock onto. *Dry abrasion* consists of lightly and uniformly sanding the surface of the substrate material with medium (180–325-grit) abrasive paper. *Wet abrasion* consists of using an abrasive slurry that automatically removes the abrasive residue. Many types of both dry and wet abrasion equipment are commercially available.

Composite abrasive materials, such as *Scotch-Brite*® (3M Company), have proved popular for mechanical surface preparation. These commercial abrasive materials are available in pad and sheet form, and they can conform easily to the shape of a surface. When combined with water flushing, they provide clean, almost oxide-free surfaces. Hand sanding, wire brushing, and other abrasion methods that are highly related to the operator's skill, and patience must be carefully controlled. These processes are a source of inconsistency and should be used only when no other method is possible.

Abrasive finishing for cosmetic purposes may be one of several types of operations including *deflashing*, *smoothing* and *polishing*, *grinding*, and *sanding*. Deflashing is the removal of flash or gate material from a molded plastic part. Flash can be removed by tumbling the plastic part with an abrasive material. The abrasives used for deflashing include ground walnuts, hard nylon, and polycarbonate pellets.

Abrasive finishing processes, such as smoothing and polishing, can be used to remove surface defects; light, residual flash; and marks from machining operations. Most of these processes consist of holding the surface to be finished next to a soft rotating wheel containing a moderately abrasive substance. *Ashing* uses a wet abrasive applied to a loose muslin wheel. *Buffing* is an operation in which grease- or wax-filled abrasive cakes are applied to a loose or sewn muslin wheel. Polishing uses wax compounds filled with fine abrasives. Polishing wheels are generally made of loose flannel or chamois.

Grinding and sanding are generally performed on a machine (belt, disk, or band), by hand (using a silicon carbide abrasive no rougher than number 80), or by an abrasive blasting operation using sand, plastic pellets, glass beads, or other hard abrasives.

Excessive overheating of the plastic must be prevented in abrasive finishing operations. Thus it is necessary to avoid exceedingly hard buffing with high pressures or speeds. Usually, the smoothing or polishing operation is completed after the part has undergone rough grinding or sanding operations.

See also grit blasting; deflashing; and tumbling.

absolute viscosity Also known as *dynamic viscosity*, the absolute viscosity is the tangential force on a unit area of either of two parallel planes at unit distance apart when space between the planes is filled with the fluid in question and one of the planes moves with unit differential velocity in its own plane.

Viscosity is measured in terms of flow in pascal-seconds (Pa·s)—the higher the number, the less the flow. However, the more common unit for absolute viscosity is the *poise* (P), where $1\ \mathrm{P} = 1\ \mathrm{dyn \cdot s/cm^2}$, which is equivalent to 0.01 Pa·s. The *centipoise* (cP) unit (0.01 P) is also often used.

See also viscosity.

absorption Absorption is the penetration of the mass of one substance into another (e.g., moisture into a plastic material). The penetrants are commonly gases or liquids. If the material is nonporous, the take-up of penetrant will be due to *diffusion*. If the material is porous, the penetrant will be taken up primarily into the pores by a *wicking* process; however, some penetrant may also diffuse into the solid material.

At times, the term absorption is also used to describe the process in which energy is dissipated within a specimen, for example, sound absorption and mechanical absorption.

See also hysteresis.

accelerator An accelerator is a chemical used to accelerate the rate of curing reaction. The term is often used interchangeably with *promoter*. For example, cobalt naphthanate is an accelerator that is used to accelerate the reaction of certain polyester resins.

Accelerators will also speed gel time, pot life, etc., and they may provide a reaction that is so fast that it is unmanageable. These are critical components that control the curing rate, storage life, and working life of the formulation. An accelerator is often used along with a *catalyst*, a *hardener*, or a *curing agent*, which produces the main polymerization reaction.

Accelerators are typically used in polyurethane systems and in unsaturated polyester formulations where they react with the curing agent to speed cure. Accelerators are also commonly used in elastomeric vulcanization processes.

accumulator The accumulator is an auxiliary cylinder and piston (plunger) that is mounted on injection molding or blowing machines and used to provide faster molding cycles. In blow molding, the accumulator cylinder is filled (during the time between *parison* deliveries or shots) with melted plastic coming from the main (primary) extruder. The plastic melt is stored, or "*accumulated*", in this auxiliary cylinder until the next shot or parison is required. At that time, the piston in the accumulator cylinder forces the molten plastic into the dies that form the parison.

acetal: polyacetal, polyoxymethylene (POM) Acetals or polyacetals are high-performance thermoplastics that are often considered as an alternative for metal parts. They have sufficiently high mechanical properties and chemical resistance to be classified as an *engineering plastic*. Acetal resins are also known by the name *polyoxymethylene* (*POM*). The resins are made from the polymerization of formaldehyde or trioxane. The materials have a very good performance-to-cost ratio because their starting raw material is inexpensive methanol. The repeating group —CH_2O— characterizes acetals (Fig. A.1).

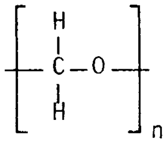


Figure A.1 General chemical structure of polyacetal resin.

The high degree of crystallinity gives acetal polymers their high strength, toughness, and rigidity. These plastics are also noted for good moisture, heat, and chemical resistance. Acetal parts have high tensile strength and stiffness, resilience, good recovery from deformation under load, and toughness under impact. They have very good creep resistance and low moisture absorption, which provides excellent dimensional stability. Acetal resins have low specific gravity, low thermal and electrical conductivity, and a "warm to the touch" feel. They are easily filled with various reinforcements and colorants. Processing aids, ultraviolet (UV) stabilizers, impact modifiers, and reinforcements are often added to the basic resin to contribute to certain properties.

Acetal parts can be manufactured by common thermoplastic processes. However, most parts are made by injection molding and extrusion. The resin's sharp crystalline melting point provides quality injection-molded parts. Often, small acetal parts can be injection molded in multicavity molds.

Major applications include industrial (plumbing, automotive), commercial (appliance, tools, electrical and electronic), and consumer (disposable pens, combs, zippers) products. Acetal resins are also often used in medical products because of their unique properties and resistance to sterilization conditions.

As a result of their dimensional stability, acetal parts are commonly used to make precision parts. Their low coefficient of friction and hard, smooth, glossy surface make them attractive for moving parts with low friction and high wear. They often find application in machined rollers, bearings, gears, and other wear-resistant parts. Typical parts and products made of acetal include pump impellers, conveyor links, drive sprockets, automobile instrument clusters, spinning reel housings, gear valve components, bearings, and other machine parts.

The most common types of acetal polymers are the acetal *homopolymer* (Delrin by Du Pont) and the acetal *copolymer* (Celcon by Hoescht Celanese-Ticona). The homopolymer is produced from polyformaldehyde and the copolymer from trioxane (a crystalline form of formaldehyde).

Acetal homopolymers are highly crystalline linear polymers formed by polymerizing formaldehyde and capping it with acetate end groups. The homopolymer has better short-term mechanical properties, is harder and more rigid, and has higher resistance to fatigue than the copolymer (Table A.1). They retain their strength close to the melting point of 175°C.

Table A.1 General Properties of Acetal Homopolymer and Copolymer

Property	Homopolymer, Unfilled General Purpose	Copolymer, Unfilled General Purpose
Specific Gravity	1.425	1.410
Tensile Strength, psi	10,000	8,800
Flexural Strength, psi	14,100	12,000
Elongation, %	25-50	40-75
Dielectric Strength, volts/mil	500	500
Hardness, Rockwell	M94	M80

Acetal copolymers are a family of highly crystalline thermoplastics prepared by copolymerizing trioxane with small amounts of comonomer that randomly distribute carbon-carbon bonds in the polymer chain. These bonds, as well as hydroxyethyl terminal units, give the acetal copolymers a high degree of thermal stability and resistance to strong alkaline environments. The copolymer is better for applications requiring long-term, high-temperature service or resistance to hot water.

Several grades are generally available including high molecular weight, medium molecular weight or general purpose, and high flow. The high impact strength of acetal resins can be enhanced even further by the addition of elastomers such as polyurethane, polybutadiene, acrylonitrile butadiene styrene, or ethylene propylene rubber. Delrin AF (Du Pont) is an acetal that is filled with a fluorocarbon fiber (tetrafluoroethylene) for application in moving parts with low friction and high wear.

Commercial producers of acetal copolymer resins include Hoechst Celanese-Ticona (Celcon), BASF (Ultraform), Mitsubishi Gas (Iupital), and LNP (Lubricomp). Only Du Pont (Delrin) and Ashai Chemical (Tenac) manufacture the homopolymer.

acid index Acid index is a value used to characterize the acidity of the products of combustion of polymeric materials. Acid index values are used as an aid in estimating respiratory and corrosion hazards presented by burning plastics and elastomers.

Acid index is defined as the number of milliequivalents of acid ($pH < 4$) evolved per cubic centimeter of the polymeric material when burned under standard conditions in pure oxygen. Examples of acid index values are

- Polyethylene, approximately 0
- Polyvinyl chloride, 22
- Acrylonitrile butadiene styrene with flame retardant, 3
- Polyphenylene sulfide, 22

acrylic fiber The acrylic fibers are polymers containing at least 85 percent acrylonitrile. Other monomers are often used in small amounts to make the polymer amenable to dyeing with conventional textile dyes. Common comonomers are vinyl acetate, acrylic esters, and vinyl pyrrolidone. Generic classes of fibers closely related to acrylics are the *modacrylic fibers*, containing 35–85 percent acrylonitrile and usually 20 percent or more vinyl chloride or vinylidene chloride.

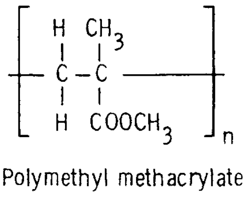
The acrylic fibers exhibit the high strength, stiffness, toughness, abrasion resistance, resilience, and flex life that are associated with the synthetic fibers as a class. They are relatively insensitive to moisture and have good resistance to stains, chemicals, insects, and fungi. Their weatherability is outstandingly good. In continuous filament form, they are considered to have a superior "feel." As crimped staple, they are noted for bulkiness and a wool-like "hand."

See also fiber.

acrylic plastic Acrylics are plastics whose base polymers are (1) polymers of acrylic acid or (2) polymers of monomers structurally derived from acrylic acid or are copolymers of acrylic acid or its derivatives with other monomers. An example of a popular plastic in this family is polymethyl methacrylate, also known simply as *acrylic* or *Plexiglas*.

See also acrylic: polymethyl methacrylate (PMMA).

acrylic: polymethyl methacrylate (PMMA) An acrylic resin is a synthetic resin prepared from *acrylic acid* or a derivative of acrylic acid. Acrylic plastics are based generally on polymethyl methacrylate with the chemical structure shown in Fig. A.2.



$$\left[-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}} - \overset{\displaystyle CH_3}{\underset{\displaystyle COOCH_3}{\overset{|}{\underset{|}{C}}}} - \right]_n$$

Figure A.2 General chemical structure of polymethyl methacrylate.

Acrylic resins are available as (1) sheet, tubes, or rods that can be machined, bonded, and formed into a variety of different parts and (2) a bead form that can be conventionally processed via extrusion or injection molding.

The large forms of this material (e.g., sheet, rods, and tubes) are polymerized in situ by casting a monomer that has been partly prepolymerized by removing any inhibitor, heating, and adding an agent to initiate *free radical polymerization*. This agent is typically an *organic peroxide*. As such, this technique is not suitable for producing injection molding resin, but it does aid in producing material that has a large rubber plateau and has a high enough elevated-temperature strength to allow for band sawing, drilling, and other common finishing processes, as long as the localized heating does not reach the polymer's decomposition temperature. These bulk-polymerized materials generally have such a high molecular weight that they cannot be subjected to additional thermal processing or fabrication without degradation. Cast acrylic is used extensively as bathtub material, such as in showers and in whirlpools; display parts; and household decorative items.

Acrylic beads are made via *suspension polymerization*. This produces a material with low enough molecular weight to allow for typical melt processing via injection molding, casting, extrusion, or vacuum and pressure forming.

Acrylic plastics are noted primarily for their good optical properties (i.e., clarity and resistance to discolorization and loss of light transmission). Parts molded from acrylic powders in their natural state may be crystal-clear and nearly optically perfect. The index of refraction ranges from 1.486 to 1.596. The total light transmittance is as high as 92 percent, and haze measurements average only 1 percent. Light transmittance and clarity can be modified by the addition of a wide range of transparent and opaque colors, most of these being formulated for long outdoor service.

Many chemicals, including ordinary solvents, attack acrylic resins. Stresses must be carefully analyzed because of the material's rather brittle nature. This is especially true for load-bearing applications or for molded parts having geometric complexity (sharp corners, small holes, etc.). Because of these high-stress regions, molded acrylic parts often must be *annealed* before additional finishing or use. Annealing generally requires that the part be heated to just below the plastic's heat distortion temperature (2–4 hr at 60–77°C). This is often a recommended practice when acrylic parts are to be joined by *solvent welding* methods.

Table A.2 Advantages and Disadvantages of Acrylic Plastics

Advantages	Disadvantages
Optical clarity; does not discolor	Attached by strong solvents, gasoline, and similar fluids
Good weather resistance	Load bearing parts should be carefully analyzed for long term loading
Moderate strength	Molded parts can be highly stressed
Good electrical characteristics	
Low water absorption	
Slow burning rate, will not flash-ignite	
Dimensional change with humidity is less than 0.5%	

Acrylic plastics provide several advantages and disadvantages compared with other common plastics (Table A.2). Acrylic plastics are fairly brittle but can be toughened by copolymerization with another monomer such as polybutadiene or by blending with an elastomer similar to high-impact polystyrene. *Acrylic-PVC* alloys offer high-impact, stiffness, and good thermoforming characteristics. The copolymer of PMMA and α-*methyl styrene* provides higher service temperature than PMMA by 11–23°C. Copolymerizing methyl methacrylate with styrene improves melt flow. Copolymerization with acrylic or *methacrylic acid* provides superior hardness and abrasion resistance but the product is more susceptible to temperature effects.

Properties of several types of acrylic plastics are shown in Table A.3.

Table A.3 Properties of Several Types of Acrylic Plastics

Property	Cast	PMMA Molding Compound	Heat Resistant Molding Compound	Impact Modified Molding Compound
Specific Gravity	1.17-1.20	1.17-1.20	1.16-1.22	1.11-1.18
Tensile Strength, psi	66-11000	7000-10500	9300-11500	5000-9000
Flexural Strength. psi	12000-17000	10500-19000	12000-18000	7000-14000
Elongation, %;	2-7	2.5-5	2-10	4.6-70
Dielectric Strength, volts/mil	450-550	400-500	400-500	380-500
Hardness, Rockwell	M80-102	M68-105	M94-100	M35-78

Typical applications for acrylic are those that optimally use its clarity (up to 92% light transmission depending on thickness). Acrylic plastics have strong weather resistance that is well suited for automotive rear light assemblies, lenses, aircraft cockpits, dentures, windshields, and steering wheel bosses. The cast products are used often as architectural materials even though the coefficient of thermal expansion is 8 to 10 times that of glass.

Acrylic resin formulations have been used for outdoor, weather-resistant adhesives. Pressure-sensitive acrylic adhesives are common on decals, bumper stickers, decorative plates, etc. Two-part *thermosetting acrylic* formulations have been developed and packaged for encapsulating, potting, and structural adhesives. Thermosetting acrylics cure by free radical–initiated addition polymerization. These materials can be cured at room temperature with benzoyl peroxide and an amine promoter (dimethyl aniline).

Acrylic resins are available in extrusion, injection molding, and blow molding grades. The major suppliers of these materials are Elf Atochem (Plexiglas), ICI Acrylics (Perspex), Plaskolite (Optix), CYRO (Cyrolite), and Nova Chemicals (NAS and Zylar).

acrylic styrene acrylonitrile (ASA) terpolymer Acrylic styrene acrylonitrile (ASA) is a specialty product with mechanical properties similar to those of acrylonitrile butadiene styrene (ABS) but which offers improved outdoor weathering properties. This is because of the grafting of an acrylic ester elastomer onto the styrene acrylonitrile backbone. Sunlight usually combines with atmospheric oxygen to result in embrittlement and yellowing of thermoplastics, and this process takes a much longer time in the case of ASA.

ASA finds applications where its toughness, substantial modulus, and outdoor weathering resistance are assets. These include applications in garden appliances, covers for outdoor machinery, gutters, drainpipe fittings, park swings, streetlight housings, mailboxes, shutters, window trims, and outdoor furniture.

ASA resins are available for blow molding, extrusion, and injection molding. ASA resins are also blended with polycarbonate, polyvinyl chloride, and acrylonitrile ethylene styrene for specific property enhancements. The main suppliers are BASF (Luran and Centrex), BP Chemicals (Barex), Bayer (Centrex), LG Chemical (LI and LE polymers), and GE (Geloy).

acrylonitrile Acrylonitrile is a monomer with the structure CH_2CHCN. It is most useful in copolymers. Its copolymer with butadiene (*acrylonitrile butadiene*) is also called *nitrile rubber* (*NBR*). Several copolymers with styrene exist that are tougher than polystyrene. Acrylonitrile polymers are also used as synthetic fibers and chemical intermediates.

See also polyacrylonitrile.

acrylonitrile butadiene *See* nitrile rubber (NBR).

acrylonitrile butadiene styrene (ABS) Acrylonitrile butadiene styrene (ABS) plastics are derived from acrylonitrile, butadiene, and styrene. They are also known as ABS copolymer. ABS has the general chemical structure shown in Fig. A.3. The acrylonitrile structure provides the heat resistance, strength, and chemical resistance.

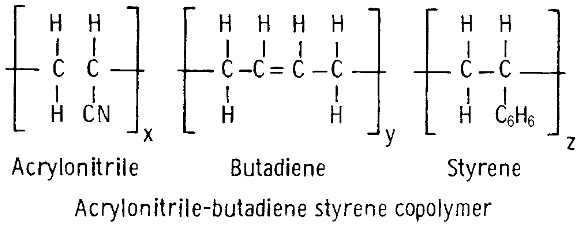


Figure A.3 General chemical structure of acrylonitrile butadiene styrene.

The butadiene structure provides impact resistance, toughness, good low-temperature properties, and flexibility. The styrene structure imparts rigidity, a glossy surface finish, and easy processing properties. The general ratio is approximately 20–30 percent acrylonitrile, 20–30 percent butadiene, and 40–60 percent styrene. The relationship of the various components can be controlled to take maximum advantage of a single property or sets of properties.

Table A.4 Properties of Several Grades of ABS Plastic

Property	ABS General	ABS/PC	ABS Heat Resistant
Specific Gravity	1.16-1.21	1.17-1.23	1.05-1.08
Tensile Strength, psi	3300-8000	5800-9300	4800-7500
Flexural Strength, psi	6200-14000	12000-14500	9000-13000
Elongation, %	1.5-80	20-70	3-45
Izod Impact, ft lb/in	1.4-12	4.1-14	2.0-6.5
Dielectric Strength. volts/mil	350-500	450-760	350-500

ABS provides a generally good balance of properties for many applications. The properties of various grades of ABS are shown in Table A.4.

The polymer is made by one of two routes: (1) *The graft polymerization* of styrene and acrylonitrile onto a polybutadiene latex is followed by, blending in styrene acrylonitrile latex and then coagulating and drying. (2) The *graft polymer* can be manufactured separately from the styrene acrylonitrile latex, and then the two grafts are blended and granulated after drying.

Acrylonitrile copolymer can be processed by many methods including extrusion, blow molding, injection molding, thermoforming, and compression molding. Typical products are electronic equipment housings, under-hood automotive applications, and refrigerator linings. The commodity plastics of polyethylene, polypropylene, polystyrene, and polyvinyl chloride only surpass the use of ABS.

There are many ABS modifications and blends of ABS with other thermoplastics. These modifications result in improved impact resistance, toughness, and heat resistance. Heat-resistant ABS is equivalent to acetal, polycarbonate, and polysulfone in room-temperature creep at 3000 psi. Blends of ABS with polycarbonate are easier to process than pure polycarbonate and have high heat and impact resistance and lower cost.

When chlorinated polyether is used instead of butadiene, a copolymer called acrylonitrile-chlorinated polyethylene styrene (ACS) is produced. This copolymer has improved flame resistance and weatherability. [See also acrylonitrile-chlorinated styrene (ACS) teropolymer polyethylene styrene (ACS) terpolymer.] Acrylic styrene acrylonitrile (ASA) is produced by grafting an acrylic ester elastomer onto the styreneacrylonitrile segment. This results in better outdoor weathering. ASA is used in products such as gutters, mailboxes, shutters, and outdoor furniture. (See also acrylic styrene acrylonitrile.) Modifications are also available that enhance adhesion of electroplated coating to the ABS plastic. ABS is the most widely used material for electroplated plastic parts.

Advantages and disadvantages of ABS plastics over other common plastics are shown in Table A.5.

There are many commercial suppliers of ABS resins and derivatives. The leading suppliers include BASF (Terlux), Bayer (Lustran), Daicel USA (Cevian), Dow Chemical (Magnum), GE (Cycolac), EniChem, LG Chemical, LNP, Nova Polymers (Cryogel), RTP, and Uniroyal, Inc. (Usalite).

Table A.5 Advantages and Disadvantages of ABS Plastics

Advantages	Disadvantages
Hardness	Opacity
Rigidity without brittleness	Weather resistance
Moderate cost	Flame resistance (can be improved with flame retardants)
Balance of tensile strength, impact resistance, surface hardness, rigidity, heat resistance, low temperature properties and electrical characteristics	
Stability under limited load	
Retention of impact resistance as temperature decreases	
Physical properties not affected by moisture (this leads to dimensional stability)	

acrylonitrile-chlorinated polyethylene-styrene (ACS) terpolymer Acrylonitrile-chlorinated polyethylene styrene (ACS) terpolymer is made by using chlorinated polyethylene in place of the butadiene segments in ABS. The terpolymer ACS has properties very similar to those of the engineering terpolymer ABS, but the addition of chlorinated polyethylene imparts improved flame retardance, weatherability, and resistance to electrostatic deposition of dust, without the addition of antistatic agents.

The addition of the chlorinated olefin requires greater care in injection molding to ensure that the chlorine does not dehydrohalogenate. Mold temperatures are recommended to be kept at between 190 and 210°C and not to exceed 220°C, and the residence times should be kept relatively short in the molding machine.

Applications of ACS include housings and parts for office machines such as desktop calculators, copying machines, and electronic cash registers as well as housings for television sets and videocassette recorders.

activation Activation is a process, usually chemical, that starts the polymerization process or enhances the action of an accelerator. (See also Accelerator.) An *activator* is a chemical material (usually a minor additive) used in the activation process. Activators are commonly used in unsaturated polyester resin systems and elastomer formulations.

Activation is sometimes used to describe the modification of a substrate surface so that coatings or adhesives will more readily bond to that surface. Activation, in this sense, is a surface pretreatment such as chemical etching, flame treating, and corona treating. *See also* surface preparation.

Another use of the term activation is to describe certain adhesive systems that are activated just before bonding. Some adhesives, for example, are activated by exposure to moisture or heat; others require coating with solvent to achieve a tacky state. Such adhesives are generally used because of their convenience.

addition polymer An addition polymer is one that is formed by a chain reaction, generally through the addition polymerization or free radical polymerization process. Polyethylene and polystyrene are examples of addition polymers. With addition polymers, the loss of a small molecule does not take place during *polymerization* (as it does with condensation polymers).

addition polymerization Addition polymerization is the polymerization of monomers by a chain mechanism involving active sites on the growing chain. Addition polymerization is frequently accomplished with unsaturated monomers. It is also called *vinyl polymerization* when the unsaturated monomer contains the group $\text{—CH}_2\text{═CH}_2\text{—}$.

Addition polymerizations have two distinct characteristics: (1) no molecule is split out (hence, the repeating unit has the same formula as the monomer), and (2) the polymerization reaction involves the opening of a double bond.

One of the most important types of addition polymerization is *free radical polymerization*. This process is initiated by the action of *free radicals* (electrically neutral species with an unshared electron). Free radicals for the initiation of addition polymerization are usually generated by the thermal decomposition of organic peroxides or azo compounds. The polymerization of unsaturated polyesters with a peroxide catalyst is an example of a free radical polymerization process.

additive Additives (also known as *modifiers*) are substances added to a material usually to improve its properties, but they can also be used as *extenders* to reduce cost. Although some additives provide a broad use and are applicable to many plastics, others may be used exclusively for only one or two plastics; for example plasticizers are generally developed for specific plastics.

Additives were originally used in plastic compounding to overcome limitations of the base resin. For example, they provided more effective flame resistance or improved flexibility. Gradually, the uses of additives and modifiers were extended to provide advantages in processing of the materials (e.g., lubricants and slip agents). More recently, the uses of additives and modifiers have been extended even further to provide completely new types of materials with properties much different from those of the base resin. Examples of this are blowing agents that can be used to produce foamed plastic products and adhesion promoters that can be used to improve adhesion to internal reinforcement materials.

Plastic additives are comprised of an extremely diverse group of materials. Some are complex organic molecules (e.g., antioxidants and light stabilizers) designed to achieve dramatic results at very low loadings. At the opposite extreme are a few commodity materials (e.g., talc and glyceryl monostearate) that can impart significant property improvements.

Added to this complexity is the fact that many varied chemical materials can, and frequently do, compete for the same function. Also, the same additive type may perform more than one function in a host plastic. An example would include the many surfactant-type materials based on fatty acid chemistry that impart lubricant, antistatic, mold release, and/or slip properties to a plastic matrix, depending on the materials involved, loading level, processing conditions, and application.

Given the range of materials used, plastic additives are generally classified by their function rather than by chemistry. The following is just a short list of additives based on the functions they can provide in polymeric formulations: adhesion promoters, antiblocking agents, antifogging agents, antioxidants, antistatic agents, biocides, blowing agents, coupling agents, defoamers (or air release agents), flame retardants, heat stabilizers, impact modifiers, low-profile additives, lubricants, plasticizers, slip agents, thickeners, thixotropes, UV stabilizers, and wetting agents.

Appendix M summarizes common additives/modifiers, indicates why they are used, and describes plastics that are commonly modified by these agents. *See also* the specific additive by the function that it performs (e.g., *antistatic agent*).

See also modifier.

adherend An adherend is a body that is held to another body by an *adhesive*. An adhesive is applied to and bonds to an adherend. Sometimes the terms adherend and *substrate* are used synonymously. However, a substrate generally refers to a surface *before* it is bonded, and an adherend to the surface *after* it is bonded.

adhesion Adhesion is the state in which interfacial forces hold two surfaces together. It is the attraction of two different substances resulting from intermolecular forces between the substrates. This is much different from *cohesion*, which involves only the intermolecular attractive forces within a single substrate.

These interfacial forces may consist of chemical bonds, valance forces, electrostatic forces, mechanical interlocking, polymeric diffusion, or a combination of these. However, the intermolecular forces acting in both adhesion and cohesion are primarily van der Waals forces.

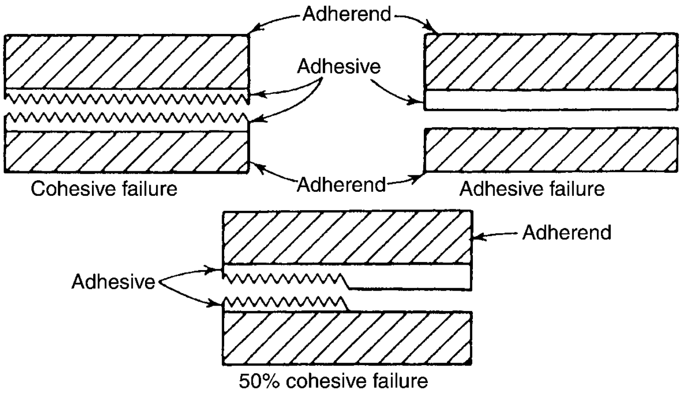


Figure A.4 Examples of cohesive and adhesive failures.

Figure A.4 shows the differences between adhesion and cohesion, using an adhesive joint as an example. Adhesive failure is an interfacial bond failure between the adhesive and the adherend. Cohesive failure could exist either within the adhesive material (cohesive failure of the adhesive) or within the adherend itself (cohesive failure of the adherend).

See also adhesion theory; van der Waals forces.

adhesion promoter Adhesion promoters are liquids that form a very thin (usually monomolecular) layer between a substrate and an adhesive for the purpose of improving adhesion. They are also known as *coupling agents*. Usually chemical bonds are formed between the adhesion promoter and the adhesive and also between the adhesion promoter and the substrate's surface. These bonds are often stronger than the internal (cohesive) chemical bonds in the adhesive or the plastic substrate. Adhesion promoters also provide an interfacial region that is more resistant to physical stress or chemical attack than when the adhesion promoter is absent.

The adhesion promoter can be applied by incorporating it directly into the adhesive formulation or by applying it to the substrate surface similar to a primer. When applied in situ, through the adhesive formulation, the adhesion promoter migrates to the interface region before the adhesive cures.

The adhesion promoter can also be applied to particulate filler for reinforcing molding compounds and to fibers for reinforcing composite materials. The process of applying the adhesion promoter to filled plastics can be the same as for adhesives—either the promoter can be applied directly to the filler or it can be formulated into the resin and attached to the filler during the mixing or polymerizing process. The bulk properties of filled plastics, such as tensile and impact strength, as well as the interfacial properties are positively affected by applying adhesion promoters in this way. Virtually all glass fibers used in glass fiber-reinforced plastics are treated with *silane* adhesion promoters.

Silanes are the most common commercial adhesion promoter. They are commonly used to enhance adhesion between polymeric and inorganic materials. They usually have the form $X_3Si—R$, where X is typically a chlorine or alkoxy group and R is the organofunctionality. The organofunctional portion bonds with the resin in the adhesive or the organic medium, and the silane portion bonds to the inorganic or substrate surface.

Although silanes predominate as adhesion promoters, the use of *titanate*, *zirconate*, and other agents is growing. Titanate adhesion promoters can provide a dual function of improving the dispersion of fillers and enhancing bond performance. Titanates have been used predominantly to modify the viscosity of filled resin systems. A small percentage of titanate in a heavily filled resin system can reduce the viscosity significantly.

Zirconate coupling agents have a structure very similar to that of titanates. *Zirconium propionate* is used as an adhesion promoter in printing ink formulations for polyolefins. Like the titanates, zirconate coupling agents are useful in improving the dispersion characteristics of fillers in polymer systems.

Chrome complexes have been formed as adhesion promoters by the reaction of chromium chloride with methacrylic acid. These are commonly used as a primer for aluminum foil to increase the strength and durability of aluminum/polyethylene interfaces.

Other types of coupling agents include *1,2-diketones* for steel, nitrogen heterocyclic compounds such as *benzotriazole* for copper, and some *cobalt compounds* for the adhesion of brass-plated tire cords to rubber.

See also coupling agent.

adhesion theory Various theories attempt to describe the phenomena of adhesion. No single theory explains adhesion in a general way. However, knowledge of adhesion theories can assist in understanding the basic requirements for a good bond.

mechanical theory The surface of a solid material is never truly smooth but consists of a maze of microscopic peaks and valleys. According to the mechanical theory of adhesion, the adhesive must penetrate the cavities on the surface and displace the trapped air at the interface.

Such mechanical anchoring appears to be a prime factor in bonding many porous substrates. Adhesives also frequently, but not always, bond better to abraded surfaces than to natural surfaces. This beneficial effect of surface abrasion may be due to

1. Mechanical interlocking
2. Formation of a clean surface
3. Formation of a more reactive surface
4. Formation of a larger surface area

adsorption theory The adsorption theory states that adhesion results from molecular contact between two materials and the surface forces that develop. The process of establishing intimate contact between an adhesive and the adherend is known as wetting. For an adhesive to wet a solid surface, the adhesive should have a lower surface tension than the solid's critical surface tension.

Most organic adhesives easily wet metallic solids, but many solid organic substrates have surface tensions less than those of common adhesives. It is apparent that epoxy adhesives will wet clean aluminum or copper surfaces. However, epoxy resin will not wet a substrate having a critical surface tension significantly less than that of epoxy, approximately 47 dyne/cm. Epoxies will not, for example, wet either a metal surface contaminated with silicone oil or a clean polyethylene substrate.

See also surface tension, wetting.

After intimate contact is achieved between adhesive and adherend through wetting, it is believed that adhesion results primarily through forces of molecular attraction. Four general types of chemical bonds are recognized: electrostatic, covalent, and metallic, which are referred to as primary bonds, and van der Waals forces, which are referred to as secondary bonds. The adhesion between adhesive and adherend is thought to be due primarily to van der Waals forces of attraction.

See also van der Waals forces.

electrostatic and diffusion theories The electrostatic theory states that electrostatic forces in the form of an electrical double layer are present at the adhesive/adherend interface. These forces account for resistance to separation. The theory gathers support from the fact that electrical discharges have been noted when an adhesive is peeled from a substrate.

The fundamental concept of the diffusion theory is that adhesion arises through the interdiffusion of molecules in the adhesive and the adherend. The diffusion theory is primarily applicable when both the adhesive and the adherend are polymeric, having long-chain molecules capable of movement. Bonds formed by solvent or heat welding of thermoplastics result from the diffusion of molecules.

weak boundary layer theory According to the weak boundary layer theory, when bond failure seems to be at the interface, usually a cohesive break of a weak boundary layer is the real event. Weak boundary layers can originate from the adhesive, the adherend, the environment, or a combination of any of the three.

Weak boundary layers can occur on the adhesive or adherend if an impurity concentrates near the bonding surface and forms a weak attachment to the substrate. When bond failure occurs, it is the weak boundary layer that fails, although failure seems to occur at the adhesive/adherend interface.

Two examples of a weak boundary layer effect are polyethylene and metal oxides. Conventional grades of polyethylene have weak, low-molecular-weight constituents evenly distributed throughout the polymer. These weak elements are present at the interface and contribute to low failing stress when polyethylene is used as an adhesive or adherend. Certain metal oxides are weakly attached to their base metals. Failure of adhesive joints made with these adherends will occur cohesively within the weak oxide layer. Weak boundary layers can be removed or strengthened by various surface treatments.

Weak boundary layers formed from the shop environment are also very common. When the adhesive does not wet the substrate, a weak boundary layer of air is trapped at the interface, causing lowered joint strength. Moisture from the air may also form a weak boundary layer on hydrophilic adherends.

adhesive An adhesive is a substance capable of holding at least two surfaces together in a strong and permanent manner. Adhesives can be made of organic or inorganic material. They are chosen for their bonding and holding power. They are generally materials having high shear and tensile strength.

Structural adhesive is a term generally used to define an adhesive whose strength is critical to the success of the assembly. This term is usually reserved for adhesives with high shear strength (generally in excess of 1000 psi) and good environmental resistance. Structural adhesives are usually expected to last the life of the product to which they are applied. Examples of structural adhesives are epoxy, thermosetting acrylic, and urethane systems.

Nonstructural adhesives are adhesives with lower strength and permanence. They are generally used for temporary fastening or to bond weak substrates such as paper and foam. Examples of nonstructural adhesives are pressure-sensitive tapes, wood glue, elastomers, and sealants. These adhesives are sometimes used for temporary fastening or sealing.

Adhesives can also be broadly classified as being *thermoplastic*, *thermosetting*, *elastomeric*, and *alloy blends*. These four adhesive classifications can be further divided by specific chemical composition, as shown in Appendix K.

The types of resins that make up thermosetting and alloy adhesives are noted for their high strength, creep resistance, and resistance to environments such as heat, moisture, solvents, and oils. Their physical properties are well suited for structural adhesive applications. Elastomeric and thermoplastic adhesive classes are not used in applications requiring continuous load because of their tendency to creep under high stress. Many common service environments also degrade them. These adhesives find greatest use in nonstructural, low-strength applications such as pressure-sensitive tape, sealants, and hot-melt products.

Adhesives may also be classified by the way they are applied or cured. Hence, *anaerobic adhesives* are adhesives that set only in the absence of air, for instance, when confined between plates or sheets. A *contact adhesive* is one that is apparently dry to the touch but will adhere to itself instantaneously on contact (also called *contact bond adhesive* and *dry bond adhesive*). A *heat-activated adhesive* is a dry adhesive film that is made tacky or fluid by application of heat or heat and pressure to the assembly. A *pressure-sensitive adhesive* is a viscoelastic material that in solvent-free form remains permanently tacky. Such materials will adhere instantaneously to most solid surfaces with the application of very slight pressure. *Room-temperature setting adhesives* are those that set in the temperature range of 20–30°C. These are usually two-component adhesives that must be mixed before application. A *solvent adhesive* is an adhesive that has a volatile organic liquid as a vehicle and sets or becomes tacky after the solvent has evaporated. A *solvent-activated adhesive* is a dry adhesive film that is rendered tacky just before use by application of a solvent.

There are many types and suppliers of adhesives. The major suppliers of formulated adhesives range from large international businesses to very small regional shops. The major source of information regarding adhesives and adhesive bonding processes can be either the adhesive supplier or the supplier of the substrate material that is to be bonded. For example, most polymeric material suppliers are experts on the types of adhesives and processes that can be used to assemble products made with their materials.

See also structural adhesive; individual resins.

adhesive bonding Adhesive bonding is the process of joining two substrates (or *adherends*) with a third substance, usually an organic or inorganic resin. The resin or *adhesive* is applied in the liquid state and hardens after application and joining of the parts.

Adhesive bonding presents several distinct advantages over other methods of fastening substrates (Table A.6). Bonding, as a method of assembly, is often preferred when different types of substrates (e.g., metals to plastics) need to be joined, when high-volume production is necessary, or when the design of the finished part prohibits the use of mechanical fasteners.

Although there are various ways of joining plastics to themselves or to other materials, adhesive bonding has often proved to be the most effective assembly method. In many applications the use of adhesives rather than metal fasteners reduces product cost and the weight of the assembly, in some cases providing longer service life. Adhesive bonding can also be used very effectively in prototypes and with large or intricate assemblies that for economic or design reasons cannot be

Table A.6 Advantages and Disadvantages of Adhesive Bonding

Advantages	Disadvantages
1. Provides large stress-bearing area.	1. Surfaces must be carefully cleaned.
2. Provides excellent fatigue strength.	2. Long cure times may be needed.
3. Damps vibration and absorbs shock.	3. Limitation on upper continuous operating temperature (generally 350°F).
4. Minimizes or prevents galvanic corrosion between dissimilar metals.	4. Heat and pressure may be required.
5. Joins all shapes and thicknesses.	5. Jigs and fixtures may be needed.
6. Provides smooth contours.	6. Rigid process control usually necessary.
7. Seals joints.	7. Inspection of finished joint difficult.
8. Joins any combination of similar or dissimilar materials.	8. Useful life depends on environment.
9. Often less expensive and faster than mechanical fastening.	9. Environmental, health, and safety considerations are necessary.
10. Heat, if required, is too low to affect metal parts.	10. Special training sometimes required.
11. Provides attractive strength-to-weight ratio.	

molded or processed as a single part. *Solvent* and *heat welding* may be considered, in the case of plastic substrates, as a type of adhesive bonding process in which the adhesive is actually a part of the substrate itself.

However, the joining of plastics with adhesives can be made difficult because of their low surface energy and poor wetting, the presence of contaminants such as mold release agents and low-molecular-weight internal components (e.g., flexibilizers, UV inhibitors, and processing aids), and possible susceptibility to moisture and other environmental factors. Fortunately, numerous adhesives and processing methods are available for the joining of plastic materials and have been successfully used in many applications. Many of these products and applications are described in articles and handbooks on the subject. The plastic resin manufacturer is generally the leading source of information on the proper methods of joining a particular plastic.

See also adhesion; solvent cementing; heat welding.

adhesive failure Adhesive failure occurs when there is rupture of an adhesive bond such that the separation appears to be at the adhesive/adherend interface. When rupture occurs within one of the materials (either the adhesive or the adherend), the failure is said to be a *cohesive failure*.

See also adhesion theory.

adhesive joint The adhesive joint is the location at which two adherends are held together with a layer of adhesive. It is the general area of contact for a bonded structure. Generally, the adhesive joint is made up of components other than the adhesive and adherend. Metal oxides, contamination, mold release agent, moisture, and other such components may also be present at the adhesive joint area.

See also interphase; joint design (adhesive bonding).

adhesive stress To effectively design joints for adhesive bonding, it is necessary to understand the types of stresses that are common to bonded structures. Four basic types of loading stress are common to adhesive joints: tensile, shear, cleavage, and peel. Any combination of these stresses, illustrated in Fig. A.5, may be encountered in an adhesive application.

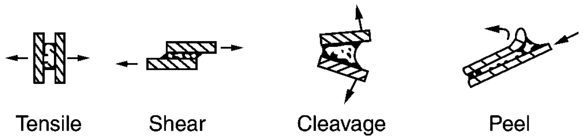


Figure A.5 Examples of common types of loading stress on a bonded joint: tensile, shear, cleavage, and peel.

Tensile stress develops when forces acting perpendicular to the plane of the joint are distributed uniformly over the entire bonded area. Adhesive joints show good resistance to tensile loading because all the adhesive contributes to the strength of the joint. In practical applications, unfortunately, loads are rarely axial and cleavage or peel stresses tend to develop. Because adhesives have poor resistance to cleavage and peel, joints designed to load the adhesive in tension should have physical restraints to ensure axial loading.

Shear stresses result when forces acting in the plane of the adhesive try to separate the adherends. Joints dependent on the adhesive's shear strength are relatively easy to make and are commonly used. Adhesives are generally strongest when stressed in shear because all the bonded area contributes to the strength of the joint.

Cleavage and *peel stresses* are undesirable. Cleavage occurs when forces at one end of a rigid bonded assembly act to split the adherends apart. Peel stress is similar to cleavage but applies to a joint where one or both of the adherends are flexible. Joints loaded in peel or cleavage provide much lower strength than joints loaded in shear because the stress is concentrated on only a very small area of the total bond. Peel stress particularly should be avoided where possible, because the stress is confined to a very thin region at the leading edge of the bond fracture. The remainder of the bonded area makes no contribution to the strength of the joint.

See also joint design (adhesive bonding).

adhesive tests Adhesive tests may be both long- and short-term tests. Unfortunately, because of the complexity of the adhesive bonding processes (and possible bond degradation processes) and because of the complex nature of the stresses on practical or "real-life" adhesive joints, it is very difficult to extrapolate test values to actual joint strength or to lifetime values. However, these tests are excellent ways of comparing different adhesive materials and processes under similar sets of conditions.

Strength values determined by short-term tests do not give an adequate indication of an adhesive's permanence during continuous environmental exposure. Laboratory-controlled aging tests seldom last longer than a few thousand hours.

To predict the permanence of an adhesive over a 20-year product life requires accelerated test procedures and extrapolation of data. Such extrapolations are extremely risky because the causes of adhesive bond deterioration are many and not well understood.

A number of standard tests for adhesive bonds have been specified by the American Society for Testing and Materials (ASTM). The properties usually reported by adhesive suppliers are ASTM tensile shear and peel strength. Common ASTM test methods that are used in the adhesives industry are shown in Appendix K.

lap-shear tests The lap shear or tensile shear test measures the strength of the adhesive in shear. It is the most common adhesive test because the specimens are inexpensive, easy to fabricate, and simple to test. This method is described in ASTM D1002, and the standard test specimen is shown in Fig. A.6. The specimen is loaded in tension, causing the adhesive to be stressed in shear until failure occurs. Because the test calls for a sample population of five, specimens can be made and cut from large test panels.

Figure A.6 Standard lap-shear test specimen design. (a) Form and dimensions of lap-shear test specimen. (b) Standard test panel of five lap-shear specimens. (Ref: ASTM D1002, American Society of Testing and Materials)

tensile tests The tensile strength of an adhesive joint is seldom reported in the adhesive suppliers' literature because pure tensile stress is not often encountered in actual production. Tensile test specimens also require considerable machining to ensure parallel surfaces.

ASTM tension tests are described in ASTM D897 and D2095 and use bar- or rod-shaped butt joints. The maximum load at which failure occurs is recorded in pounds per square inch of bonded area. Test environment, joint geometry, and type of failure should also be recorded.

A simple cross-lap specimen to determine tensile strength is described in ASTM D1344. This specimen has the advantage of being easy to make, but grip alignment and adherend deflection during loading can cause irreproducibility. A sample population of at least 10 is recommended for this test method.

peel tests Because adhesives are notoriously weak in peel, tests to measure peel resistance are very important. Peel tests involve stripping away a flexible adherend from another adherend that may be flexible or rigid. The specimen is usually peeled at an angle of 90° or 180°. The most common types of peel test are the T-peel and climbing-drum methods. The values resulting from each test method can be substantially different; hence it is important to specify the test method used. Peel values are recorded in pounds per inch of width of the bonded specimen. They tend to fluctuate more than other adhesive test results because of the extremely small area at which the stress is localized during loading.

The T-peel test is described in ASTM D1876 and is the most common of all peel tests. Generally, this test method is used when both adherends are flexible. A 90° peel test, such as the Bell peel test (ASTM D3167), is used when one adherend is flexible and the other is rigid. The flexible member is peeled at a constant 90° angle through a spool arrangement. Thus the values obtained are generally more reproducible. The climbing-drum peel specimen is described in ASTM D1781. This test method is intended for determining peel strength of thin metal facings on honeycomb cores, although it can be generally used for joints where at least one member is flexible. A variation of the T-peel test is a 180° stripping test described in ASTM D903. It is commonly used when one adherend is flexible enough to permit a 180° turn near the point of loading. This test offers more reproducible results than the T-peel test because the angle of peel is kept constant.

cleavage tests Cleavage tests are conducted by prying apart one end of a rigid bonded joint and measuring the load necessary to cause rupture. The test method is described in ASTM D1062. Cleavage values are reported in pounds per inch of adhesive width. Because cleavage test specimens involve considerable machining, peel tests are usually preferred.

fatigue tests Fatigue testing places a given load repeatedly on a bonded joint. Standard lap shear specimens are tested on a fatiguing machine capable of inducing cyclic loading (usually in tension) on the joint. The fatigue strength of an adhesive is reported as the number of cycles of a known load necessary to cause failure. Fatigue strength is dependent on adhesive, curing conditions, joint geometry, mode of stressing, magnitude of stress, and duration and frequency of load cycling.

impact tests The resistance of an adhesive to impact can be determined by ASTM D950. The specimen is mounted in a grip and placed in a standard impact machine. One adherend is struck with a pendulum hammer traveling at 11 ft/s, and the energy of impact is reported in pounds per square inch of bonded area.

creep tests The dimensional change occurring in a stressed adhesive over a long time period is called *creep*. Creep data are seldom reported in the adhesive suppliers' literature because the tests are time consuming and expensive. This is very unfortunate, because sustained loading is a common occurrence in adhesive applications. All adhesives tend to creep, some much more than others. With weak adhesives, creep may be so extensive that bond failure occurs prematurely. Certain adhesives have also been found to degrade more rapidly when aged in a stressed rather than an unstressed condition.

Creep tests are made by loading a specimen with a predetermined stress and measuring the total deformation as a function of time or measuring the time necessary for complete failure of the specimen. Depending on the adhesive, loads, and testing conditions, the time required for a measurable deformation may be extremely long. ASTM D2294 defines a test for creep properties of adhesives utilizing a spring-loaded apparatus to maintain constant stress.

environmental tests Strength values determined by short-term tests do not necessarily give an adequate indication of an adhesive's permanence during continuous environment exposure. However, there are several short-term environmental tests that will determine the *relative* resistance of an adhesive system to a specific environment.

adipic acid Esters of adipic acid, $HOOC—(CH_2)_4—COOH$, are excellent *plasticizers* for cellulosic plastics and polyvinyl chloride (PVC), especially where low-temperature properties are required (e.g., *dioctyl* and *dinonmy adipate*). *Dibutoxy ethyl adipate* is used as a plasticizer for *polyvinyl butyral* in safety glass laminations. Other available adipates include *dimethyl*, *diethyl*, *di-isobutyl*, *dimethoxy ethyl*, *dethoxy ethyl*, and *ditetrahydrofurfural adipates.*

admixture An admixture is the addition and homogeneous dispersion of several discrete components before cure. The term generally refers to any well-blended mixture of materials that is ready for final processing. More specifically, it refers to polymer alloys that are blends of two or more discrete polymeric resins that do not chemically react but form a compatible mixture.

See also alloy.

adsorption Adsorption is the adhesion of the molecules of gases, dissolved substances, or liquids in a more or less concentrated form to the surface of the solid or liquid with which they are in contact. Adsorption, which is a surface effect, is different from *absorption*, which is a bulk effect. Both adsorption and absorption are determined by the environments to which the material is exposed and by the chemical nature of the polymeric surface or the bulk material.

advanced composite Advanced composites are composite materials that are reinforced with continuous fibers having a modulus higher than that of fiberglass fibers. The term includes metal matrix and ceramic matrix composites, as well as polymeric composites that are reinforced with graphite, boron, ceramic, and fiber structures of the like.

Generally, an advanced composite is designed and constructed by varying the direction of the fibers purposely to optimally counteract the stresses that are expected on the final product during service.

See also composite; laminate.

afterflame, afterglow Afterflame is the persistence of the flaming of a material after the ignition source has been removed. Afterglow is the continuation of the glowing of a material after any afterflame has ceased or, if no flaming took place, after removal of the ignition source. Afterflame time and duration and afterglow time and duration are sometimes considered flammability parameters to compare various plastics and elastomers.

See also flammability.

aggregate Aggregate is a hard, coarse material, usually of mineral origin, that is used with an epoxy binder (or other resin) to construct plastic tooling. Aggregate is also used as filler in resinous flooring or as a surface medium for architectural structures. An example of an aggregate in this type of application is crushed stone.

aging Plastic properties can be destroyed only by (1) further chain growth and linkage, which would result in a hard, brittle material, or (2) a chain rupture, which would result in a weak plastic or even a resinous mass. The degrading agents mostly considered are sunlight, heat, oxygen, stress, atmospheric ozone, atmospheric moisture, and atmospheric nitrous oxide. Chain growth or crosslinking will usually decrease elongation and increase hardness and tensile strength, whereas chain rupture will have the opposite effect. Some plastics will continue to harden, others will soften, and still others show an initial hardening followed by softening. All aging phenomena are irreversible responses.

As defined in the laboratory, aging is the change in properties of a material with time under specific conditions. Aging can be either natural or *artificial* (laboratory simulation) with specified conditions and predetermined time periods. Aging can be *accelerated* (for testing) by increasing the effect of a particular environment, for example temperature, to obtain critical data in a shorter time period. Test standards that are concerned with aging processes in which elevated temperatures are used to simulate aging at a faster rate include ASTM D3045.

Aging of plastics is usually considered to be caused by either weathering or thermal exposure. However, there are many different forms of aging (e.g., fatigue and chemical resistance). Other aging tests are ASTM D573 (oven aging tests for rubber), ASTM D756 (test for changes in weight and shape of plastics under accelerated service conditions), ASTM D1870 (aging tests in tubular ovens), ASTM D1042 (tests for dimensional changes after oven aging), and ASTM D2126 (thermal/humid aging test for rigid cellular plastics).

air-assist forming Air-assist forming is a method of thermoforming in which air flow or compressed air pressure is used to partially preform the thermoplastic sheet immediately before the final pull-down onto the hot mold with a vacuum.

See also thermoforming.

air blasting Air blasting, *grit blasting*, or *sand blasting* is the process of blowing, via air pressure, a very fine-grit material through a stencil on a specific area of a plastic article. With plastic materials, this changes the appearance of the part to produce a matte effect as a contrast to the rest of a glossy surface on the article.

Air blasting and associated blasting processes can also be used to remove unwanted surface materials before painting or adhesive bonding. (*See also* surface preparation.) These processes can also be used as a finishing operation to remove unwanted gates, burrs, and other surface imperfections from molded plastic parts.

See also abrasive finishing.

air gap In extrusion coating, the air gap is defined as the distance from the die opening to the nip formed by the pressure roll and the chill roll.

airless spraying Originally introduced for paint-saving purposes, airless spraying is a high-pressure spraying process in which pressure is sufficiently high to atomize liquid coating particles without air. The droplets have low velocities because they are not propelled by air pressure as in conventional spray guns.

Advantages of airless spray coating are reduced solvent use, less overspray, less bounce-back, and compensation for seasonal ambient air temperature and humidity changes. A disadvantage of airless spray is its slower coating rate.

See also coating process.

air lock An air lock is an extremely shallow, regular or irregular depression in the surface of a molded plastic. It has practically no depth and is visible chiefly because of its sharply defined rim. The depression may lie wholly within the boundaries of one surface or extend completely across a surface, which makes the part look as if it were divided in two. This condition is sometimes called *frog skin*.

air ring In processing blown tubing, an air ring is a circular manifold used to distribute an even flow of cooling air onto a hollow tubular form passing through the center of the ring. The air cools the tubing uniformly to provide a uniform firm thickness.

air-slip forming A method of thermoforming, air-slip forming is a variation of *snap back forming* in which the male mold is enclosed in a box such that when the mold moves forward toward the hot plastic, air is trapped between the mold and the plastic sheet. As the mold advances, the plastic is kept away from it by this air cushion until the full travel of the mold is completed, at which point a vacuum is applied, destroying the cushion and forming the part against the ring. This process is shown in Fig. A.7.

See also thermoforming; snap back forming.

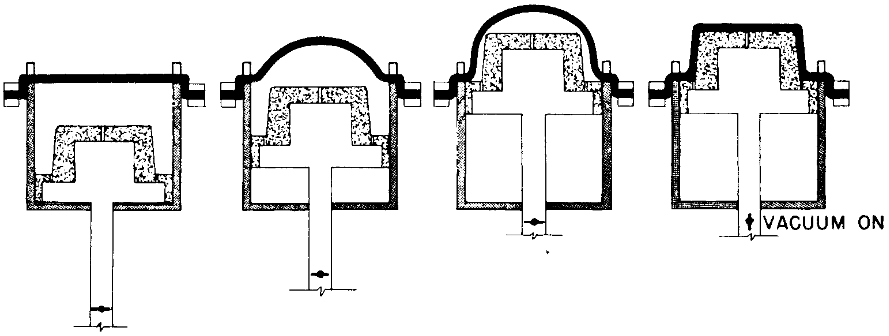


Figure A.7 Air-slip forming process. (Courtesy of Dow Chemical Company)

air vent The air vent is a groove or hole machined into a mold section to permit escape of air or gas that would otherwise be trapped in the mold cavity (Fig. A.8). Air vents are sometimes attached to vacuum pumps to increase their effectiveness. When the air or gas is not able to escape, it will prevent the proper filling of the cavity, and this results in moldings with voids or *air locks*.

See also vent; air lock.

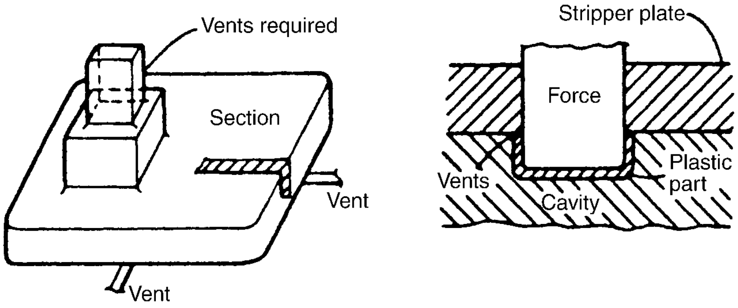


Figure A.8 Parting line vents. (Ref: Hull, J.L., "Design and Processing of Plastics Parts", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., McGraw-Hill, New York, 1996)

alcohol Alcohols are the hydroxyl derivatives of hydrocarbons. They form a homologous series, beginning with *methyl alcohol* (CH_3OH), then *ethyl alcohol* (C_2H_5OH), etc. Some alcohols are used as solvents. They also are chemicals used in the production of chemicals and resins.

aldehyde Aldehydes are substances that are characterized by the presence of a CHO radical. The simplest aldehyde is *formaldehyde*, HCHO. They are volatile liquids with sharp, penetrating odors that are slightly less soluble in water than corresponding alcohols. Aldehydes are widely used in industry as chemical building blocks in organic synthesis.

aliphatic Aliphatic is a generic term for hydrocarbons of open-chain structure as opposed to an *aromatic* ringlike structure. Aliphatic compounds are organic compounds of straight- or branched-chain arrangement of the carbon atoms. The aliphatic subgroups are (1) *paraffins*, which are saturated and unreactive; (2) *olefins*, which are unsaturated and quite reactive; and (3) *acetylenes*, which contain a triple bond and are highly reactive. *Aliphatic hydrocarbons* are saturated hydrocarbons having an open-chain structure (e.g., gasoline and propane).

alkane The term alkane refers to the *paraffin* series of hydrocarbons. It is the homologous series of hydrocarbons of which the first member is methane, CH_4, and each succeeding member adds CH_2, for example, ethane C_2H_6.

alkene Alkene is a generic name for acyclic hydrocarbons, branched or unbranched, having one double bond in the molecule. It is another name for the olefins, a homologous series of hydrocarbons of the general formula C_nH_{2n}, of which the first member is ethylene, C_2H_4.

alkyd Alkyds are thermosetting resins that are the reaction products of an organic acid with an organic alcohol. The selection of suitable polyfunctional alcohols and acids permits selection of a large variation of repeating units. Formulating can provide resins that demonstrate a wide range of characteristics involving flexibility, heat resistance, chemical resistance, and electrical properties. These resins are sometimes very complex and can be modified with fatty acids, natural resins, styrene monomer, or drying oils. Possible monomers are *styrene*, *diallyl phthalate*, and *methyl methacrylate*.

The alkyds are *polyester resins*, but as the latter term is applied to the more recently developed unsaturated types, the older name *alkyd* is usually limited to the saturated types. Alkyds are convertible to thermoset, cross-linked materials with the aid of additives containing double bonds or suitable functional groups.

Alkyd molding compounds are essentially thermosetting compositions, typically comprising cross-linkable alkyd resins, curing agents (commonly peroxides), and other additives such as fillers, reinforcement, lubricants, and colorants. They are available in granular, rope, and putty form as well as standard forms. Some are suitable for molding at relatively low pressures and at temperatures in the range of

150–200°C. Alkyd compounds often contain glass fiber filler but may also include clay, calcium carbonate, or alumina.

Alkyds are easy to mold and economical to use. Molding dimensional tolerances can be held to within ±0.001 in/in. Postmolding shrinkage is small. The compounds are molded by compression, transfer, and sometimes injection molding techniques.

The general alkyd's greatest limitation is its relatively low degree of resistance to extremes of temperature (above 177°C) and high humidity. *Silicones* and *diallyl phthalates* are superior in these respects—silicones especially with regard to temperature and diallyl phthalates with regard to humidity.

Alkyd resins are often used in molding electrical or electronic articles. Components include switches, housings, connector mountings, and other insulated parts. Straight and modified alkyd resins are used in the manufacture of enamels and other finishes. They are also used in printing inks and as adhesives to bond glass fabric and other materials for polyester laminates. Surface coating is a major application for alkyd resins.

Major commercial suppliers of alkyd resins include Rogers Corp. (ARMC grade molding compound), Cytec Industries Inc. (Glasskyd molding compound), P. D. George Co., Plastics Engineering Co., and U.S. Chemicals Inc.

alkyl *Alkyl* is a general term for any organic group derived from an aliphatic hydrocarbon by the elimination of one atom of hydrogen, for example, C_2H_5 (derived from C_2H_6).

alloy The term alloy is used to represent the physical *admixture* of two polymers. An alloy is a composite material made by blending two or more different polymers under selected conditions. The materials in an alloy formulation are generally not chemically reacted together but exist as discrete blended regions of material.

The object is to combine resins with widely differing properties into a homogeneous mass and at the same time overcome phase separation problems associated with blending of polymers that differ significantly in molecular weight.

Alloying occurs by establishing sites of compatibility along molecular chains such that a degree of physical crosslinking can occur. This is not a true chemical process but is achieved by addition of special wetting agents or compounding under high-shear conditions.

The concept of alloying or blending has become popular in the plastics industry. Some of the alloy blends familiar to the industry include styrene-modified PPS, ABS-polysulfone, SAN-polyolefin, PVC-acrylic, PVC-ABS, polycarbonate-ABS, nylon-elastomer, and polycarbonate-PBT blends. The number of potential alloys and blends seems almost limitless as suppliers continually offer new variations.

allyl The most broadly used allyl resins are prepared from the prepolymers of either *diallyl orthophthalate* (DAP) or *diallyl isophthalate* (DAIP), which have been condensed from dibasic acids. The DAP monomer is an ester produced by the esterification process involving a reaction between a dibasic acid (phthalic anhydride) and an alcohol (allyl alcohol), which yields the DAP ortho monomer. Similar reaction with dibasic acids will yield the DAIP prepolymer. These monomers are capable of crosslinking and will polymerize in the presence of certain peroxide catalysts such as dicumyl peroxide (DICUP), *t*-butyl perbenzoate (TBP), and *t*-butyl peroxyisopropylcarbonate (TBIC). *See* Fig. A. 9.

Diallyl phthalate (ortho) *Diallyl isophthalate (meta)*

Figure A.9 General chemical structures for diallyl phthalate and diallyl isophthalate.

Allyls are among the best of the thermosetting plastics with respect to high insulation resistance and low electrical losses. These properties are maintained at up to 200°C and in the presence of high humidity. DAIP will withstand somewhat higher temperatures than DAP. Certain grades of allyls are also good for food contact. Allyl resins are naturally flammable, although flame-retarded compounds are available.

Allyl resins are also easily molded and fabricated. The allyl resins have excellent dimensional stability, offering very low after-shrinkage (on the order of 0.1%). The largest commercial product is filled with short glass fiber filler, which combines moldability in thin sections with extremely high tensile and flexural strengths.

Commercial thermosetting DAP and DAIP molding compounds include fiber-reinforced grades for compression, transfer, and injection molding. Major commercial manufacturers of allyl molding compounds include Cosmic Plastics (Cosmic and Poly-Dap) and Rogers Corporation (FS and RX series).

See also diallyl phthalate (DAP).

allyl diglycol carbonate (ADCO) Allyl diglycol carbonate is an allyl ester that can be cured with heat and peroxide catalysts and can polymerize with styrene and other vinyl monomers. It is a thermosetting, crystal-clear plastic with exceptional scratch resistance. ADCO also has a high heat deflection temperature. Maximum recommended operating temperature for long-term use is 100°C and for short-term use is 150°C.

The plastic resin is often used for safety glasses, scratch-resistant glazing, lens covers, etc. It is manufactured as a cast sheet by PPG. The allyl diglycol carbonate monomer is available commercially from Polymer Products.

alternating copolymer An alternating copolymer is a copolymer in which the molecules of each monomer alternate in the polymer chain (—A—B—A—B—A—B—).

See also block copolymer; random copolymer.

alternating stress Alternating stress is a stress that varies between two maximum values that are equal but of opposite signs, according to a specification determined in terms of time. Alternating stress is a form of *fatigue*, and long periods of alternating stress can result in degradation and failure below the tensile strength of the plastic. An *alternating-stress amplitude* is a test parameter of a dynamic fatigue test. It is one-half the algebraic difference between the maximum and minimum stress in one cycle.

See also fatigue.

alumina trihydrate (ATH) The filler alumina trihydrate (ATH) generally is used as an extender in resins to combat higher prices or supply problems. However, this filler is also the highest-volume flame-retardant additive used in the plastics industry. Of the common fillers used in plastics, only ATH has flame-retarding and smoke-suppressing properties as well as being a low-cost resin extender. Other performance characteristics include enhanced arc and track resistance.

When ATH is used in plastic formulating, processing temperatures should be below 200°C. Extended-use temperatures for finished parts should be limited to 180°C to prevent long-term evolution of trace water vapor.

Aluminum trihydrate is available in a variety of grades that differ in particle size, color, and surface treatment. ATH finds use in such resins as polyesters, epoxies, and polyvinyl chloride (PVC). Commercial manufacturers of ATH include Akochem Corp.; Alcoa Industrial Chemicals; Pluess-Staufer International Inc.; and Whittaker, Clark & Daniels.

aluminum filler Pure aluminum conductive fillers are available in several forms, including powders, flakes, and fibers. These fillers are generally used to increase electrical conductivity or decrease thermal expansion coefficients of the plastic formulation. They give higher conductivity versus volume loading in comparison to carbon blacks and carbon fibers.

The powder and flake forms are recommended for injection molding applications. Either flake or fiber is effective in compression molding. The higher aspect ratio of the fibers will show better conductivity at a given concentration level.

Aluminum powders have been added to acetals and nylons to produce conductive moldings suitable for plating. Epoxy resin formulations that are highly filled with aluminum have been used to cast tools and guides and for producing metal cements and coatings.

amide The amides are a group of chemicals derived from acid by a substitution of hydroxyl groups (OH) with NH_2. For amides applied as an epoxy resin catalyst, *see also* amido-amine.

amido-amine The amido-amines are epoxy resin curatives. Many so-called "amides" used in epoxy resin formulations are actually amido-polyamines. The hydrogens of the amide group are sluggishly reactive, with elevated temperatures being required for a satisfactory rate.

They are polyamide resins with amine functionality and lower viscosity. These curing agents are used in standard two-component epoxy adhesive systems that cure at room temperature. Amido-amines can be found commercially in viscosities ranging from motor oil to clay-like.

See also epoxy resin curing agent.

amine The amines are a large group of chemicals derived from ammonia, NH_3, in which one or more of the hydrogen atoms have been replaced with an organic radical. The amine is primary, secondary, or tertiary depending on whether one, two, or three of the hydrogen atoms have been replaced.

A *primary amine* has one ammonia hydrogen substituted (e.g., methylamine). Primary amines are used as a catalyst and solvent in the manufacture of resins. They are also used as an isocyanate coreactant in the polymerization of polyurethane.

Amines are used commonly as curing agents for *epoxy* resins and adhesives. Aliphatic primary amines provide a fast room-temperature cure but provide poor elevated-temperature resistance. They also produce resin systems with a very high exotherm. Common primary amines used in these formulations include *diethyltriamine* (*DETA*) and *triethylenetetramine* (*TETA*).

Aromatic amines offer improved heat and chemical resistance in epoxy formulations. They are generally solid curing agents and can be used to provide a B-stage cure. Typical aromatic amines include *m-phenylenediamine* (*MDA*) and *diaminodiphenyl sulfone* (*DDS*).

Tertiary amines are primarily used as catalysts for epoxy formulations with other curing agents, but they can also be used as a room- or elevated-temperature curing agent on their own.

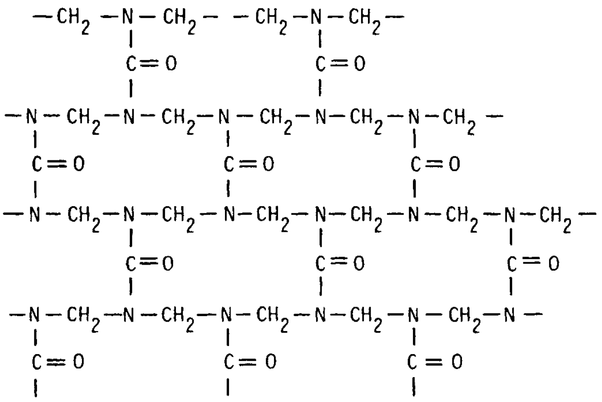
See also epoxy resin curing agent.

amine adduct Amine adducts are the products of the reaction of an amine with a deficiency of a substance containing epoxy groups. Amines may be adducted with a variety of epoxidized resins and other components. Amine adducts are common curing agents for epoxy resins. A typical amine adduct is produced by reacting diethylene triamine with DGEBA epoxy resin.

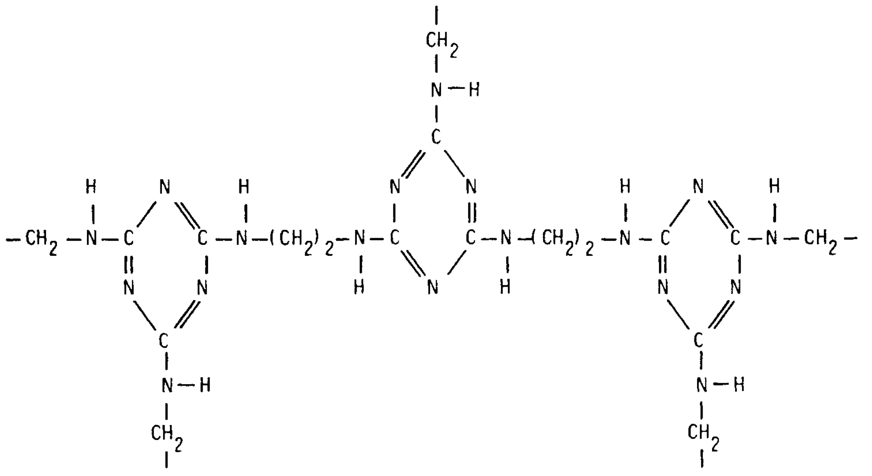
These adducts have lower volatility due to a higher molecular weight and usually a somewhat heightened reactivity. Because of the higher molecular weight, the adducts are used at higher and more convenient ratios than the amine epoxy catalysts.

amino resin Amino resins are thermosetting compounds. Melamine, a trimer of cyanamide, and urea react with formaldehyde, first by addition to form methanol compounds and then by condensation in reactions much like those of phenol and formaldehyde. These may be polymerized to crosslinked resins by loss of water.

The two important classes of amino resins are the condensation products of urea and melamine with formaldehyde (Fig. A.10). The melamine product is known as *melamine formaldehyde* (*MF*) or *melamine phenoformaldehyde* (*MPF*); the urea product is known as *urea formaldehyde* (*UF*). They are generally considered together because of the similarity in their production methods and applications. These resins are also known as *aminoplasts*.



Urea Formaldehyde



Melamine Formaldehyde

Figure A.10 General chemical structures for urea formaldehyde and melamine formaldehyde.

In general, the melamine resins have somewhat better properties (hardness, heat resistance, and moisture resistance) than the ureas but are higher in price. A distinct advantage of the amino resins over the phenolics is the fact that they are clear and colorless, so that objects of light or pastel color can be produced. The tensile strength and hardness of the amino resins are better than those of the phenolics, but their impact strength and heat and moisture resistance are lower. The melamine resins have better hardness, heat resistance, and moisture resistance than the ureas.

Amino plastics can be used as molding compounds, adhesives, and laminating resins. Practically all urea molding compounds are cellulose filled. The melamines, although predominantly cellulose-filled, are also used with other fillers. Addition of α-cellulose filler, the most commonly used filler for aminos, produces an unlimited range of light-stable colors and high degrees of translucency.

Amino molding compounds can be fabricated by economical molding methods. Because of their poorer flow characteristics, the urea resins are usually compression-molded, but transfer molding is common with the melamines. Amino resins exhibit relatively high mold shrinkage. Product applications for amino resins include dinnerware, buttons, toilet seats, knobs, handles, ashtrays, food utensils, mixing bowls, and military equipment. Parts are typically joined with adhesives and fasteners.

Amino molding compounds are hard, rigid, and abrasion resistant, and they have high resistance to deformation under load. These materials can be exposed to subzero temperatures without embrittlement. Under tropical conditions, melamines do not support fungus growth. Amino materials are self-extinguishing and have excellent electrical insulation characteristics. They are unaffected by common organic solvents, greases and oils, and weak acids and alkalis. Aminos do not impart taste or odor to foods.

Melamines are superior to ureas in resistance to acids, alkalis, heat, and boiling water, and they are preferred for applications involving cycling between wet and dry conditions or rough handling. Cracks develop in urea moldings that are subjected to severe cycling between dry and wet conditions. Ureas are unsuitable for outdoor exposure. Melamines experience little degradation in electrical or physical properties after outdoor exposure, but color changes may occur.

Melamines and ureas provide excellent heat insulation and resistance; temperatures up to the destruction point will not cause parts to lose their shape. Amino resins exhibit relatively high shrinkage on aging. Prolonged exposure to high temperature affects the color of both urea and melamine products. A loss of certain strength and electrical characteristics (except arc resistance) also occurs when amino moldings are subjected to prolonged exposure to elevated temperatures.

Amino resins have found applications in the fields of industrial and decorative laminating, adhesives, protective coatings, textile treatment, paper manufacture, and molding compounds. Amino resins are used in adhesive formulations for bonding plywood and furniture. The melamine resins give excellent boil-resistant bonds but for economy are usually blended with ureas.

Melamine resins are also widely used for producing decorative laminates. These are usually assembled with a core of phenolic-impregnated paper and a melamine-impregnated overlay. They are cured by hot pressing and are widely used for countertops, cabinettops, and tabletops.

Because of their colorability, solvent and grease resistance, surface hardness, and mar resistance, the urea resins are widely used for cosmetic container closures, appliance housing, and stove hardware. The production of high-quality dinnerware from cellulose-filled compounds is one of the largest uses for the melamine resins.

Amino resins also modify textiles such as cotton and rayon by imparting crease resistance, stiffness, shrinkage control, fire retardance, and water repellency. They also improve the wet strength, rub resistance, and bursting strength of paper. Alkylated resins, in which butyl- or amyl-substituted monomethyl ureas or melamines are used, are combined with alkyd resins to give baking enamels. The urea-based enamels are used for appliances, and the melamine formulations in automotive finishes.

Other amino resins include those based on *ethyleneurea*, used in textile applications; *guanamine*, used in surface coatings; and *aniline*, used in molded and laminated electrical insulation.

BIP Chemicals, Cytec Industries (Fiberite and Beetle), Perstorp, and Plastics Engineering (Plenco) are among several manufacturers that commercially produce melamine formaldehyde resins.

See also aniline formaldehyde.

amorphous phase An amorphous phase is one that is devoid of *crystallinity* and has no defined molecular order. At processing temperatures, the crystalline plastics are normally in the amorphous state.

See also amorphous polymer; crystalline.

amorphous polymer An amorphous polymer is one in which the polymer exists in a random unordered structure. An example of an amorphous polymer is polystyrene. Generally, the structure of the polymer chain is such that it cannot be packed into an orderly network.

On the other hand, if the structure of the polymer backbone is a regularly ordered structure, then the polymer can tightly pack into an ordered *crystalline* structure, although the material will generally be only *semicrystalline*. Examples of crystalline polymers are polyethylene and polypropylene.

The exact detail and makeup of the polymer backbone will determine whether the polymer is capable of crystallizing. This microstructure can be controlled by different synthetic methods. For example, *Ziegler-Natta catalysts* are capable of controlling the microstructure to produce stereospecific polymers.

See also polymer; crystalline; Ziegler-Natta catalyst.

anaerobic adhesive An anaerobic adhesive is one that cures only in the absence of air after being confined between assembled parts. These well-known adhesives and sealants are used to lock mechanical fasteners and for form-in-place gaskets. They can be found in most auto parts stores and hardware stores.

Anaerobic adhesives are generally acrylate monomer-based adhesives. They are essentially monomeric, thin liquids that polymerize to form a tough plastic bond when confined between closely fitting metal joints. They generally require a metal substrate because the metal ions catalyze the reaction process. However, catalyzed primers are available for curing anaerobic adhesives on nonmetallic substrates.

anchorage In molding, an anchorage is the part of an insert that is molded inside the plastic and held fast by the shrinkage of the plastic.

anelastic deformation An anelastic deformation is any portion of the total deformation of a body that occurs as a function of time when load is applied and that disappears completely after a period of time when the load is removed. In practice, *anelastic deformation* also describes the viscous deformation of a body.

angle press The angle press or *side-ram press* is a hydraulic molding press equipped with horizontal and vertical rams. It is specially designed for the production of complex moldings containing deep undercuts. The orientation of the press greatly facilitates the ejection of molded parts having undercuts or projections. This type of press can apply pressure both horizontally and vertically.

anhydrous Anhydrous compounds are those from which water is removed or those that do not have the presence of water.

aniline Aniline is an important organic base with the structure $C_6H_5NH_2$. It is made by reacting chlorobenzene with aqueous ammonia in the presence of a catalyst. Aniline is used in the production of *aniline formaldehyde* resins and in the manufacture of certain rubber accelerators and antioxidants.

aniline formaldehyde Aniline formaldehyde is a member of the *amino plastics* group made by the condensation of formaldehyde and aniline in an acid solution. The resins are thermoplastic and can be molded into flat sheets and other forms of dark, brownish-red color.

Aniline formaldehyde resins are used to a limited extent in the production of compression-molded and laminated insulating materials. Products made from these resins have high dielectric properties that are stable over a wide range of frequencies and under high-humidity conditions. The resin has good chemical stability. It is unaffected by ultraviolet light and by weather conditions. Although it is attacked by strong acids, it is unaffected by alkalis and is not soluble in any common organic solvents.

See also amino resin.

anionic polymerization Anionic polymerization is an addition polymerization process that is initiated by anions. A wide variety of anions can be used, but the use of organic alkali metal salts has the greatest commercial importance.

Anionic polymerization is propagated by carbon atom intermediates, which contain an unshared pair of electrons and are negatively charged (carbanions). The conventional method of initiation of ionic chains involves the addition of a negative ion to the monomer, with the opening of a bond or ring and growth at one end. In an inert medium, there is no termination step. The chains will continue to grow until the monomer supply is exhausted.

The ionic chain end is stable, and the growth of the chains can be resumed by the addition of more monomer. For this reason, these materials have been aptly termed *living polymers*.

See also living polymer; addition polymerization.

anisotropic An anisotropic material is one in which the properties are different in different directions along the laminate plane. A unidirectional composite is an example of an anisotropic material. It has different properties in the directions parallel to the fibers compared to the direction perpendicular to the fibers. Wood is another example of an anisotropic material. It has properties that are different in the direction of the grain and perpendicular to the grain.

annealing Annealing or *afterbake* is the heating of a molded article in an oven after it is taken from the press or the primary curing process. The purpose of an annealing process is generally to either (1) relieve internal stresses and strains or (2) hasten the cure and ultimate shrinkage of a molded piece. The part is usually heated to a temperature that is near, but below, its melting point. The part then is allowed to cool slowly after annealing. Annealing is often used on molded thermoplastic articles to relieve local stresses set up by flow of the resin into the mold.

Annealing is a common procedure if the part is known to have internal stress and if it will see harsh chemical environments either for the purpose of assembly (such as solvent welding) or during service. Acrylic parts are the most common plastic that is susceptible to stress crazing. For this reason they are often annealed before cleaning, finishing, assembly, etc. Acrylic parts, for example, are heated to 50–70°C, depending on the grade, in a forced circulating air oven for up to 24 h and then cooled in the oven or in still air at room temperature.

antiaging additive Antiaging additives are incorporated into plastic compounds to improve the resistance of the resin to aging—generally, oxidative aging. Examples of aging include attack by oxygen, ozone, dehydrochlorination, and ultraviolet (UV) light degradation. Aging often results in chain scission, addition of polar groups, or the addition of groups that cause discoloration. Additives are used to help prevent these reactions.

Antioxidants are added to the polymer to stop the free radical reactions that occur during oxidation. Antioxidants include compounds such as phenols and amines. Phenols are often used because they have less of a tendency to stain.

Peroxide decomposers are also added to improve the aging properties of thermoplastics. These include mercaptans, sulfonic acids, and zinc dialkylthiophosphate.

The presence of metal ions can act to increase the oxidation rate, even in the presence of antioxidants. *Metal deactivators* are often added to prevent this from taking place. *Chelating agents* are added to complex with the metal ion.

See also ultraviolet stabilizer, antioxidant.

antiblocking agent Antiblocking or *flatting agents* act to prevent various plastic films (e.g., polyvinyl chloride, polyolefins) from adhering to each other because of static electricity buildup or cold flow. *Slip agents* perform many of the same functions. However, slip agents also play a role during processing in preventing plastics from sticking to metal.

Antiblocking agents can be applied externally or internally and include such materials as waxes, metallic salts, fatty acids, fumed silicas, and even other plastics (e.g., polyvinyl alcohol, polysiloxanes, and fluoroplastics). Silicates and silicas can also be used as flatting agents to affect the surface of the films so that they will not adhere to each other. These function by roughening the surface film to give a spacing effect. Typical of this application is the use of calcium silicate in PVC.

Years ago, efforts were made to provide antiblocking by dusting the surface with cornstarch or silica. This process was abandoned because of potential health concerns. Antiblocking agents are now melt incorporated into the thermoplastic either via direct addition or by use of a master batch.

Although both organic and inorganic materials are used as antiblocking agents, the inorganics make up the bulk of the market. The four major types of antiblocking agents are diatomaceous earth, talc, calcium carbonate, and synthetic silicas and silicates.

Antiblocking agents are used in polyolefin films in conjunction with slip agents in such consumer items as trash bags, shipping bags, and a variety of packaging applications

Commercial manufacturers of antiblocking agents are Akzo Engineering Plastics, Ferro Corporation, Modern Dispersion Inc., Quantum Chemical Corporation, and Summit Chemical Company.

See also slip agent.

antifogging agent These agents are intended to prevent fogging that could obscure viewing in products such as polyvinyl chloride (PVC) packaging film or PVC windows. The fogging effect in these products is the result of water condensation on the inside surface of the film (e.g., in a package the water will often come from the packaged products such as food). The antifogging agents, typically specific fatty acid esters, function either by causing the water droplets to form a continuous film on the inside surface or by imparting a hydrophobic characteristic to the film surface, thereby preventing the water droplets from forming.

Akzo Chemicals, Eastman Chemical Products, Henkel Corp., ICI Americas, and Witco Corporation commercially manufacture antifogging agents.

antimicrobial Antimicrobials or *algicides* prevent degradation of plastics by fungi, bacteria, and algae. This degradation can take the form of shortening of useful life, odor and embitterment, and lowering of tensile strength and electrical properties.

Antimicrobials are incorporated into a plastic formulation to preserve the polymeric material by destroying or inhibiting the growth of microorganisms on the product's surface. The constant presence of a biocide on the surface of antimicrobial plastics is essential for successful inhibition of microorganisms. Antimicrobials should migrate to the surface at a rate sufficient to maintain an effective concentration of biocide at the surface.

Antimicrobials for plastics are considered pesticides and must be registered with the U.S. Environmental Protection Agency (EPA). Registration requires the submission of toxicity, efficacy, safety, handling, and environmental data.

The bulk of antimicrobials have been used for flexible PVC, polyurethane foams, and adhesives in formulations that are used in stressful environments. Typical environments in which antimicrobial additives are used include pool and ditch liners, outdoor furniture, marine upholstery, roofing membranes, tarpaulins and tent fabrics, shower curtains, and wall and floor coverings.

Antimicrobials for plastics contain active ingredients dispersed in a carrier material — a plasticizer, solvent, or resin. Liquid, powdered, and pelleted versions featuring even distribution in formulation and ease of handling are available. The most widely used active ingredients for polymer materials are *10,10-oxybisphenoxarsine*, *OBPA* (Intercide from Alcros Chemicals), and *2-n-octy-4-ixothiazolin-3-1* (Micro-Check from Ferro Corp.). Other chemistries are also available. Antimicrobials are also commercially manufactured by Akzo Chemicals, Morton International Inc., Hexcel Corporation, and Uniroyal Chemical Company.

antimony oxide Antimony oxides are essentially antimony trioxide (Sb_2O_3) and pentoxide (Sb_2O_5). Both are used as flame retardants in many plastics. The pentoxide came into use more recently, but often these are considered together simply as antimony oxide. Antimony oxide is a dry, white powder. The particle size of antimony oxide is an important consideration in selection because the size can affect physical properties, dispersal, or processability, and it can affect color control in the finished product. Antimony pentoxide is now available in a very fine particle form from PQ Corp. (Nyacol).

In polymers that do not contain chlorine, the presence of a halogenated additive, in practice normally a brominated or chlorinated organic compound, is required to enable the antimony oxide to exert its flame-retardant action.

Antimony oxide works synergistically with reactive or additive halogenated compounds to improve the flame-retarding effect of the halogens so that less of the halogenated compound needs to be used, with consequently less effect on physical properties. Antimony oxide is effective when used in combination with such organic flame-retardant compounds as chlorinated paraffins, chlorinated cycloaliphatics, aromatic bromine compounds, alkyl chlorine, or bromine and phosphates. It is used in such resins as ABS, polyethylene, polypropylene, polystyrene, thermoplastic polyester (PBT), and unsaturated polyesters.

See also flame retardant.

antioxidant Antioxidants are used in a variety of resins to prevent oxidative degradation. Degradation is initiated by the action of highly reactive free radicals caused by heat, radiation, mechanical shear, or metallic impurities.

Plastics degradation starts with the initiation of *free radicals* on exposure to heat, UV radiation, and mechanical shear or in the presence of reactive impurities such as catalyst residues. The radicals thus initiated have a high affinity for reacting with oxygen to form unstable peroxy radicals. These radicals, in turn, attract neighboring labile hydrogens to produce unstable hydroperoxides plus additional free radicals that keep the process going. This leads to degradation of the polymer.

Only when a nonradical inert product is formed will the cycle be terminated. In preventing this type of degradation, the antioxidants function by intercepting the radicals or by preventing radical initiation during the plastic's life cycle.

The function of an antioxidant is to prevent the propagation of oxidation. Because many plastics are susceptible to oxidative degradation, the role of antioxidants in slowing down the process and imparting longer life to many products has taken on added importance. Depending on the aging environment, most plastics can benefit from antioxidants. Plastics especially susceptible to oxidation such as polypropylene, polyethylene, ABS, and polystyrene often include antioxidants in their formulations.

Antioxidants can be divided into two basic classifications: primary and secondary antioxidants. *Primary antioxidants* interrupt oxidation degradation by tying up the free radicals. *Secondary antioxidants* destroy the unstable hydroperoxides that function as sources of free radicals during oxidative degradation.

The two major groups among the primary antioxidants are *hindered phenolics* and *aromatic amines*. The most widely used antioxidants in plastics are phenolics. The products generally resist staining or discoloration. However, they may form quinoid (colored) structures on oxidation. Phenolic antioxidants include simple phenolics, bisphenolics, polyphenolics, and thiobisphenolics. Hindered phenolics, such as *butylated hydroxytoluene* (*BHT*), *high-molecular-weight phenolics*, and *thiobisphenolics*, are the most popular of the primary antioxidants.

Aromatic amines, normally arylamines, may be more effective than phenolics, but most are staining and discoloring and lack FDA approval for use in contact with food. Amines are commonly used in the rubber industry but also find minor uses in plastics such as black wire and cable formulations and in polyurethane polyols.

Secondary antioxidants are used in conjunction with primary antioxidants to provide added stability to the polymer. Typical compounds contain sulfur or phosphorus. The more popular secondary antioxidants are *thioesters* (*thiodipropionic acid derivatives* and *polythiodipropionates*) and *organophosphites.*

Organophosphites provide color stability but have a hygroscopic tendency. Hydrolysis of phosphites can ultimately lead to the formation of phosphoric acid, which can corrode processing equipment. Tris-nonylphenyl phosphite (TNPP) is the most commonly used organophosphite followed by tris(2,4,-di-tert-butylphenyl)phosphite (Ciba Giegy's Irgafos 168). Thioesters have high heat stability but have an inherent odor, which can be transferred to the host polymer. A new phosphite secondary antioxidant, based on butyl ethyl propane diol, reputedly yields high activity, solubility, and hydrolytic stability in a range of polymers.

Antioxidant systems combining two or more materials are generally used. The most effective mixture will combine a free radical inhibitor with a peroxide decomposer. The free radical inhibitor retards the initiation of reaction chains, but some hydroperoxide is nevertheless formed. A peroxide decomposer available to react with the hydroperoxide prevents it from decomposing with free radicals. The nature of the resin will influence the kind and amount of antioxidant used.

Table A.7 lists the chemical types of primary and secondary antioxidants and their major resin applications.

Lactone stabilizers are a new class of materials that are reputed to stop the autoxidation process before it starts. These products are derivatives of the benzofuranone family. Some blends (Ciba Giegy's HP) claim to be particularly effective in high-temperature and high-shear processing.

Table A.7 Antioxidants by Chemical Type with Major Resin Applications

Types	Major resins	Comments
Primary:		
Amine	Rubber, some pigmented plastics, and polyurethane polyols	Arylamines tend to discolor and cause staining.
Phenolic	Polyolefins, styrenics, and engineering resins	Phenolics are generally stain resistant and include simple phenolics (BHT), various polyphenolics, and bisphenolics.
Metal salts	Polyolefin wire and cable	These are metal deactivators used in the inner coverings next to the metal.
Secondary:		
Organophosphite	Polyolefins, styrenics, and engineering resins	Phosphites can improve color stability, and engineering resins but can be corrosive if hydrolyzed.
Thioester	Polyolefins and styrenics	The major disadvantage with thioesters is their odor which is transferred to the host polymer.

Antioxidants are commercially manufactured by many companies, including Akrochem Corporation, Akzo Chemicals Inc., Harwick Chemical Corporation, ICI Americas Inc., Monsanto Chemical Co., R.T. Vanderbilt Co., and Witco Corporation. Numerous suppliers offer both primary and secondary antioxidants to complete their product line. However, very few actually manufacture both primary and secondary antioxidants, because the products are based on different manufacturing methods and feedstock. As a result, it is quite common in this industry to resell products produced by another company.

See also metal deactivator.

antistatic agent Antistatic agents reduce the tendency of plastics to pick up static electricity. Plastics, being normally insulative materials [typical surface resistivities in the range of 10^{12}–10^{14} ohms/square], are quite receptive to static electricity. Plastics cannot be grounded or otherwise forced to dissipate the charge unless modified with antistatic additives. The presence of static electricity can create many problems such as dust pickup, interference in processing, static cling in films, difficulty in demolding or denesting parts, sparking (fire and explosion hazard), and damage to electrical components.

The primary role of an antistatic agent, or antistat, is to prevent the buildup of static electrical charge resulting from the transfer of electronics to the surface. This static electricity can be generated during the processing, transportation, and handling, or in final use. Typical electrostatic voltages can range from 6,000 to 35,000 V. Secondary benefits of antistat incorporation into polymer systems include improved processability and mold release as well as better internal and external lubrication.

Most antistats are hydroscopic materials and function primarily by attracting water to the surface. This process allows the charge to dissipate rapidly. Therefore, the ambient humidity level plays a vital role in this mechanism. With an increase in humidity, the surface conductivity of the treated polymer is increased, resulting in a rapid flow of charge and better antistatic properties. Conversely, antistats that rely on humidity to be effective may offer erratic performance in dry ambient conditions.

There are two main forms of antistatic agents: internal and external. *External antistatic agents* are generally used for temporarily getting the plastic part through processing or handling. For long-term static protection, internal antistats are recommended. There are also two types of *internal antistats*: migratory, which is more common, and permanent.

External, or topical, antistats are applied to the surface of the finished plastic part through techniques such as spraying, wiping, or dipping. A broad range of chemistries are possible. The most common external antistatic additive is quaternary ammonium salt, or “quats” applied from a water or alcohol solution.

Migratory antistats have chemical structures composed of hydrophilic and hydrophobic components. These materials have limited compatibility with the host plastic and migrate or bloom to the surface of the molded product. If the surface of the part is wiped, the migratory antistat is temporarily removed, reducing the antistat characteristic. These surface-active antistatic additives can be cationic, anionic, and nonionic compounds. The optimal choice and addition level for migratory antistats depend on the nature of the polymer, the type of processing, the processing conditions, the presence of other additives, the relative humidity, and the end use of the polymer.

Permanent antistats are polymeric materials that are compounded into the plastic matrix. They do not rely on migration to the surface and subsequent attraction of water to be effective. The primary advantages of these materials are insensitivity to humidity, long term performance, minimal opportunity of surface contamination, low off-gassing, and color and transparency capability.

There are two generic types of permanent antistats: hydrophilic polymers (currently the dominant product) and conductive polymers. Typical hydrophilic materials that have been used successfully are such polyether block copolymers as Pebax from Atochem and Stat-rite from B.F. Goodrich. Conductive fillers (*carbon black*, *carbon fiber*, *metals*, etc.) compounded into the resin form a conductive path. These make good permanent antistats. Inherently conductive plastics are still in the developmental stages.

Antistatic agents have proved very effective in polyolefins. Nonionic materials, usually ethoxylated, propoxylated, or glycerol compounds, provide the right degree of polarity. Ethoxylated amines, both naturally derived and synthetic, are the most widely used. Glycerides with a high mono content (90%) have proved successful. Loading requirements are very low — a few tenths of a percent at most. Quaternary ammonium compounds provide effective antistat for polyvinyl chloride (PVC).

Antistats are also available for polyurethanes, acrylics, thermoplastic polyester, and other resins. They are seldomly used in engineering resins, where the higher melt temperatures are not amenable to these internal anitstats.

Antistatic agents are commercially manufactured by Akzo Chemicals Inc., Cabot Corporation, Dow Chemical, Eastman Chemical Products, Emery Group (Henkel Corp.), PPG Industries Inc., and Witco Corporation.

apparent density Apparent density is the same as bulk density. It is the mass per unit volume of a void-containing material. The term is usually applied to particulate and loose material (e.g., powders or pellets), and the voids are interparticle spaces. A method of determining the apparent density is described in ASTM D1895.

See also bulk density.

aramid Aramid is a generic name for aromatic polyamides and polyamide-imides. They are highly oriented organic materials derived from a *polyamide* but incorporate an aromatic ring structure.

See also aromatic polyamide.

aramid composite Aramid composites are widely used for pressure vessels but have largely been supplanted by the very high-strength carbon/graphite fibers. Aramid composites have outstanding toughness and creep resistance, and their failure mode in compression, shear, or flexure is not in a brittle manner and requires a relatively great deal of work. For this reason they are found useful in armor and shielding applications. Aramid composites have relatively poor shear and compression properties. Careful design is required for their use in structural applications that involve bending.

Aramid composites are very difficult to machine because of the extreme toughness of the aramid fiber. Special cutting and machining techniques and equipment are required. Information on the processes required for aramid composites is available from Du Pont, the producers of Kevlar, an aramid fiber, commonly used in high-strength, low-weight advanced composites.

aramid fiber Aramid fibers are synthetic fibers that were introduced by Du Pont, in 1972 and carry the tradename Kevlar. The fiber-forming substance is a long-chain synthetic aromatic polyamide in which at least 85 percent of the amide linkages are directly attached to two aromatic rings.

The aramids have very high strength and modulus-to-weight ratios. They also have high degrees of thermal, chemical, and flame resistance. Aramid fibers have also shown great consistency with a low coefficient of variation, permitting high design allowables in composite construction. The specific tensile strength of Kevlar was, at its introduction, the highest of any fiber.

The aramids fibers, however, have relatively poor shear and compression properties in a composite. Components, such as pressure vessels, that avoid these stresses make the most efficient use of aramid fiber.

See Kevlar.

arc- and track-resistant plastic Arc- and track-resistant plastics are those plastics that resist the formation of a carbon track on the surface of the plastic under high-voltage operating conditions. Carbon track formation is caused by decomposition of the plastic under the high energy of high voltage, resulting in a decomposed, pure carbon track between the high-voltage electrodes. This carbon track is conductive and thus destroys the desired insulating property of the plastic and the assembly made of that plastic.

Polytetrafluoroethylene (PTFE) has a very high dry arc resistance (over 200 s). Among the thermosets frequently used as insulators, alkyds and melamine resins are reported to be superior to phenolics. Polyethylenes have a relatively high arc resistance (around 150 s), whereas polystyrene and polyvinyl chloride have a relatively low arc resistance (around 70 s).

Arc-extinguishing plastics are materials that give off a gas that has arc-extinguishing properties under flash conditions.

See also arc resistance; track resistance; high voltage; high-voltage-resistant plastic.

arc resistance Arc resistance is measured as the time required for a given electric current to render the surface of a material conductive because of carbonization by the arc flame. When an electric current is allowed to travel across an insulator's surface, the surface will degrade over time and become conductive.

Arc resistance is a measure of the time, in seconds, required to make an insulating surface conductive under a high-voltage, low-current arc under specified conditions. In ASTM D495 continuous and intermittent arcs are applied to the surface with pointed electrodes to measure the arc resistance.

See also track resistance.

aromatic *Aromatic hydrocarbons* are derived from or characterized by the presence of unsaturated resonant ring structures (e.g., benzene rings). They generally have high-temperature resistance because of the aromaticity.

An *aromatic polymer* is one having an unsaturated hydrocarbon with one or more benzene ring structures in the monomer. The polymeric structure, which can be expressed as a chain of aromatic rings, is also known as a *ladder polymer*. The aromatic structure generally provides increased thermal stability.

See also ladder polymer.

aromatic amine Aromatic amines are synthetic amines derived from the reaction of urea, thiourea, melamine, or allied compounds with aldehydes that contain a significant amount of aromatic subgroups.

Aromatic amines, such as *metaphenylenediamine (MPDA), methylenedianiline (MDA), and diaminodiphenyl sulfone (DADPS),* are used as epoxy curing agents. They provide high temperature resistance and yield somewhat better chemical resistance than do aliphatic amine curing agents. These three curing agents are solid. They are incorporated into epoxy formulations by mixing with the resins at a temperature of 65–95°C. These curing agents will allow a room-temperature gel (or B-stage) to occur.

See also amine; epoxy resin curing agent.

aromatic polyamide Aromatic polyamide is a polymer related to nylon except that aromatic groups are present along the polyamide backbone. This imparts a great deal of stiffness and temperature resistance to the polymer chain. One difficulty encountered in this class of material is its tendency to decompose before melting. However, certain aromatic polyamides have gained commercial importance. They are known generally as *aramid polymers*. They retain about 60 percent of their strength at 245–260°C, which would melt conventional nylons. Aramid polymers have good dielectric strength and volume resistivity and a low dissipation factor.

The aromatic polyamides can be classified into three groups: amorphous copolymers with a high Tg, crystalline polymers that can be used as a thermoplastic, and crystalline polymers used as fibers.

The copolymers are noncrystalline and clear with a Tg from 150 to 160°C. The rigid aromatic chain structure gives the materials a high Tg. One of the oldest types is Trogamid T (Creanova, Inc.) poly (trimethylhexamethylene terephthalatamide). Other glass-clear polyamides include Hosamid and Grilamid TR55 (ERS-American Grilon Inc.). These aromatic polyamides are tough materials and compete with polycarbonate, polymethyl methacrylate, and polysulfones. They are used in applications requiring transparency. They have been used for solvent containers, flowmeter parts, and clear housing for electrical equipment.

An example of a crystallizable aromatic polyamide is poly-*m*-xylylene adipamide. It has a Tg near 85–100°C and a Tm of 235–240°C. Highly filled grades are normally produced to obtain high heat deflection temperatures. Applications include gears, electrical plugs, and mowing machine components.

Crystalline aromatic polyamides are also used in fiber applications. Examples of this type of material are Kevlar and Nomex. Kevlar (Du Pont) is a highly heat-resistant, strong, lightweight fiber used in bullet-proof vests and composite structures. Nomex (Du Pont) is a highly heat-resisting fiber and paper used primarily for electrical insulation. Nomex can also give flame retardance to cloth when used as a coating. It is also used in wrapped electrical insulation constructions, such as transformer coils and motor stators. It retains high tensile strength, resistance to wear, and electrical properties after prolonged exposure of up to 260°C.

artificial aging Artificial aging is the exposure of a plastic to laboratory conditions that are meant to accelerate the effects of time. Such conditions may include heating, exposure to cold, flexing, application of electric field, exposure to chemicals, ultraviolet light, and so forth. Typically, the conditions chosen for such testing reflect the conditions under which the plastic article will be used. Usually the length of time the article is exposed to these test conditions is relatively short. Properties such as dimension stability, mechanical fatigue, chemical resistance, stress cracking resistance, and dielectric strength are evaluated in such testing.

A risk in doing accelerated testing is that the choice of test parameter (such as temperature) is more severe than the part will actually see in service. This temperature choice may affect another chemical or mechanical deterioration mechanism that would not normally be seen in actual service. Also, it is difficult to reproduce the exact combination of aging environments in the laboratory that the test specimen will see in service.

See also aging.

artificial weathering Artificial weathering is the process of subjecting a plastic material to laboratory conditions in which the factors are suitably controlled with a view to affecting the observable properties in a short time equivalent to those in which they would be affected by prolonged, continuous, natural exposure outdoors. Whereas artificial aging is generally intended to accelerate the effects of time, artificial weathering more specifically attempts to accelerate the effects of weathering and outdoor exposures.

Typical conditions used to accelerate weathering are exposure to radiant energy, temperature, relative humidity, and sporadic contact with both liquid and gaseous water along with other relevant elements related to weathering.

The following standards are concerned with artificial weathering of plastics: ASTM D1499 (exposure to light and water in a carbon arc-type apparatus), ASTM D2565 (similar to D1499 but for xenon arc-type apparatus), ASTM G23 (operating light exposure apparatus for nonmetallic materials), ASTM G26 (similar to G23 but for xenon arc-type apparatus), ASTM G53 (similar to G23 but for fluorescent UV condensation-type apparatus), and ASTM D4674 (accelerated test for color stability of plastics).

ASTM B117 and ASTM G85 describe operation of test apparatus for determining the effects of exposure to marine and coastal-type environments on plastics and laminates. Such exposures usually include corrosive environment such as salt spray.

asbestos Asbestos is a gray, nonburning, nonconducting, and chemical-resistant naturally occurring fiber or fibrous mat that was at one time commonly used as a filler or reinforcement of common molding compounds. Today, concern over the hazardous nature of asbestos particles drastically reduces the use of this material.

Asbestos fibers (crysotile) have been used in laminates to impart flame resistance and thermal stability. Used extensively in the past, they are listed in NEMA Laminate Standard LI-1 as grade AA, but concerns about asbestosis limit their use, and they have now been phased out of the laminate industry.

ash content Ash content is the residue remaining after controlled combustion of a plastic in a test to determine its inorganic materials content. *Ashing* is the term used to describe the combustion process used in determining the ash content of plastics.

In ashing, combustion generally occurs on a small sample heated within a *muffle furnace* to temperatures sufficiently high to burn off the organic components.

Normally after a short period of time only inorganic matter remains, because all the organic matter has been vaporized by the high temperatures. The residue is weighed, and the ash content is expressed as a percentage by weight of the original test specimen. ASTM D5630 provides a method for determining the ash content of thermoplastics.

See also muffle furnace; solids content.

atactic Atactic is one of three major types of polymer configurations. (See Fig. T.2 under tacticity.) The other two types are *isotactic* and *syndiotactic*. Atactic polymers are polymers characterized by a chain of molecules in which the position of the substituted group is more or less random.

See also isotactic; syndiotactic; tacticity.

attenuation As used in fiber optics, attenuation is the diminution of optical power in an optical waveguide occurring as a result of radiation losses. The diminution occurs over time or distance. Such losses are mainly caused by absorption and light scattering.

autoacceleration Autoacceleration is the increase in the rate of polymerization and molecular weight of some vinyl monomers polymerized in bulk or concentrated solution. It is due to the increase in viscosity of the reaction medium as the reaction proceeds. This impedes termination but does not appreciably affect propagation. Autoacceleration is also often called the *Trommadorff effect*.

autoclave An autoclave is a closed strong vessel for conducting chemical reactions or other operations under high pressure and heat. In the composites industry, it is a round or cylindrical container in which heat and gas pressure can be applied to resin-impregnated products positioned in layers over a mold. Autoclaves are widely used for bonding and curing reinforced plastic laminates. They are especially useful for curing reinforced plastics of large and nonflat construction.

autoclave molding Autoclave molding is a modification of the *pressure bag method* for molding reinforced plastics. After the layup on the mold, the entire assembly is placed in an autoclave. Generally, a covering bag is placed over the layup. Steam or high-pressure air up to 200 psi is admitted, supplying both pressure and heat. If steam is used, the covering bag must not have holes or leaks because steam will enter the layup and ruin the molding. Additional pressure achieves higher reinforcement loadings and improved removal of air. *See* Fig. A.11.

Autoclave molding is also similar to *vacuum bag* and *hand-layup molding*, except that the pressure plate is removed and the entire mold and layup are placed in an autoclave. The chief advantages of autoclave molding processes are faster cycle times and improved physical properties.

See also hand layup; pressure bag molding; vacuum bag molding.

Figure A.11 Schematic diagram of an autoclave (pressure bag) molding process. (Ref: Schwarts, S.S and Goodman, S.W., Plastics Materials and Processes, van Nostrand Reinhold, New York, 1982)

autodeposition coating Autodeposition or autophoretic coating is a dipping method in which coatings are applied on the product from an aqueous solution. Unlike electrocoating, no electric current is applied. Instead the driving force is chemical.

Advantages of autophoretic coating are no VOC emission, no metal pretreatment other than cleaning, and uniform coating thickness. This technique requires 30 percent less floor space than electrocoating, and capital equipment costs are 25 percent lower than for electrocoating. Disadvantages of autophoretic coatings are that black is the only color available and that corrosion resistance is lower than that of electrocoated products.

automatic mold An automatic mold is a mold for injection or compression molding that repeatedly goes through the entire cycle, including ejection, without human assistance.

average molecular weight The average molecular weight is the molecular weight of the most typical chain in a given plastic. There will always be a distribution of chain sizes and, hence, molecular weights in any polymer. There are several ways of determining molecular weight including viscosity, vapor pressure osmometry, light scattering, and gel permeation chromatography.

Because of the distribution of molecule sizes in a polymer, molecular weight can be measured as weight-average and number-average molecular weight. The weight-average molecular weight is equal to or greater than the number-average. The two are equal only for a monodisperse (all molecules the same) polymer. The ratio of weight-average to number-average molecular weight is known as the *polydispersity index* and is a measure of the breadth of the molecular weight distribution. *See* Fig. A.12.

Figure A.12 Distribution of molecular weights in a typical polymer. (Ref: Bryant, W.M.D., *J. Polymer Science*, Vol. 56, 1962, p. 277)

axial winding In filament winding processes, an axial winding is a winding with the filament parallel to, or at a small angle to, the axis (0° helix angle). This is a filament winding angle that will provide very high stiffness of the wound form but very low hoop or circumferential strength because the main direction of the reinforcement is in the direction of the pipe length.

B

B-stage The B-stage is designated as the intermediate stage in the curing of a thermosetting resin; it occurs between the *A-stage* and the *C-stage*. The term *A-stage* is used to describe an earlier stage in the curing reaction, and the term *C-stage* is sometimes used to describe the completely cured resin.

In the B-stage resins can be heated and caused to flow, thereby allowing final curing in the desired shape. A *prepreg*, dry molding compound, or preformed shapes are examples of materials in the B-stage. Most thermosetting molding materials are in the B-stage when supplied for compression or transfer molding.

See also prepreg.

backing plate In injection molding, the backing plate is a heavy steel plate used as a support for the cavity blocks, guide pins, bushings, and other components attached to the mold. Where the cavity or plunger is made in sections, a hardened backing plate is often used for greater stiffness. In blow molding, a backing plate is the steel plate on which the cavities are mounted.

back pressure Back pressure is the viscosity resistance of a material to continued flow. In compression molding, back pressure is the resistance of the material when the mold is closing. In extrusion, it is the resistance to the forward flow of molten material.

By increasing the back pressure, the amount of work undergone by the plastic can be regulated to cause more shear, higher temperatures, and a greater degree of

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plastification. This is usually accompanied, however, by a slower cycle. These adjustments are particularly important for heat-sensitive plastics.

back pressure relief port The back pressure relief port is an opening in an extrusion die that allows excess material to escape.

bag molding The bag molding process is a method of applying pressure during bonding or molding. It is generally used in molding reinforced plastics. In bag molding, a flexible cover, generally a thin film or cloth, is used in connection with a rigid die or mold. The rigid die or mold is the primary support for the shape of the article to be molded.

The molding material is placed between the mold and the thin film, and the thin film or bag exerts pressure on the materials being molded, through the application of air pressure or by drawing of a vacuum. Application of the film over an uncured part and sealing the edges so that a vacuum can be drawn is called *bagging*. The *bag side* is the part of the product that is cured against the vacuum bag.

Bakelite Bakelite is the first tradename for the phenol formaldehyde resin. This was the first commercial polymer. Bakelite was designated after its inventor *Leo Hendrick Baekeland* (1863–1944), a Belgian who did the work on the synthesis of phenolic resins and their commercial development in the early 1900s.

Bakelite is still used today as a generic name in some foreign countries. The tradename also applies to *phenolic* and other plastic materials produced by Union Carbide Corp. The tradename Bakelite is generally followed by the specific name of the plastic.

balanced construction In woven reinforcements, a balanced construction is one in which there are equal parts of warp fibers (running lengthwise) and fill fibers (running crosswise). It is a construction in which reaction to tension and compression loads results in extension or compression deformation only. Flexural loads produce pure bending of equal magnitude in the axial and lateral directions. (*See also* warp; fill; weave.)

In filament winding, a *balanced design* is one in which the winding pattern is so designed that the stresses in all filaments are equal. In laminate construction, a *balanced laminate* is one in which all laminae lie at angles other than 0° and 90°, occur only in $+/-$ pairs (not necessarily adjacent), and are symmetrical around the centerline.

balanced runner Balanced runner molding systems are designed to place each cavity at an equal distance from the sprue. A balanced runner system will minimize the possibility of *short shots* (partially filled cavities where the pressure is low) and/or *flash* (where the pressure is so high as to cause the mold to open slightly and produce flash at certain cavities).

Although runners should deliver melt to each cavity at the same time, they may be naturally balanced (the distance from sprue to all gates is the same) or artificially balanced (the same pressure drop from sprue to all gates).

See also runner.

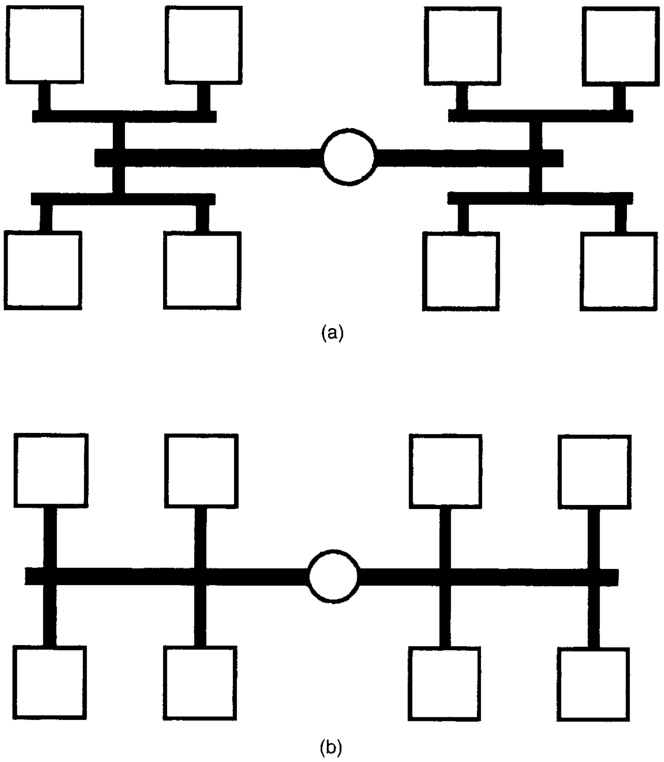


Figure B.1 Runner system: (a) balanced and (b) unbalanced. (Ref: Barry, C.M.F., and Orroth, S.A., “Processing of Thermoplastics”, *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

ball mill A ball mill is a process to mix and/or dissolve resin systems in organic solvents. The ball mill utilizes rubber-faced rollers that are used to rotate cans or other containers for the purpose of dissolving solid resins in organic solvents. The resin is cut into small pieces or may already be in a powdered or granular form. Ceramic balls are added to the ingredients inside the container to provide friction and movement. This is similar to the rotational mixing of paint in cans, with the exception that mixing balls are incorporated into the cans.

Banbury mixer The Banbury mixer is an apparatus for compounding materials. It is composed of a pair of contra-rotating rotors (arms) that masticate the materials to form a homogeneous blend. The arms are in a confined area with small clearances between the blades and the body of the mixer. Cooling is usually required, particularly with heat-sensitive materials, because of the frictional heat evolved.

The one drawback to this type of mixer is the small capacities, which limit production to small batches. However, this is an internal-type mixer that produces excellent mixing. The Banbury mixer is often used in compounding elastomer formulations.

Barcol hardness The Barcol hardness value is obtained with a Barcol hardness tester, which gauges hardness of soft materials by indentation of a sharp steel point under a spring load. The instrument called, the Barcol impressor (Barber and Coleman), uses an indentor similar to that used in the Shore D method, except for a flat tip instead of a round one. It gives a direct reading on a 0 to 100 scale.

ASTM D2583 specifies the Barcol hardness test. The hardness value can be used as a measure of the degree of cure of a plastic material. Barcol hardness is generally measured for rigid plastics, particularly reinforced thermosetting resins. The usual range is about 50B–90B. Barcol 60B is equivalent to Shore 80D and to Rockwell M100.

See also hardness.

barium sulfate (barytes) Barytes is a term used for minerals composed largely of barium sulfate. It is used as filler for elastomers, shellac, and other resins. This filler has an exceptionally high specific gravity (4.4) along with chemical inertness and low water solubility. Plastics filled with barium sulfate are opaque to X-rays. Barium sulfate also finds special use in sound-deadening compounds.

Natural barium sulfates, having selected particle size distributions, impart increased density and load-bearing properties and improved processing, drape, and handling properties to polyurethane foam. *Plastisol* compositions containing barium sulfate (particularly for sealing rings on food jar covers) require less resin/plasticizer, yet they yield optimum properties.

barrier coat A barrier coat is an exterior coating applied to a composite structure to provide protection. In filament-wound fuel tanks, for example, a barrier coating is applied to the inside of the tank to prevent fuel from permeating the side wall.

barrier properties Barrier properties of materials indicate their resistance to diffusion and sorption of molecules. A good barrier polymer has low values of both diffusion and solubility coefficients. Because the *permeability coefficient* (P) is a derived function of both diffusion (D) and solubility (S) coefficients, a high-barrier polymer is one that has a low value of P.

The *diffusion coefficient* is a measure of how fast a penetrant will move within the polymer, whereas the *solubility coefficient* gives the amount of penetrant taken or sorbed by the polymer from a contacting phase per unit of sorbate concentration. Both diffusion and solubility can be applied to the reverse process of sorption, that is, the migration of compounds from the polymer to a surrounding medium.

See also permeability; diffusion.

barrier resin *Barrier resin* is a general term applied to a group of lightweight, transparent, impact-resistant plastics, usually rigid copolymers of acrylonitrile content. The barrier plastics are generally characterized by gas, aroma, and flavor barrier characteristics approaching those of metal and glass. An example of a barrier resin is the nitrile-based compounds that have been developed for soft drink bottles.

Several factors influence the effective value of diffusion and solubility coefficients, and thus barrier properties, in polymers:

1. Chemical compositions of the polymer and the permeant
2. Polymer morphology (diffusion and sorption occur mainly through the amorphous phase and not though crystalline regions)
3. Temperature (as temperature increases, diffusion increases while solubility decreases)
4. Glass transition temperature, T_g
5. The presence of plasticizers and fillers

Barrier resins are resins expressly developed as a barrier to the passage of gases. They are generally incorporated as an external film on other resins that provide the physical structure.

base The resin base is the principal component of a polymeric formulation. The base provides many of the main characteristics of the formulation and the final product such as viscosity, flow characteristics, curing properties, strength, environmental resistance. The base is often by weight the largest component in the formulation, but this is not always the case, especially with highly filled polymeric systems.

The base is generally the component from which the name of the formulation or molding compound is derived. For example, an epoxy molding compound may have many components, but the primary material or base is an epoxy resin. Once the base is chosen, the other necessary ingredients then can be determined.

See also binder.

basket weave

See weave.

beading Beading is a rolled edge that increases the rigidity and strength of thin-gauge material in fabricated containers. A beading may also provide a lap for cementing purposes or for joining. The operation can be done manually, semi-automatically, or entirely automatic as in large-scale production of plastic containers.

In molded parts, a *parting line* raised above the adjacent surface is said to be beaded or *peaked*. A beaded parting line precludes the necessity of having close alignment and contour matching of the cavity and plunger, thus keeping both mold and finishing costs down.

benzene Benzene is a basic chemical derived from *coal tar*. It is largely used for the production of styrene, synthetic phenol, and nylon. It is an *aromatic hydrocarbon* of the structural formula C_6H_6.

The *benzene ring* is the basic structure of benzene. It is an unsaturated resonant six-carbon ring having three double bonds. One or more of the six hydrogen atoms of benzene may be replaced by other atoms or groups.

benzophenone Benzophenone ($C_6H_5COC_6H_5$) is a crystalline plasticizer having a melting point of 48°C. It is used in *cellulose nitrate* lacquers to impart special properties to the polymer.

beryllium copper Beryllium copper is a metallic alloy used for the construction of injection and compression molds. Because it can be cast, beryllium copper is economical when intricate design detail rather than high dimensional accuracy is required. Beryllium copper's rapid heat transfer characteristic is also desirable in some applications, cutting down the molding cycle. The material is hardenable but wears more quickly than steel. It may be made into molds by pressure casting.

beta gauge The beta gauge or *beta ray gauge* is a gauge consisting of two facing elements, a beta ray-emitting source, and a beta ray detector. When a sheet of material, such as a laminate, is passed between the elements, some of the beta rays are absorbed, the percentage absorbed being a measure of the density or the thickness of the sheet. This technique is sometimes used for nondestructive testing and detection of voids or unbonded areas in adhesives, laminates, and composites.

biaxial orientation Biaxial orientation denotes the stretch imparted to a plastic product, such as a film or fiber, by forcible extension in two mutually perpendicular directions. Such stretching is done to orient the molecular segments of the polymer. This will provide significantly improved physical properties in the direction of the orientation.

ASTM D2673 provides a standard specification for oriented polypropylene film, and similarly ASTM D3664 provides a specification for biaxially oriented polyethylene terephthalate film for electrical applications.

biaxial stress A biaxial state of stress is developed when a circular diaphragm, pipe, or container is subjected to pressure. Here the stress is oriented in at least two directions because of the nature of the product's shape and the stress.

bifunctional monomer Bifunctional monomers are monomers that contain two chemical groups or constituents that are capable of *polymerization* or *copolymerization*. For example, methacrylic anhydride and glycol dimethacrylate each contain two ethylene bonds and can be copolymerized to form a thermosetting type of acrylic.

bi-injection molding Bi-injection molding is when two distinct polymeric materials are involved in the molding of a single part. The two materials may just have different colors, one may contain reinforcement or gas cells, or they may be entirely different resins to provide specific properties at different locations in the part. This process requires two distinct feed units and a single mold unit.

The expressions also used for this process are *bicomponent injection, coinjection*, or *two-shot molding*. When a plastic part, previously molded in a specific mold, is introduced in another mold, in the same way as a metal insert, and a different plastic is molded over it, the expression *overinjection* is sometimes used.

binder A binder is a general term for the resinous ingredient that holds together the other ingredients (fillers, reinforcements, etc.) of a plastic composition. This may be the continuous phase in a reinforced plastic that holds together the reinforcement. It also could be the continuous resin phase in a molding compound or adhesive formulation.

See also base.

biocide Biocides, also known as *antimicrobials*, *preservatives*, *fungicides*, *mildewcides*, or *bactericides*, are used to impart protection to plastic parts against mold, mildew, fungi, and bacterial growth. Without biocides certain plastics in moist environments may experience development of spores on the surface of the material, which could cause allergic reactions, odors, staining, and embrittlement. Such degradation could actually cause the part to fail prematurely.

It should be noted that biocides are intended only to protect the plastic part. They are not intended to protect humans from microbial contamination. There is often confusion regarding claims made concerning biocides. In the United States, all biocides are also considered pesticides and must be registered with the EPA.

Biocides are usually dispersed in plasticizer, oils, or other low-molecular-weight carriers that can migrate to the surface of the part. The rate of migration relative to the rate of leaching of the biocide from the surface is an important parameter in formulating with biocides. This mobility results in the gradual leaching of the additive. If significant leaching occurs, the product will be left unprotected after time. The proper balance between the rates of migration and leaching determines the durability of protection.

Biocides are available as an active ingredient or as a formulated product. They can be powders, liquids, or pellets. Concentrations in the final plastic part vary from 1 percent down to 0.04 percent depending on the activity of the biocide. Biocides are generally formulated with a carrier (usually a plasticizer) into concentrations of 2–10 percent of the active ingredient. The plasticizer, commonly epoxidized soybean oil or diisodecyl phthalate, aids in the migration of the biocide to the surface of the part.

Biocides are commonly used in flexible polyvinyl chloride (PVC) parts that are intended for moist, warm environments. Applications include PVC flooring, garden hoses, pool liners, shower curtains, etc. They are also used with polymeric foams and other resins.

Commercially available biocides include OBPA (10,10-oxybisphenoloxarsine) from Akzo Nobel, Witco, and Morton; zinc-omadine (zinc 2-pyridinethanol-1-oxide) from Olin; and Triclosan (trichlorophenoloxyphenol) from Allied Resinous Products, Ciba Specialty, and Microban. Major suppliers also include Ferro, Huels, Microban, Ciba, and Rohm and Haas.

See also antimicrobial.

biodegradable plastic Biodegradable is a term generally used to describe plastics that are specifically formulated to degrade rapidly in an environmentally accepted manner once their useful life is completed. All polymers are subject to some type of biodegradation.

Biodegradation can be separated into two types: chemical and microbial. *Chemical biodegradation* includes degradation by oxidation, photodegradation, thermal degradation, and hydrolysis. *Microbial degradation* can include both fungi and bacterial. The susceptibility of a polymer to biodegradation depends on the structure of the backbone. For example, polymers with hydrolzyable backbones can be attacked by acids or bases, breaking down the molecular weight. Polymers that fit into this category are most natural-based polymers, such as polysaccharides and synthetic materials such as polyurethanes, polyamides, polyesters, and polyethers. Polymers that contain only carbon groups in the backbone are more resistant to biodegradation.

Photodegradation can be accomplished by using polymers that are unstable to light sources or by the use of additives that undergo photodegradation. Copolymers of divinyl ketone with styrene, ethylene, or polypropylene are examples of materials that are susceptible to photodegradation. The addition of a UV-absorbing material will also act to enhance photodegradation. An example is the addition of iron dithiocarbamate. In all cases, the degradation must be controlled to ensure that the polymer does not degrade prematurely.

Polymers that have been considered for intentional biodegradation include polyvinyl alcohol (because of its water solubility), cellulose-based polymers (biodegradable grades of cellulose acetate are available from Rhone-Poulenc, *Bioceta* and *Biocellat*), starch-based products [blends of starch with vinyl alcohol are produced by Fertec (Italy) and are used in both film and solid product applications], polyactides (PLA) and copolymers, and polycaprolactones. A product developed by Warner-Lambert, called *Novon*, is a blend of polymer and starch. Polyactides and polyglycolides (PGA) are highly crystalline thermoplastic polyesters. These materials find application in surgical sutures, resorbable plates and screws for fractures, and food packaging.

A more recent biodegradable polymer is polyhydroxybutyrate-valerate copolymer (PHBV) from ICI Americas Inc.. These copolymers are produced through biochemical means. In fact, these natural thermoplastics are derived from bacteria. They are fully degradable in many microbial environments. Other biodegradable polymers include *Konjac*, a water-soluble polysaccharide produced by FMC; *Chitin*, another polysaccharide that is insoluble in water; and *Chitosan*, which is soluble in water.

biphenol derivatives The most versatile group of biphenol derivatives is the chlorinated biphenyls. Depending on the degree of chlorination, these compounds range in properties from mobile, oily liquids to hard, transparent resins. Often used as plasticizers, they are widely compatible, particularly with cellulose nitrate, ethyl cellulose, polyvinyl chloride (PVC), and chlorinated rubber.

Biphenol derivatives are quite resistant to hydrolysis and oxidation and have excellent electrical characteristics. The more highly chlorinated types are flame resistant and impart this quality to resins with which they are used. They are of special interest in chlorinated rubber, paints, and PVC electrical compositions.

Ortho-nitrobiphenyl ($C_{12}H_9NO_2$) is an amber crystalline plasticizer compatible with practically all of the thermoplastics, with the possible exception of polyamides.

It is used as a plasticizer for cellulose acetate, cellulose nitrate, polyvinyl acetate, and PVC. Amylbiphenyl and diamylbiphenyl are used as secondary plasticizers of PVC.

bismaleimide (BMI) Bismaleimide (BMI) is a type of thermosetting polyimide that cures by addition rather than a condensation reaction. These materials are generally prepared by reaction of diamine and maleic anhydride.

It is generally considered to have higher temperature resistance than epoxy but not as high as condensation-cured polyimides. The cured material has a glass transition temperature in the vicinity of 300°C and a decomposition temperature of 460°C. However, the cured material is very brittle.

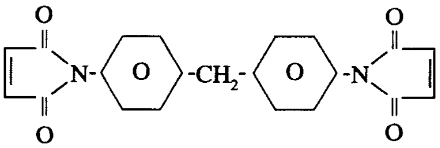


Figure B.2 General chemical structure for bismaleimide.

Bismaleimide is easier to process than condensation-cured polyimide resins. The typical cure consists of several hours at 177–204°C. Generally, a postcure of 220–260°C is required for high-temperature applications.

BMI provides a continuous service temperature of 177°C in a moist environment. These are often used in high-temperature laminates and as adhesives in the electrical/electronics industries. Major suppliers of bismaleimide resins are Rhone Poulenc Inc. (*Kerimid*) and Technochemie GmbH, BTL Specialty Resins, Ciba-Giegy, and Mitsubishi Petrochemical Co.

bituminous plastic Bituminous plastics are cold-molded organic plastics that use asphalt as a binder.

black marking Black marking is a term for black smudges on the surface of a pultruded product that result from excessive pressure in the die when the pultrusion is rubbing against it or from an unchromed die surface. The black marking cannot be removed by cleaning or scrubbing or by wiping with solvent.

blanking (die cutting) Blanking or die cutting is a method of cutting thermoplastic sheet stock by means of dies on standard presses. This process provides a simple and economical way of producing flat pieces of definite outline. Some plastics are best blanked immediately after being heated to a mildly elevated temperature (40–95°C); others can be blanked easily at room temperature.

Thicker plastics generally need to be blanked at elevated temperature. Acrylic, cellulose acetate, cellulose nitrate, ethyl cellulose, polyethylene, polystyrene, vinyl butyral, and polyvinyl chloride can commonly be blanked. The process is accurate to about 1/64 in. Allowance must also be made for thermal shrinkage when the material has been preheated.

bleeding Bleeding is the diffusion of color from one material to another or within a material, as from the body of a coated fabric to the surface. Bleeding also refers to the undesirable movement of certain materials in a plastic, such as plasticizers in vinyl, to the surface of the finished article or into an adjacent material. This process is also called *migration*.

As used primarily in filament winding, *bleedout* is the excess liquid resin that migrates to the surface of a winding.

blend Blend is a term often used interchangeably with *alloy*; however, it has a broader meaning. A blend is a compound of mutually compatible polymers. The blend could be of various types such as a powder blend or dry blend.

See also alloy.

blenders Blenders are instruments for liquid mixing, dry blending, or dough mixing of polymeric formulations. There are many types of blenders. In most plastic mixing, horizontal mixing blades are used. For dry blending a spiral ribbon blade is sufficient, whereas dough mixing requires more powerful interlocking blades of the sigma design. The size of these blenders varies from a gallon to over several hundred gallons. They are usually jacketed for heating and cooling of the mixtures.

Small clearances between the blades and the mixer sides are used to produce a wiping action for a dispersion of the solid particles in the mix. A pair of mixing arms operating at different speeds provides the pulling and shearing action necessary for more viscous mixtures.

blister A blister is the raised area on the incompletely hardened surface of a molding or plastic part caused by the pressure of the gasses inside it. The gasses could be generated from entrapped air in the plastic compound, water from a condensation reaction, solvents, reaction products, etc. A blister may burst and become flattened.

block copolymer A block copolymer is an essentially linear copolymer of the type (—AAAAA—BBBB—) in which the backbone consists of regions or blocks of one monomer (—AAAA—) along with regions or blocks of another monomer (—BBBB—) of different chemical structure.

blocking Blocking is the undesired adhesion between touching layers of a material, such as occurs under moderate pressure during storage or use. Blocking occurs most readily when the two surfaces are smooth and flat, they are in intimate contact under pressure, and at least one surface is a soft, tacky plastic. Blocking typically occurs when the product is a soft film and is stacked in layers or wound into a roll configuration.

Blocking may be quantitatively assessed by determining the force required to separate the surfaces involved. The relevant standard test method is ASTM D3354.

In many cases blocking may be counteracted by incorporation of antiblocking agents in the plastic. These are generally fine-particle silicas and silicates or certain paraffin and waxes. Where applicable, suitable modification of processing conditions or the application of an appropriate surface coating can also provide resistance to blocking.

See also antiblocking agent.

bloom In the general context of plastics, bloom is the extrudate or efflorescence of stabilizer, lubricant, plasticizer, etc. that diffuses to the surface of the plastic part. Exudation of this kind can be caused by weathering or exposures to high temperatures. Bloom is the result of ingredients coming out of solution in the plastic and migrating to the surface. *See also* lubricant bloom.

In relation to pultruded products, *fiber blooming* is the exposure of fibers at the surface of the product. Also, in pultrusion, *undercure blooming* is a dull, often whitish appearance on the surface of a pultruded product resulting from inadequate curing of the resin at the surface.

blowing agent Blowing agents are added to a polymer formulation to produce a foam or cellular structure. A blowing agent or *foaming agent* is a chemical that can be added to plastics and generates inert gases upon heating. This blowing or expansion of gases causes the plastic to expand, thus forming a foam. The foamed structure can be influenced by the type of blowing agent selected, the type of gas evolved and its solubility, the method of compounding used, temperatures and pressures involved in processing, and the melt viscosity. There are basically two groups of blowing agents: physical blowing agents and chemical blowing agents.

Physical blowing agents change from one form to another during processing. Compressed gases and volatile liquids are the two major types. Compressed gases can be dissolved under pressure in the resin and produce a foam on release of the pressure. The use of nitrogen in injection molded foam products is typical. Volatile liquids will foam resin as they change from a liquid state to a gaseous state at the high temperatures of processing. Major materials in this area are fluorinated aliphatic hydrocarbons (chlorofluoromethanes or chlorofluorocarbons). These blowing agents have been used extensively in both rigid and flexible polyurethane foams. Flexible polyurethane foams are blown with water, chlorofluorocarbons, or methylene chloride. Carbon dioxide from the water-isocyanate reaction also can function as a blowing agent.

Chemical blowing agents are solid compounds that decompose at processing temperatures to evolve the gas that forms the cellular structure. Both open and closed cell structures are possible. Chemical blowing agents can be used in almost any thermoplastic or thermoset, and they can be either inorganic or organic.

Factors that determine the formation of a fine-celled plastic foam with a regular structure are the particle size of the blowing agent, dispersion properties of the plastic processing machine used, decomposition rate of the blowing agent, and the melt viscosity of the resin being processed.

The most common inorganic chemical blowing agent is sodium bicarbonate. The most popular organics are shown in Table B.1. Chemical blowing agents are mainly hydrazine derivatives.

Table B.1 Common Chemical Blowing Agents and Their Properties

Blowing Agent	Decomposition Temperature, °F	Characteristics	Applicable Plastics
Azodicarbonamide (ABFA)	400–415	Nontoxic, FDA approved, gases can corrode beryllium copper molds	General
p-p′-oxybis (benzenesulfonyl hydrazide) (OBSH)	315–320	Odorless, nonstaining and not toxic, some FDA approvals	LDPE, EVA, and PVC
p-toluene sulfonyl semicarbozide (TSSC)	442–456	Nonstaining	HDPE, PP, ABS, High impact PS, rigid PVC, nylon and modified PPO
Trihydrazine triazine (THT)	High temperature	Fine uniform cell structure and good surface appearance; ammonia generating	General
5-phenyltetrazole (5-PT)	460–480	Decomposition gases are all N_2	ABS, nylon, PC, thermoplastic polyester, and high temperature plastics

Chemical blowing agents may also be subdivided into two major categories: endothermic and exothermic. Exothermic blowing agents release energy during decomposition, whereas endothermic blowing agents require energy during decomposition. In general, endothermic chemical blowing agents generate carbon dioxide as the major gas. Commercially available exothermic types primarily evolve nitrogen gas, sometimes in combination with other gases. Nitrogen is a more efficient expanding gas because of its slower rate of diffusion through polymers compared with carbon dioxide.

Azodicarbonamide, sulfonyl hydrazides, sulfonyl semicarbazides, and dinitropentamethylene tetramine are examples of exothermic blowing agents. Sodium borohydride, sodium bicarbonate, and polycarbonic acid are examples of endothermic blowing agents.

Chemical blowing agents can be supplied as powders that can be tumble blended with resins in pellet form, dry blended with resin in powder form, and Banbury or extrusion compounded. Blowing agents are also available in liquid or pellet concentrates that may be more convenient to handle than powders. Liquid concentrates, typically 50 percent chemical blowing agent in an inert compatible carrier, are added during processing at the throat of the machine, usually with a pumping system. Pellet concentrates are also available for most resins.

Blowing agents are used in plastics for several reasons: weight reduction, savings in cost and material, and achievement of new properties. The new properties include insulation against heat or noise, different surface appearance, improved stiffness, better quality (removal of sink marks in injection-molded parts), and improved electrical properties.

The leading supplier of chemical blowing agents in North America is Uniroyal Chemical. Bayer is the leading supplier of chemical blowing agents in Europe. Chemical blowing agents are commercially manufactured by Atochem North America Inc., Morton International, Uniroyal Chemical Co., Hoechst Celanese Corp., and Morton International Inc. Physical blowing agents are commercially available through several outlets including Expancel-Nobel Industries.

blow molding Blow molding is one of the most common processes used to produce hollow plastic parts. (See Fig. B.3.) There are several varieties of blow molding including extrusion, injection, and sequential blow molding. Ideal for producing plastic beverage bottles and other closed shapes, the blow molding process combines elements of the extrusion process and the thermoforming process in complex, fully automated machines and mold systems to produce thin-walled hollowware at very high rates.

In addition to bottles, a rapidly growing application for blow molding is the production of “technical” parts, such as automotive components—bumpers, ducts, and fluid containers. Common thermoplastic materials suited to blow molding include high-density polyethylene, polyvinyl chloride, polypropylene, and polyethylene terephthalate.

Extrusion blow molding uses a section of hot extruded tubular material called a *parison*. This is extruded into an open mold, and compressed air or steam forces the walls of the parison to the sides of a cold mold. The process is commonly used to make bottles, industrial containers, medical items, technical parts, and toys. Blow molding has a low tool and die cost, and parts can be made very rapidly and in one piece. It also can be used to produce relatively complex shapes, although limited to hollow or tubular parts. The wall thickness is difficult to control. Continuous tubing and film can be made in a manner similar to blow molding.

Injection blow molding combines injection molding and blow molding in one machine. Injection blow molding is a two-stage process. In the first stage, parisons are injection molded into a tubular shape complete with threaded and formed top. These parisons may then be stored until time for the second step. The second step involves feeding the premolded parisons into an automatic blow molding machine, where the parison is heated to the softening point, clamped between die halves, and then blown as in the extrusion blow molding process. This offers more design alternatives and is best for producing large volumes of accurately shaped containers with an exceptional finish.

Applicable materials for the injection blow molding process include high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS), styrene acrylonitrile (SAN), ethylene vinyl acetate (EVA), polypropylene (PP), polycarbonate (PC), and polyurethane (PU). Polyethylene terephthalate (PET) and polyacrylonitrile (PAN) are less commonly used in the injection blow molding processes.

Although the injection blow molding process is not suited to “handleware” bottles, it is rapidly gaining favor over extrusion blow molding for bottles up to 1.5 liters and more. Advantages include the practicality of molding strong, close tolerance necks and threads suited to childproof caps and molding wide-mouth bottles.

Sequential blow molding is used for producing bent three-dimensional shapes, for example, a convoluted heat exchange tubular panel and filler pipes in automobiles. The parison is deformed and then manipulated with programmable 3-D manipulators or six-axis robots before being placed directly into a mold cavity.

Sequential coextrusion also offers the possibility of manufacturing a single part made with different regions of hardness, elasticity, strength, or heat deflection temperatures. This opens up a wide variety of applications. Sequential coextrusion can be used, for example, when the ends of a pipe must be flexible (for connection purposes), but the middle section must be stiff and strong. Such a part, made out of thermoplastic elastomer (TPE), for example, can then be substituted for rubber parts.

Machines and molds may cost between several hundred thousand and a million dollars, depending on the throughput rates and accessories. Molds for blow molding are made from beryllium copper and aluminum because of the excellent thermal conductivity of these materials. Stainless steel and hard chrome-plated tool steels are also common.

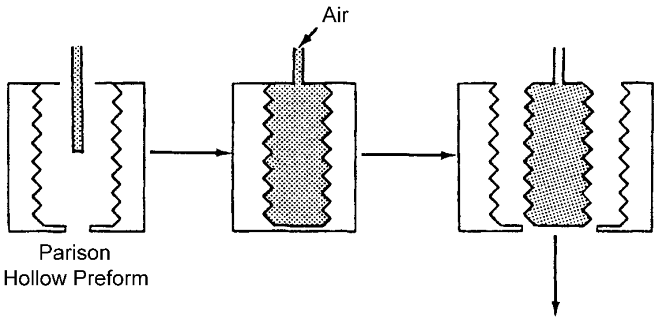


Figure B.3 Schematic depiction of the blow molding process. (Ref: Rader, C.P., "Thermoplastic Elastomers", *Handbook of Plastics, Elastomers and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

blown film and tubing Blown film and tubing can be made by extruding thermoplastic through an annular ring die and maintaining gas pressure within the tube. In this fashion, rather thin-walled, uniform-diameter tubing can be manufactured at a rapid, continuous rate. (See Fig. B.4.) By properly controlling the air rate, it is possible to increase and control the tube diameter to a point where the tube is essentially a cylindrical film. This cylinder can be slit and laid flat, yielding a continuous film of excellent uniformity. Thus this process is sometimes also referred to as the *lay-flat film* or *lay-flat tubing* process.

In some film blowing installations, the tube, after blowing and cooling, is nipped between a pair of rolls before being slit. This operation confines the air as a bubble between the extruder and the rolls, making continuous additions of air unnecessary.

See also lay-flat film and tubing.

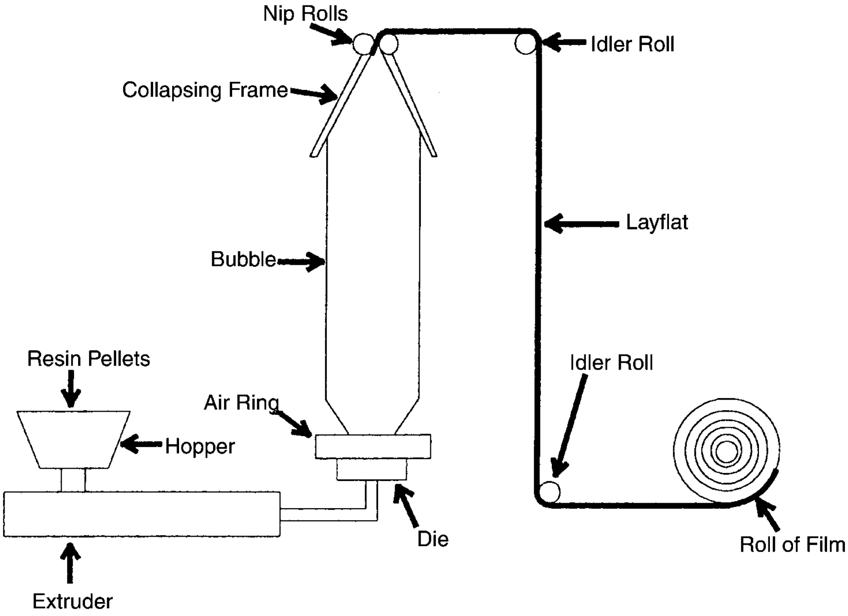


Figure B.4 Schematic of blown film line. (Ref: Barry, C.M.F., and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

blow pin A blow pin is part of the tooling used to form hollow objects or containers by the blow molding process. It is a tubular tool through which air pressure is introduced into the parison to create the air pressure necessary to form the parison into the shape of the mold. In some blow molding systems, it is a part of, or an extension of, the *core pin.*

blow pressure, blow rate The blow pressure is the air pressure used to form a hollow part by blow molding. The blow rate is the speed at which the air enters the parison during the blow molding cycle.

See also parison.

blow-up ratio In blow molding, the blow-up ratio is the ratio of the mold cavity diameter to the parison diameter. In blown tubing (film), the blow-up ratio is the ratio of the final tube diameter (before gusseting, if any) to the original die diameter.

blueing Blueing is a blemish on the mold in the form of a blue oxide film that occurs on the polished surface of a mold as a result of the use of abnormally high mold temperatures. Blueing is a surface condition that generally does not affect the part being produced.

bond A bond is made by the union of materials with adhesives or some other method. The bond often refers to the interface region where the substrates are joined together. The *bond strength* is the unit load, applied in tension, compression, flexure, peel, impact, cleavage, or shear, required to break a bonded assembly with failure occurring in or near the plane of the bond.

See also adhesive tests; adhesion.

boron compounds *Boron trichloride* (BCl_3) is used as a catalyst. *Boron trifluoride* (BF_3) is a gas used for polymerizing epoxy resins, usually in the solid form of boron ethyl amine ($BF_3—C_2H_5NH_2$), which releases the BF_3 at elevated temperatures. Thus boron trifluoride is sometimes used as a *latent catalyst*.

Carborane plastics are produced from the boron molecule (a boron hydride of composition $B_{10}H_{14}$) by replacing the four terminal hydrogens with two carbon atoms. The monomer polymerizes at high heat and pressure to form rubbery solids, which will withstand temperatures above 315°C; but the commercial plastics are usually copolymers with vinyls, silicones, or other plastics. Carboranes have been used as specialty adhesives in the aerospace industry.

boron fiber Boron fibers are high-modulus fibers produced as individual monofilaments on a tungsten or carbon substrate by pryrolytic reduction of boron trichloride in a sealed glass chamber. The relatively large cross-section fiber is used today primarily in composites that are processed at temperatures that would attack graphite fibers.

The specific gravity of boron fiber is about 2.6, and it ranges in size from 4 to 6 mil in diameter. They have tensile strengths around 500,000 psi and a modulus of elasticity of nearly 60×10^6 psi. Boron fibers can be supplied as single strands or tapes.

Boron fibers were the first fibers to be used on production aircraft. Boron fibers have been used extensively in metal matrix composites and in composites requiring a high confidence in compressive properties. Unidirectional boron-aluminum composites have tensile strength ranging from 110,000 to over 200,000 psi. Their strength-to-weight ratio is about three times greater than that of high-strength aluminum alloys.

Boron fibers have also been used in the form of epoxy prepreg tapes in which the filaments are carefully aligned and tensioned to provide a one-filament-thick tape. Generally, these tapes are composed of 65–70 percent filaments in the epoxy resin matrix. The longitudinal flexural modulus of boron-epoxy laminates made in this way is about 27×10^6 psi, and the flexural strength is 280,000 psi. Boron fibers have also been applied to reinforce epoxy novolacs, phenolics, and polyimides in laminate construction.

boron nitride Boron nitride is a fine powder used as a filler in encapsulating and potting compounds primarily to add thermal and/or electric conductivity. This powder is produced by Union Carbide (boron nitride HCJ).

boss The boss is a projection (generally round and tapered) on a plastic part. It is designed to add strength, to facilitate alignment during assembly, or to provide for fastening.

bottom blow The bottom blow is a specific type of blow molding machine that forms hollow articles by injecting the blowing air into the parison from the bottom of the mold (as opposed to introducing the blowing air at a container opening).

bottom plate The bottom plate is the part of the mold that contains the heel radius and the push-rods.

Brabender Plasticorder The C. W. Brabender Plasticorder instrument is a tabletop pilot plant designed to permit the study of all types of rubber and plastic materials under the same conditions of shear force, shear rate, and temperature as anticipated in processing. Mixing, extrusion, calendering, and molding characteristics can be predetermined in this manner.

The Brabender Plasticorder is a small mixer capable of measuring the viscosity and the gel time of thermosetting molding compounds with results that can be correlated to the performance of a compound during molding conditions. The test samples may be in the form of strips, pellets, or crumbs. The Brabender Plasticorder is often used as a quality control process to ensure consistency in polymerization processes and to test the reactivity of resin formulations.

braiding, weaving, knitting, stitching Braiding, weaving, knitting, and stitching represent methods of forming a shape to fibrous reinforcements. These processes are generally referred to as *reinforcement preforming*. The shape may be the final product or some intermediate form such as a woven fabric. With the introduction of new molding techniques and materials that allow prepregs to be used, preforming of the reinforcing fibers has taken on added importance.

Resin systems that are used with such preforms are generally epoxies or polyester, but any resin suitable for laminate construction can be used. The fiber options are similar to those for filament winding. However, the single stiff fibers, such as boron or ceramic fiber, cannot endure the tight bend radii.

The introduction of *three-dimensional braids* has extended braiding to airborne structural components with high fracture toughness requirements and high damage tolerance. The braiding process is continuous, and it is amenable to round or rectangular shapes or smooth curved surfaces. The braiding process can transition easily from one shape to the other.

Braiding in some applications has turned out to be almost half the cost of filament winding because of labor savings in assembly and simplification of design. Fiber volume of a braided composite will generally be lower than for other methods.

The other fabric preforming techniques are weaving, knitting, and the nonstructural stitching of unidirectional tapes. Weaving and knitting are compared to braiding in Table B.2. Stitching simply uses a nonstructural thread, such as nylon or Dacron, to hold dry tapes at selected fiber angles.

branched polymer In characterizing the molecular structure of polymers, a branched structure (as opposed to a linear structure) is characterized by side chains attached to the main chain. The side chains may be long or short.

Table B.2 Comparison of Fabric Formation Techniques (Ref: Ko, F.K., *Engineered Materials Handbook*, vol. 1, ASM International, 1987, p. 91)

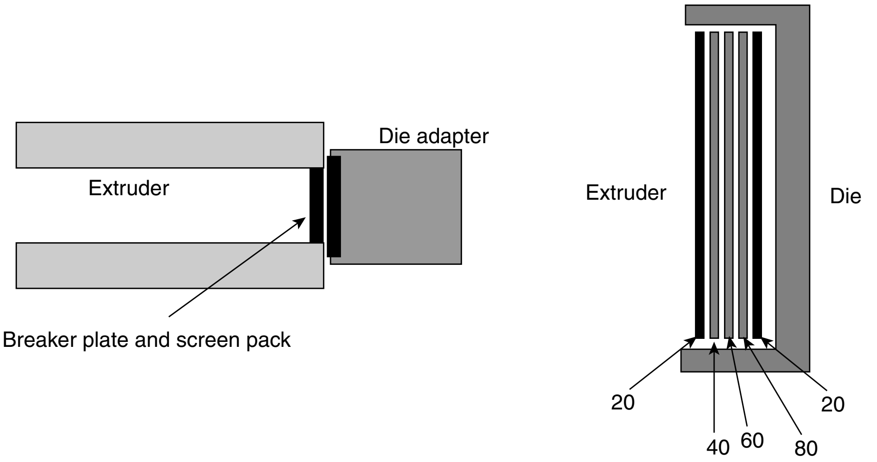
	Braiding	Weaving	Knitting
Basic direction of yarn introduction	One (machine direction)	Two (0°/90°, warp and fill)	One (0° or 90°, warp or fill)
Basic formation technique	Intertwining (position displacement)	Interlacing (by selective insertion of 90° yarns into 0° yarn system)	Interlooping (by drawing loops of yarns over previous loops)

breakdown voltage The breakdown voltage is the voltage required, under specific conditions, to cause the failure of an insulating material. Electric failure generally occurs as a breakdown or continuous arc (i.e., the insulating material ceases to be an insulator). This is the electrical property that is analogous to tensile strength in mechanical properties.

See also dielectric strength.

breaker plate The breaker plate is a perforated plate located at the rear end of an extruder head. It may also be located at the nozzle end of an injection cylinder. It often supports the screens that prevent foreign particles from entering the die. The *breaker plate support screens* are also used to keep unplasticized material out of the nozzle and to improve distribution of color particles.

See also extrusion screen pack.



(a) (b)

Figure B.5 Breaker plate (a) and screen pack (b). (Ref: Barry, C.M.F., and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

breathing Breathing, also called *degassing*, is the process of opening and closing the mold to allow gases to escape early in the molding cycle. Phenolics, for example, are degassed by opening the mold a crack for several or more seconds after the mold initially closes to allow trapped gases to escape. With some materials, this operation must be repeated at regular intervals throughout the molding cycle.

When referring to plastic sheeting or film, *breathing* indicates its permeability to air.

brittle failure Brittle failure is a failure resulting from the inability of a material to absorb energy, resulting in instant fracture on mechanical loading. Many polymeric materials will exhibit brittle-type failures when tested below their glass transition temperature.

brittleness temperature The brittleness temperature is the temperature at which a plastic or elastomer shows significantly reduced impact properties under specified conditions. The brittleness temperature is the temperature at which there is either a specified calculated percentage probability of brittle failure of the test specimen (ASTM D1790) or a calculated probability that a specified percentage of test specimens will suffer brittle failure (ASTM D746). ASTM D1790 requires the probability that 80 percent of the specimens will pass the test 95 percent of the time. The determination of brittleness temperature is relative to both plastics and elastomers.

Table B.3 Typical Brittle Points of Plastics and Elastomers (Ref: Driver, W.E., *Plastics Chemistry and Technology*, van Nostrand Reinhold Co., New York, 1979)

	Brittle Temperature	
Material	(°F)	(°C)
Polyethylene	−184	−120
Polypropylene	0	−18
Nylon 6/6	−112	−80
Polystyrene	+200	+93
Polymethyl methacrylate	+250	+121
Polycarbonate	−215	−137
Natural rubber	−80	−62
Butadiene/styrene (Buna-S)	−80	−62
Butadiene/acrylonitrile (Buna-N)	−65	−54
Polyurethane	−60	−51

Brookfield viscometer The Brookfield viscometer is the most widely used instrument for measuring the viscosity of liquids, plastisols, and other materials that have a thixotropic nature. The instrument measures shearing stress on a spindle rotating at a definite, constant speed while immersed in the sample. The degree of spindle lag is indicated on a rotating dial. This reading, multiplied by a conversion factor based on spindle size and rotational speed, gives a value for viscosity in centipoise.

There are several ASTM standards relative to specific types of material that are based on the Brookfield viscometer. By taking measurements at different rotational speeds, an indication of the degree of *thixotropy* of the sample can be obtained. Other fundamental rheological properties can be determined as well.

See also apparent viscosity; viscosity; thixotropic.

bubbler mold cooling Bubbler mold cooling is the cooling of an injection mold in which a stream of cooling liquid flows continuously into a cooling cavity. The cooling cavity is equipped with a cooling outlet normally positioned at the end opposite to the inlet. Uniform cooling can be achieved in this manner.

A *bubbler* is the device inserted into a mold that allows the water to flow deep inside the hole into which it is inserted and to discharge through the open end of the hole.

bubble viscometer In a bubble viscometer, a transparent liquid streams downward in a ring-shaped zone between the glass wall of a sealed tube and a ring air bubble. The rate at which the air bubbles rise, under controlled conditions and within certain limits, is a direct measure of kinematic viscosity of streaming liquids.

buckling Buckling is a mode of failure generally characterized by an unstable lateral material deflection due to compressive action on the structural elements involved.

buffing Buffing is usually the second step in a plastic finishing operation, after *ashing* or *sanding*. The action of a mild abrasive removes the light scratch marks and other blemishes caused by ashing or sanding.

With a slow rotating motion to avoid burning, the part to be buffed is pressed to the revolving buffing wheel to which an abrasive compound has been applied. Buffing operations are used on both thermoplastic and thermosetting materials, usually with two or three sized abrasives and at a controlled speed.

See also abrasive finishing.

bulk compression Bulk compression is the reduction in volume of a material under hydrostatic pressure, expressed as a fraction of the original volume.

bulk density Bulk density is the density of a processable material such as a molding compound in loose form (granular, nodular, etc.). It is expressed as a ratio of weight to volume. Bulk density measurements are determined with reasonably large volumes. The applicable units are g/cm^3, lb/ft^3, etc. The recommended test method is ASTM D1182.

The *bulk factor* is the ratio of the volume of loose molding powder to the volume of the same weight of resin after molding. (See Table B.4 under bulk factor.) For methods of determining the bulk factor, refer to ASTM D1895.

See also apparent density.

bulk molding compound (BMC) Bulk molding compound is a puttylike mixture generally consisting of thermosetting polyester resin, additives, and fillers. This high-viscosity mixture is often extruded into easily handled shapes for compression, transfer, or injection molding. Glass fiber-reinforced bulk molding compound grades provide tensile strengths of 3,000–10,000 psi, flexural strengths of 11,000–24,000 psi, and notched Izod impact strengths of 2–13 ft lb/in.

Washtubs, trays, and equipment housings are common applications. *Corelyn*, of Bulk Molding Compounds, Inc. and *Nu-Stone*, of Industrial Dielectrics Inc. are examples of commercial bulk molding compounds. Other major suppliers of bulk molding compounds include Haysite, Industrial Dielectrics, Plastics Engineering, Glastic, Cytec Industries (*Cyglas*), Premix (*Premi-Glas*), Rogers, and Rostone (*Rostite*)

See also thermosetting molding compound.

bulk rope molding compound Bulk rope molding compounds are bulk molding compounds made with thickened polyester resin and fibers less than 1/2 in. in

Table B.4 Bulk Factor of Molding Compounds (Ref: Schwartz, S.S. and Goodman, S.H., *Plastics Materials and Processes*, van Nostrand Reinhold Company, New York, 1982, p. 696)

Material	Bulk Factor
Alkyd	
Granular	1.8–2.4
Putty	1.1–2.0
Asbestos	1.8–2.5
Diallyl phthalate (DAP)	
Asbestos	2.2–2.3
Orlon	4.2
Dacron	4.2–7.0
Glass fiber	2.2–7.0
Epoxy	
Unfilled	2.0
Mineral	1.8–2.8
Glass fiber	2.5–3.0
Melamine	
Cellulose	4.0–7.0
Asbestos	2.1–2.5
Macerated fabric	5.0–10.0
Glass fiber	5.0–10.0
Phenolic	
General purpose	2.1–4.4
Asbestos	2.0–14.0
Mica	2.1–2.7
Macerated fabric	3.5–18.0
Glass fiber	2.0–10.0
Powdered metal	2.0–4.0
Polyester (premix)	
Mineral-filled	2.0–2.8
Glass fiber	4.0–18.0
Silicone	
Asbestos	6.0–8.0
Mineral	1.7–2.0
Glass fiber	6.0–9.0
Urea	
Cellulose	2.2–3.0

length. Supplied in continuous rope form, the unreacted compound can be cut to length, shaped, and applied to a compression mold. It molds with excellent flow and surface appearance.

See also thermosetting molding compound.

burning rate Burning rate is a term describing the tendency of plastic articles to burn at given temperatures. Certain plastics, such as those based on shellac, burn readily at comparatively low temperatures. Others will melt or disintegrate without actually burning, or will burn only if exposed to direct flame. These latter are often referred to as *self-extinguishing*.

See self-extinguishing; flammability of plastics.

burn or burn mark On a molding or extrudate or pultrusion, a burn is a visible sign of local decomposition, typically manifested as darkening to the point of blackness in the most difficult cases. Specifically on injection molding, burn marks may be caused by local overheating in the presence of hot gases or gases trapped in the mold. Burns on the surface of fabricated parts are sometimes referred to as *scorching* or *scorch marks.*

burring Burring or *reaming* is a finishing operation, generally used to remove fins (thin flash) when the mold pins butt against the opposing mold section. Burring may be carried out with a three-cornered burring tool, with a drill for the same size as the molded hole, or with a larger drill that countersinks the hole.

See also fin.

bursting strength Bursting strength is the hydrostatic pressure, given in psi, required to rupture a flat material (e.g., film or sheet) when the pressure is applied at a controlled, increasing rate through a circular rubber diaphragm that is 30.48 mm (1.2 in.) in diameter. *Points bursting strength* is the rupture pressure expressed in psi.

ASTM method D774 describes the measurement of the bursting strength of plastic films. Bursting strength is also conventionally used to characterize the strength of paper sheets and flat, thin products other than polymeric.

It should be noted that the ASTM bursting-tests (D774 and D1599) are quick burst-type tests. They are applicable to situations that may be encountered in accidental pressure surging of pipes. The evaluation of long-term resistance to lower sustained pressures is generally more representative and is the subject of several test methods in the pipe industry.

See also biaxial stress.

butadiene Butadiene ($CH_2{=}CHCH{=}CH_2$) is a gas, insoluble in water but soluble in alcohol and ether. It is obtained from the cracking of petroleum, from coal tar benzene, or from acetylene produced from coke and lime.

Butadiene is widely used in the formation of copolymers with styrene, acrylonitrile, vinyl chloride, and other monomeric substances to which it imparts flexibility to subsequent moldings. The largest use for butadiene is the production of elastomers, such as polybutadiene, styrene butadiene, polychloroprene, and acrylonitrile butadiene, or nitrile rubber.

butadiene acrylonitrile Butadiene acrylonitrile copolymers are composed of *butadiene* and *acrylonitrile* in various ratios. These copolymers yield elastomers (e.g., nitrile rubber), which are characterized by extremely low swell in water, oils, gasoline, and some of the aromatic solvents. They have fair resistance to tear, flexing, and freezing. Their resilience is fair to good, with a good resistance to abrasion and heat.

Compared to *natural rubber*, they have lower tensile strength, equivalent elongation and permanent set, and greater resistance to the diffusion of gases. As an insulating material, they are inferior to natural rubber.

Their applications include gaskets; sheet packing; oil, fuel, and solvent hose tubes; and hydraulic and oil well equipment parts.

See also nitrile rubber (NBR).

butadiene rubber (BR) Butadiene rubber is a stereospecific controlled structure like isoprene rubber. Its outstanding properties are excellent resilience and hysteresis (almost equivalent to those of natural rubber) and superior abrasion resistance compared with styrene butadiene rubber. Butadiene rubber is most similar to styrene butadiene rubber (SBR) and often finds wide use as an admixture with SBR.

Butadiene rubber can be extruded and calendered. However, it is somewhat difficult to process. For this reason, butadiene rubber is hardly ever used in amounts larger than 75 percent of the total polymer compound.

Primary applications for butadiene rubber include tire treads, conveyor belt covering, V belts, hose covers, tubing, golf balls, shoe soles and heels, sponges, and mechanical goods. Butadiene rubber is blended with SBR as an admixture for tire treads to improve abrasion and wear resistance.

butadiene styrene *See* styrene butadiene polymer and rubber (SBR).

butt fusion Butt fusion is a method of joining pipe, sheet, or other similar forms of thermoplastic resin. The ends of the two pieces to be joined are heated to a molten state (generally by contact with a hot plate) and then rapidly pressed together to form a homogenous bond. Pressure must be maintained on the joint until the plastic in the interface cools and forms a structural bond.

See also heat welding (direct); thermal welding.

butylene (butene) plastics Butylene plastics are those plastics whose base polymers may be homopolymers of butylenes or copolymers in which butylene is the mayor monomeric component. The significant butylene plastic application was polybutylene pipes, which were once considered suitable for hot water installations but are currently being questioned by many residential building codes.

See also polybutylene.

butyl rubber (IIR) Butyl rubber (IIR) is an isobutylene-based rubber that includes copolymers of isobutylene and isoprene, halogenated butyl rubbers, and isobutylene/*p*-methylstyrene/bromo-*p*-methylstyrene terpolymers. Butyl rubber can absorb and dissipate large amounts of energy because of its high mechanical hysterisis over a useful temperature range.

Butyl rubber's outstanding physical properties are low air permeability (about 1/5 that of natural rubber) and high energy-absorbing qualities. It has excellent weathering and ozone resistance, excellent flexing properties, excellent heat resistance, good flexibility at low temperature, tear resistance about that of natural rubber, tensile strength in the range of styrene butadiene rubber (SBR), and very good insulation properties. It has very poor resistance to petroleum oils and gasoline but excellent resistance to corrosive chemicals, dilute mineral acids, vegetable oils, phosphate ester oils, acetone, ethylene, glycol, and water. Butyl rubber is also very nonpolar.

Most butyl rubber is used in the tire industry. Isobutylene-based rubbers are used in underhood hose for the polymer's low permeability and temperature résistance, and high damping, resilient butyl rubbers are used for noise and vibration attenuation applications such as automotive mounts for the engine and vehicle. Chloro- and brominated butyl rubber formulations are used in automotive hose applications where contact with fuel or air conditioning fluids occurs.

Low-molecular-weight "liquid" butyls are used for sealants, caulking compounds, potting compounds, and coatings. This *depolymerized virgin butyl rubber* is high viscosity and is used for reservoir liners, roofing coatings, and aquarium sealants. It has property values similar to those of conventional butyl rubber. To make high-viscosity depolymerized butyl rubber pourable, solvents or oil are added to the base polymer.

C

C-scan C-scan is the back and forth scanning of a specimen with ultrasonics. It is a nondestructive testing technique for finding voids, delamination, defects in fiber distribution, etc. in laminates and other composite structures.

See also ultrasonic inspection; nondestructive testing.

C-stage The C-stage is the final stage in the reactions of a thermosetting resin in which the material is relatively insoluble and infusible. Thermosetting resins that are fully cured are in this stage.

See also A-stage; B-stage.

calcium carbonate Calcium carbonate is the most widely used extender, pigment, or filler for plastics. It is used in polyvinyl chloride (PVC), polypropylene, polyethylene, phenolic, epoxy, polyester, polyurethane, ethylene propylene diene monomer (EPDM) compounds, styrene, and nylon.

It is a naturally occurring, low-cost mineral. Well-known forms include *marble*, *limestone*, *calcite*, *chalk*, *aragonite*, and *dolomite*. It is generally available in a range of sizes from coarse grinds to fine pigments averaging a fraction of a micrometer. Calcium carbonate has a specific gravity of 2.71 at 23°C. Their refractive indices, between 1.4864 and 1.6584, are not high enough to interfere with effective coloration of plastic compounds, yet not low enough to impart transparency. Calcium carbonate is a relatively soft material with hardness of Mohs 3. Its solubility in water is about 0.0013 g/100 g water. It reacts with heat at about 900°C to evolve CO_2; it also evolves CO_2 on reaction with acids.

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

There are several ways of producing calcium carbonate for plastic processing. *Dry-processed calcium carbonate* is used for a variety of applications including vinyl foam carpet backing and dark floor tiles. The finest grind is about 12 μm in diameter; size distribution is wide, and color varies with feedstock. *Wet ground calcium carbonate* is a wet-processed type. Coarser particles can be removed from wet ground calcium carbonate by centrifuging.

Beneficiated ground calcium carbonate is the highest-volume usage for plastics. It is purified by removing iron and silica to minimize plastic degradation and finely ground to give filled plastics high physical properties at the lowest possible cost. Median particle diameters are from 1 to 10 μm for beneficiated calcium carbonate. Plastics in all colors, from white plastics with titanium dioxide to black plastics with carbon black, can be produced with minimum interference from calcium carbonate.

Precipitated calcium carbonate is a synthetic form obtained by the recarbonization process. This type is available in high purity grades with very fine particle sizes. It has the same or higher specific gravity, and median particle sizes range from 0.7 to 2 μm. Very fine particle sizes are used for high-viscosity nonsag plastisols and polyesters.

Stearic acid, *calcium stearate*, and other coatings for calcium carbonate usually improve rheological properties. There is considerable interest in newly developed coupling agents and dispersing agents that can be applied to the filler as a coating or added to the ingredients during compounding. Major advantages claimed for these additives are lower melt viscosity, lower power requirements for mixing, lower melt temperature, high impact strength, and favorable aging properties. These coupling agents include newer *organosilicone* agents and *titanates*.

The Table C.1 indicates the general use of calcium carbonate in various filled polymers.

calcium metasilicate Calcium metasilicate ($CaOSiO_3$) is found in great quantities as the mineral *wollastonite* mixed with about 15 percent andradite. The thin, needlelike crystals are easy to crush and grind. The ground material is a brilliant white powder in short fibers. It is used in flat paints, for paper coatings, as filler in plastics, and for electrical insulators.

See also wollastonite.

calcium sulfate Calcium sulfate is a common filler for plastics to improve physical properties such as impact, tensile, and compressive strengths. It dispenses easily and is nonreactive even when used in high-temperature, corrosive applications.

Calcium sulfate is available in several forms. *Dehydrated calcium sulfate* is made by fine grinding and air separating a select, high-purity segment. Average particle size is 12.2 μm. It is used in applications in which a cellular structure is desired. *Anhydrous calcium sulfate* is a further-refined version to remove all affinity to water. This type is useful when product stability and moisture-free conditions are desired. A finer-grind anhydrous calcium sulfate is available with an average particle size of 1.4 μm. It has greater dispersibility and even distribution

Table C.1 General Use and Characteristics of Calcium Carbonate Filler in Various Polymer Systems

Polymer	Calcium Carbonate Loading, Type, etc.	Characteristics
Flexible PVC	20–60 phr of 3 micron	Fine fillers cause less decrease in physical properties at the same loading and provide better performance in thinner calendered films and coatings.
PVC plastisols and organosols	20–100 phr with a wide range of particle sizes	Coarse particles lead to lower viscosity plastisols but may form sediment during storage.
Rigid PVC	1–5 phr of 2 to 3 micron for potable water pipe; up to 40 phr of 1 to 3 micron for other pipe and conduit applications.	Stearate coated grades improve melt rheology and smoothness of extrusion.
PVC floor tile	80–400 phr of small granular size	Lighter colors are obtained from beneficiated calcium carbonate.
Polyester SMC	Loadings of up to 200 phr, 3 to 6 microns.	Low viscosity one and two component polyester resins. Size and distribution are selected for micro-smooth surfaces, no shrinkage, and low controlled viscosity.
Polyester BMC	3–6 microns. Up to 250 phr for BMC and 100–150 phr for premix, preform, and mat.	Over 400 phr is possible in certain applications.
Marine polyester	175–200 phr, 3 to 5 microns	Meets ASTM D1201 requirements of 0.15% maximum water absorption during 24 hr immersion.
Polyethylene	Ground calcite	Low and high density polyethylene.
Polypropylene	30–40 wt percent, 1 to 3 microns	Injection molded automotive parts are commonly made from mineral filled polypropylene (Hercules, Profax 6523)

throughout the resin matrix, with high resin/filler contact for maximum structural strength and integrity.

The anhydrous forms are pure white in color, ranging in whiteness from 98 to 99 percent on the Beckman scale. This is particularly important for white products requiring titanium dioxide. The purity and whiteness of the calcium sulfate filler enable compounders to use less titanium dioxide to achieve the same degree of whiteness.

Calcium sulfate fillers can be used to extend both rigid and flexible thermoplastics and reinforced and unreinforced thermosets. Anhydrous calcium sulfate has been compounded into polyvinyl chloride (PVC), polypropylene, and nylon, as well as sheet and bulk molding compounds (SMC and BMC) and other polyesters. It improves impact strength and helps retain dimensional stability and dielectric properties. In thermosets normal loading levels are 60–70 phr, with loadings of more than 100 phr for SMC, resulting in improved physical properties when the materials are subjected to corrosion, high voltage, heat, or stress.

Typical applications in thermosets include housings, automotive, corrosion-resistant applications (such as chemical and marine fittings and shower bases), electrical applications, and consumer goods (recreational equipment parts, power mower housings, furniture components, power tool handles and housings, appliance bases and covers).

In thermoplastics (especially PVC and polypropylene), calcium sulfate has achieved good results with loading levels of 50–60 phr. In PVC extrusion applications, anhydrous calcium sulfate provides higher loading capabilities, lower compounding costs, and smoother extrudates. In cellular vinyl extrusions, it provides more uniform cell structure. In polypropylene calcium sulfate enhances tensile strength because it maintains high resin contact for greater structural integrity, and impact strength is also enhanced.

Compounding factors include proper drying for optimum loading applications. As with many finely divided fillers, a small amount of moisture is out-gassed during compounding. Surface treatment and *coupling agents*, such as *stearates* and *silanes*, can also be used.

calender As a verb, calender refers to the process of preparing material by pressure between two or more counterrotating rolls. Calendering is usually used for the continuous manufacture of *calendered sheet* or *calendered film*. Granular resin, or thick sheet, is passed between pairs of highly polished heated rolls under high pressure.

For the production of thin film, a series of roll pairs is used with gradual reduction in roll separation as the stock progresses through the unit. Proper calendering

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Figure C.1 Diagram of a four roll calender. (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 493) requires precise control of roll temperature, pressure, and speed of rotation. By maintaining a slight speed differential between a roll pair, it is often possible to impart an exceedingly high gloss to the film or sheet surface.

An embossed design can be produced on the surface by means of an appropriately engraved calender roll. By calendering a mixture of granular resin chips of varying color, it is possible to produce unusual decorative effects (e.g., marbleization) in the product. This technique is widely employed in the manufacture of flooring compositions.

Web thicknesses range from 3 to 30 mils off the calender, down to between 1 and 2 mils after stretching. Product widths can vary between 72 and 120 in. Thermoplastics such as polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), and ethylene vinyl acetate (EVA) can be easily calendered.

As a noun, *calender* refers to the machine that performs an operation by which sheets of materials are prepared by pressure between two or more counterrotating rolls. A calender line typically consists of the following equipment and characteristics: raw materials bulk handling and mixing; plasticizing and calender feeding; calendering and postcalendering treatment; tempering and cooling rolls; and an automatic double- or triple-turret winder (this includes pick-off or take-up devices and cutting devices).

The PVC film industry uses two dominant types of calender and roll arrangements depending on whether the material is rigid or flexible PVC. Rigid PVC manufacturers prefer the L-configuration with four to seven rolls. The most common calender for flexible PVC is a four-roll inverted L- or F-type. This enables the plasticizer-saturated vapors to be drawn to the suction hood above the calender and be filtered and removed before reaching the atmosphere.

Calenders having a Z-arrangement have also been installed. This arrangement permits a compact design and makes a calender with only two rolls in any one plane so that the loads developed in one working bank do not affect the gauge of subsequent passes.

Primary manufacturers of calendering equipment include Global Equipment & Machinery Sales, Inc.; IMD Corp.; Kobe Steel Ltd.; B. F. Perkins Co.; and Processing Technologies, Inc.

capacitance In a system of conductors and dielectrics (such a system is a *capacitor*), the capacitance is that property which permits the storage of electrically separated charges when potential differences exist between the conductors. Capacitance is at times also called *capacity*. Capacity is measured in farads.

See also dielectric constant.

capacitor A capacitor is a component consisting essentially of two conducting surfaces separated by an insulating material or dielectric such as air, paper, mica, glass, plastic film, or oil. One factor in determining the capacitance value of a capacitor is the dielectric constant of the dielectric material used.

A capacitor stores electrical energy, blocks the flow of direct current, and permits the flow of alternating current to a degree dependent essentially on the capacitance and the frequency. In electronics, capacitors are often mounted on plastic substrates, such as printed circuit boards.

See also dielectric constant.

capillary rheometer The capillary rheometer measures the viscosity properties of polymers and provides a direct measure of viscosity and the change in viscosity with time and flow rate at plastication temperatures. The capillary orifice simulates the gate and runner system of actual molding conditions, thus providing valuable flow information for molding compounds.

A capillary rheometer is a rheometer, usually of the piston type, in which a thermoplastic is converted to a melt by heating in controlled conditions in the body (the cylinder or barrel) of the apparatus and then extruded through a capillary die.

The dimensions of the cylinder, the piston, and the die must be chosen and carefully defined appropriate to a particular application. The temperature and pressure that is applied to the melt and the output rate must also be accurately controlled and/or measured. ASTM D3835 specifies measurement of a polymer's flow characteristics via a capillary rheometer.

caprolactam Caprolactam is a cyclic amide-type compound containing six carbon atoms. When the ring is opened caprolactam is polymerizable into a nylon resin known as *type 6 nylon* or polycaprolactam. The properties of polycaprolactam are in general similar to those of *6/6 nylon*, but the caprolactam has a lower crystalline melting point (225°C vs. 265°C for 6/6 nylon) and is somewhat softer and less stiff. The major use for this polymer is in fiber, especially tire cord.

Caprolactam can be made in a large number of ways. One method that is used commercially involves oxidation of cyclohexane to cyclohexanone, from which the oxime is made. This oxime reacts by the Beckmann rearrangement to give caprolactam. The polymerization of caprolactam is carried out by adding water to open the rings and then removing the water again at elevated temperature, where linear polymer forms. An autoclave or a continuous reactor can be used.

Polycaprolactam is in equilibrium with about 10 percent of the monomer, which must be removed by washing with water before the polymer can be spun. At the fiber spinning temperature more monomer is formed to restore the equilibrium, and this must again be removed to achieve good properties in the yarn.

Caprolactam can also be polymerized by ionic chain mechanisms. The reaction can be carried out below the melting point of the nylon and at atmospheric pressure, making the technique very attractive for the production of large cast articles.

The major suppliers of caprolactam include Allied Signal Inc. (*Capron*), Bayer Corp. (*Durethan*), Ferro Corp., RTP Co., Shakespeare Monofilaments and Specialty Polymers (*Isocor*), and Shanghai Genius Advanced Materials Co. Ltd.

See also nylon.

carbonate A carbonate is a compound resulting from the reaction of a carbonic acid with an organic compound. It forms an ester (e.g., *diethyl carbonate* and *diphenyl carbonate*).

carbon black Carbon black is a black pigment produced by the incomplete burning of natural gas or oil. It is widely used as a filler, particularly in the thermoplastic and rubber industry. Because it possesses useful ultraviolet (UV) protective properties, it is used often in polyethylene compounds intended for such outdoor applications as cold water piping and black agricultural sheet.

Carbon blacks range in particle size from about 5 to 500 μm, with the particles usually in grapelike clusters called "structures." Chemisorbed surface volatiles are formed during production. Most carbon blacks today are the *furnace type*, characterized by low particle size, high structure, and low volatiles. The latter two properties are tailorable to the expected application.

Carbon black can function as a UV stabilizer, thermal antioxidant, extender in crosslinked polyethylene (XLPE) cable compounds, antistat in vinyl records, modifier of polymerization rate in unsaturated polyesters, conductive filler, and colorant. Although commonly used in rubbers and thermoplastics, carbon black does not improve the properties of thermosetting resins significantly. However, it is often used as a pigment and for obtaining electrical conductivity.

Long-term UV stabilization is obtained with no more than 2.5 percent loading. The preferred grade has a 20 μm particle size, high structure, and low to moderate volatility. Small particle size is also effective for thermal oxidation protection.

Improved grades of carbon black extend the uses of the filler. A high efficiency grade offers good electrical conductivity at low loadings; another grade features low impurities; and a third has low dusting properties.

Carbon blacks are supplied as powder or pellets. Powders are confined mostly to dry blending. Pellets are preferred for concentrates, with high-shear equipment mandatory. *Micropulverized delayed coke*, a relatively new form of carbon black, is a coarse filler offered as an alternative to thermal blacks for tinting and UV stabilization in some uses.

The major suppliers of carbon black include Akrochem Corp., Akzo Chemicals Inc., Cabot Corp., Degussa Corp., J. M. Huber Corp. and Summit Chemical Co.

carbon fiber Carbon fiber is a term often used interchangeably with *graphite fiber*.

See graphite fiber.

carbonyl The carbonyl group is represented molecularly by the group $C{=}O$. It is present in aldehydes, ketones, organic acids, sugars, and carboxyl groups.

carboxyl The carboxyl group is a chemical group characteristic of carboxylic acids and represented by the group $COOH$.

carpet plot Carpet plots graphically show the range of properties available with a specific laminate configuration. These plots are useful for preliminary analysis of a multilayered composite. For more detailed analysis, there are a significant number of computer programs to perform the matrix multiplications and the transformations.

carrier Carrier is a term generally used in the adhesive industry. A carrier or reinforcement is usually a thin fabric, cloth, or paper used to support the semicured adhesive composition to provide a tape or film. In pressure-sensitive tapes, the carrier is the backing on which the adhesive is applied. The backing may be used for functional or decorative purposes.

In films or structural tape, the carrier is usually porous and the adhesive saturates the carrier. Glass, polyester, and nylon fabric are common carriers for supported B-staged adhesive films. With fabric constructions, (1) the carrier provides for a method of applying the adhesive; (2) it may also may act as reinforcement for the adhesive; and (3) it can provide an internal “shim” to control the thickness of the adhesive regardless of the amount of pressure applied to the joint during the time of curing.

casein Casein is a protein material precipitated from skimmed milk by the action of either rennet or dilute acid. *Rennet casein* finds its main application in the manufacture of plastics. *Acid casein* is a raw material used in a number of industries including the manufacture of adhesives. Casein is also used as sizing for paper and textiles, washable interior paints, leather dressings, and as a diabetic food.

Casein plastics can be fabricated in the same manner as cast plastics. The hardening operation, which is considered to be a condensation reaction between the aldehyde and the amino group of the casein molecule, transforms the material from a thermoplastic to a thermosetting condition. Casein plastics are nonflammable and extremely tough. These properties along with its availability in all colors have given casein its widest use in the manufacture of buttons, buckles, etc. The usefulness of the material is somewhat limited by its odor, but more importantly by its absorption of water (7–14% after 24-h water immersion). Because of this hygroscopic nature, casein plastics are not suitable where dimensional stability is desired. Casein plastics are not widely used today.

Dry-mixed casein adhesives are simply mixed with water before use. They are used at room temperature and set by the loss of water through a porous substrate and by a certain degree of chemical conversion. Mixed casein adhesives have a finite pot life. They are commonly used for paper labels, woodworking, and other interior applications. They cannot be used outdoors, although they are resistant to dry heat up to 70°C. Resistance to organic solvents is generally good.

The major suppliers of casein adhesives include American Casein Co., National Casein Co., and Ultra Additives, Inc.

casting As a noun, the term casting refers to the finished product of a casting operation. In the casting processes, a liquid material is poured into a mold (without pressure) and solidified by physical (e.g., cooling) or chemical (e.g., polymerization) means and the solid object is removed from the mold. Casting uses low-cost equipment. Molds can be made out of soft, inexpensive materials (such as rubber and plaster), but casting is a relatively slow process.

Thermosetting resins are cast by using the material in the *A-stage*, where the resin is still fusible and liquid. After the mold is filled, the resin is cured in an oven or at room temperature. Such processes are commonly used for epoxies, polyurethanes, polyesters, phenolics, and allylic esters. (*See also* casting resins.)

Thermoplastic castings can also be made by working with the liquid monomers. Vinyl polymers, primarily the acrylic resins such as polymethyl methacrylate, are cast by preparing a syrup of monomer and polymer and polymerizing the monomer in the mold. Sheets, rods, and tubes are prepared in this way. Cellulose acetate butyrate and mixtures of ethyl cellulose and wax are cast by plasticizing the resins to the point where they flow freely when hot but solidify on cooling.

Cylindrical articles such as pipe and drums can by made by *centrifugal casting*. In this process the cylindrical metal mold is charged with granular polymer and rotated. The granules cover the walls of the mold and are fused in place by the application of heat from the outside.

Another casting process is the forming of a plastic film or sheet by pouring the liquid resin onto a moving belt or by precipitation in a chemical bath. For example, a cast film is made by depositing a layer of plastic (molten, in solution, or in a dispersion) onto a surface, solidifying, and removing the film from the surface.

Cast films, including photographic film and cellophane, are made by flowing a solution of the polymer onto an extremely smooth surface in the form of a large polished wheel or a metal belt or band. After the solvent has evaporated (or, in the case of cellophane, the polymer has coagulated) the film is stripped from the casting surface.

The key advantages of casting are low mold cost, ability to produce large parts with thick cross-sections, good surface finish, and suitability for low-volume production. The major disadvantages are that it is limited to relatively simple shapes and, except for cast films, becomes uneconomical at high-volume production levels. It is not suitable for most thermoplastics.

When used as a verb, the term *cast* refers to the embedding of a component or assembly in a liquid resin, by using molds that separate from the part for reuse after the resin is cured. Curing or polymerization is accomplished without external pressure. The mold may contain objects that will have been prepositioned in the mold, and they become embedded by the resin as it cures. This technique can be done with minimal equipment, and delicate inserts can be embedded or they can be introduced into the compound before the curing stage. The chief disadvantages of the casting process are that high-viscosity resins are difficult to handle and the occurrence of voids or bubbles can present problems.

When casting applications require fairly high-volume production, machines for mixing and dispensing the liquid plastics may be used for shorter production cycles, and curing ovens, conveyors, and other auxiliary capital equipment may be added. Thus the liquid resin casting process my be a low-cost, manual one or it may be highly automated, depending on the nature of product desired and the quantities required.

See also potting; casting resins; centrifugal casting.

casting resin Casting resins and the casting process are identical to potting resins and the potting process, except that the formulated resin mix is poured into a removable and reusable mold instead of into a container. Once cured, the mold is removed and reused. Hence, the resulting product is a ruggedized assembly without an outer case. Typical casting resins are thermosets and include epoxies, polyesters, polyurethanes, phenolics, and allylic ester resins.

Epoxy resins have proven very popular because of their versatility, excellent adhesion, low cure shrinkage, good electrical properties, compatibility with many other materials, resistance to weathering and chemicals, dependability, and ability to cure under adverse conditions. The most widely used epoxy resins in the casting field are the bisphenol-A and cycloaliphatic epoxies. Novolac epoxy resins have higher heat deflection temperatures, but they require high-temperature cure. The novolacs also have excellent resistance to solvents and chemicals. Epoxy castings are often used in electrical/electronic applications. (*See also* epoxy resin.)

General-purpose polyester, when blended with a monomer such as polystyrene and then cured, will produce rigid, rapidly curing transparent castings. Other monomers, in conjunction with polystyrene, such as α-methyl styrene, methyl methacrylate, vinyl toluene, diallyl phthalate, triallyl cyanurate, divinyl benzene, and chlorostryene, can be blended to achieve specific property enhancements. Flexible polyester resins are also available which are tougher and slower-curing and produce lower exotherm and less cure shrinkage. [*See also* polyester (thermosetting).]

Polyurethanes are reaction products of an isocyanate, a polyol, and a curing agent. The choice of curing agent influences the curing characteristics and final properties. Diamines are the best general-purpose curing agent,. The highest physical properties are produced with MOCA 4,4-methyl-bis (2-chloroaniline). The other major class of curing agents, the polyols, is more convenient to use, but the final products have lower physical properties. Polyurethanes have good abrasion resistance and a low coefficient of friction. They find applications on roller wheels and press pads as well as gaskets, casting molds, timing belts, wear strips, liners, and heels and soles. (*See also* polyurethane.)

Phenolic casting resins are available as syrupy liquids. They are produced in huge kettles by the condensation of formaldehyde and phenol at high temperature in the presence of a catalyst and with the removal of excess moisture by vacuum distillation. These resins, when blended with a chemical active hardener, can be cast and cured in molds constructed from various materials. Phenolic casting resins exhibit a broad-based property profile. (*See also* phenolic.)

Allylic ester resins possess excellent clarity, hardness, and color stability and thus are used to cast into optical parts. These castings can be either homopolymers or copolymers. The free radical addition polymerization of the allylic ester presents some casting difficulties such as exotherm control, monomer shrinkage during curing, the interaction between the exotherm and the free radical source, and the environmental heat required to decompose the peroxide and initiate the reaction. Cast allylics are noted for their hardness, heat resistance, electrical properties, and chemical resistance. They lack strength, and so their usage is confined to optical parts and some small electrical insulators. (*See also* allyl.)

See also casting; potting resin; electronic plastic.

catalyst A catalyst is a chemical that causes or speeds up the cure of a resin but does not become a chemical part of the final product. Acids, bases, salts, sulfur compounds, and peroxides are commonly used. The peroxides used with polyesters are typical catalysts. Only small quantities are usually required to influence curing. Unlike *hardeners* or *curing agents*, the amount of catalyst used is critical, and poor properties can result when resins are over- or undercatalyzed.

The catalysts required by plastics may be classified as (1) strong acid catalysts (e.g., sulfuric acid, hydrochloric acid, and phosphoric acid alone or in combination with modifiers), (2) latent acid catalysts (e.g., ammonium salts of strong acids such as ammonium chloride generally useful in accelerating the setting of urea or melamine resins), (3) aldehydic catalysts (e.g., catalysts peculiar to phenol-formaldehyde and urea-formaldehyde resins such as paraformaldehyde and hexamethylenetetramine often used in urea and resorcinol adhesives), and (4) peroxide catalysts (e.g., benzoyl peroxide and dicumyl peroxide promote polymerization of polyesters through a free radical mechanism).

See also hardener; inhibitor; promoter.

caul plate The caul plate is a rigid plate contained within a *vacuum bag* to impart a surface texture or configuration to the laminate during cure. In general, caul plates can be any metal plates between which laminates are pressed.

See also vacuum bag molding.

cavity The term cavity or *mold cavity* refers to the depression in a mold made by casting, machining, hobbing, or a combination of these methods. The plastic parts are formed by the geometry of the depression. The plastic parts harden in the cavity until they have sufficient structural strength to be removed. Depending on the number of such depressions, molds are designated as single cavity or multicavity.

Cavity retainer plates are plates in a mold that hold the cavities and plugs. These plates are at the mold parting line and usually contain the guide pins and bushings. They are also called force retainer plates. (*See* Fig. I.4.)

cell A cell is a small particle or completely enclosed cavity within a plastic part. A cell is generally a gaseous void. A plastic material made up of numerous cells is referred to as a *cellular plastic* or *foamed plastic*.

A *closed cell* is one that is totally closed by its walls and hence not interconnecting with other cells. An *open cell* is a cell not totally enclosed by its walls and hence interconnecting with other cells. *Cell striation* refers to a layer of cells within a cellular plastic that differs greatly from the characteristic cell structure of the materials.

See also blowing agent; foamed plastic; cellular plastic.

cellophane Cellophane or *regenerated cellulose* is a transparent cellulose plastic material made by mixing cellulose xanthate with a dilute sodium hydroxide solution to form a viscose. Regeneration is carried out by extruding the viscose, in sheet form, into an acid bath to create regenerated cellulose.

Cellophane film is a transparent, colorless, nontoxic, odorless film composed of regenerated cellulose, water, and a suitable humectant (plasticizer or softener), which is generally glycerol. Because of its low cost and wide range of useful properties, cellophane is one of the most widely used films today.

Cellophane (although not strictly considered to be a plastic material) is made by an extrusion process in which a solution of dissolved cellulose (viscose) is extruded through a slot into an acid bath. This insolubilizes the solution and regenerates the cellulose.

Physical properties, such as tensile strength, elongation, softness, and stiffness, depend on the composition of this three component system, which varies considerably within the following approximate limits: regenerated cellulose 60–85 percent humectant 10–25 percent and water 5–15 percent. The moisture content will further vary, because the film is susceptible to humidity changes in the atmosphere.

Cellophane is tough and generally inert chemically, except to concentrated acids and alkalis. It also transmits a high percentage of ultraviolet rays. It is available in a variety of standard colors, can be made flameproof, and can be marked and decorated by a variety of printing techniques.

Cellophane is used as a general protective wrapping material. Because of its good electrical properties, it is used in wire and cable construction and other electrical products. It also functions as a separator, barrier, or release film in plastic molding and lamination. To make it moisture proof, most of the cellophane film is coated with a lacquer composed of nitrocellulose, plasticizers, resins, and waxes. This coating can also give the cellophane film a heat-sealing property.

cellular plastic A cellular plastic is a plastic with greatly decreased density because of the presence of numerous cells or bubbles dispersed throughout its mass. The methods of production and fabrication of polymeric materials allow the incorporation of various amounts of gas in the form of voids, cells, etc. The resulting lighter material is referred to as cellular, blown, expanded, foamed, or sponge.

Cellular plastics can be generally classified as elastomeric foams and rigid foams. Elastomeric foams are those involving a elastomeric or soft plastic matrix: plasticized polyvinyl chloride, low-density polyethylene, and certain polyurethane plastics. Rigid foams are those involving rigid matrices, such as polystyrenes, unsaturated polyesters, phenolics, and certain polyurethane plastics. The type of polymer matrix, thermoplastic or thermosetting, can also form the basis for a classification scheme and is closely associated with the processing.

See also blowing agents; foamed plastic.

cellulose Chemically, cellulose is sugar, with the empirical formula $C_6H_{10}O_5$. It polymerizes into macromolecules with molecular weights distributed between 300,000 and 500,000. Cellulose is the main constituent of dried woods, jute, flax, hemp, ramie, etc. *Cotton* is almost pure cellulose.

Cellulose is a natural high-polymer carbohydrate found in most plants. It is a fibrous material that makes about 50 percent of the cell walls of plants. There are three forms of cellulose, the α-type being most abundant and the one used in plastics.

Reacted with nitric acid, acetic acid, etc. α-*cellulose* yields the cellulosic plastics. It is also a filler for *urea* and *melamine* resins, and paper with high α-cellulose content is used in the manufacture of *vulcanized fiber*.

α-*Cellulose* is a term traditionally used for pure cellulose of high molecular weight, represented by that portion of cellulose pulp that does not dissolve in 17–18 percent sodium hydroxide solution at 20°C. This portion is considered to comprise the long-chain fraction of the cellulose in pulp. ASTM in D1695 and D1696 offers more precise definitions.

cellulosic plastic: cellulose acetate (CA), cellulose acetate butyrate (CAB), cellulose acetate propionate (CAP), ethyl cellulose (EC), cellulose nitrate (CN), cellulose triacetate (CT) Cellulosic polymers are the most abundant organic polymers in the world. They are also among the toughest of plastics. Cellulosic plastics are generally economical, basically good insulating materials. However, cellulosic polymers are temperature limited and are not as resistant to extreme environments as many of the other thermoplastics. Their general mechanical structure is shown in Fig. C.2.

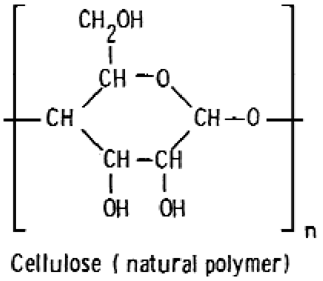

Figure C.2 General chemical structure of cellulose.

Cellulosics have similar properties that vary in degree. The four most prominent cellulosics are cellulose acetate, cellulose acetate butyrate, cellulose propionate, and ethyl cellulose. A fifth member of this group is cellulose nitrate. Cellulose materials are available in a great number of formulations and flow rates and are manufactured to offer a wide range of properties. They are formulated with a wide range of plasticizers for specific properties.

Cellulose butyrate, propionate, and acetate provide a range of toughness and rigidity that is useful for many applications, especially where clarity, outdoor weatherability, and aging characteristics are needed. The materials are fast-molding plastics and can provide hard, glossy surfaces over the full range of color and texture.

Butyrate, propionate, and acetate are rated in that order in dimensional stability in relation to the effects of water absorption and plasticizers. The materials are slow burning, although self-extinguishing forms of acetate are available. Special formulations of butyrate and propionate are serviceable outdoors for long periods. Acetate is generally considered unsuitable for outdoor uses. From an application standpoint, the acetates generally are used where tight dimensional stability under anticipated humidity and temperature is not required. Hardness, stiffness, and cost are lower than for butyrate or propionate. Butyrate is generally selected over propionate where weatherability, low-temperature impact strength, and dimensional stability are required. Propionate is often chosen for hardness, tensile strength, and stiffness combined with good weather resistance.

Cellulose acetate (*CA*) is the acetic acid ester of cellulose. It is obtained by the action, under rigidly controlled conditions, of acetic acid anhydride on purified cellulose usually obtained from cotton linters. All three available hydroxyl groups in each glucose unit of the cellulose can be acetylated. However, in the material normally used for plastics, it is usual to acetylate fully and then to lower the acetylate value (expressed as acetic acid) to 52–56 percent by partial hydrolysis. When compounded with suitable plasticizers, this gives a tough thermoplastic material. Cellulose acetate is mainly an extrusion (film and sheet) material, but injection applications include premium toys, tool handles, appliance housings, shields, lenses, and eyeglass frames.

Cellulose acetate butyrate (*CAB*) or cellulose butyrate is an ester of cellulose made by the action of a mixture of acetic acid and its anhydride on purified cellulose. It is used in the manufacture of plastics that are similar in general properties to cellulose acetate but are tougher and have better moisture resistance and dimensional stability. Cellulose acetate butyrate is used for pen barrels, steering wheels, tool handles, machine guards, and skylights.

Cellulose acetate propionate (*CAP*) or cellulose propionate is an ester of cellulose made by the action of propionic acid and its anhydride on purified cellulose. It is used as the basis of thermoplastic molding material. Cellulose acetate propionate applications include lighting fixtures, safety goggles, motor covers, brush handles, face shields, and steering wheels.

Ethyl cellulose (*EC*), best known for its toughness and resiliency at subzero temperatures, also has excellent dimensional stability over a wide range of temperature and humidity conditions. Alkalines or weak acids do not affect this material, but cleaning fluids, oils, and solvents are very harmful. Ethyl cellulose is used for flashlight cases, fire extinguisher parts, and electric appliance parts.

Cellulose nitrate (*CN*) or nitrocellulose is a nitric acid ester of cellulose manufactured by the action of a mixture of sulfuric acid and nitric acid on cellulose, such as purified cotton linters. The major use of plastics-grade cellulose nitrate is in the coating field. Despite its disadvantages of flammability, instability, and poor weathering properties, cellulose nitrate is one of the cheapest and most highly impact-resistant plastic. It still has many uses because of these properties, including fountain pens, tool and brush handles, eyeglass frames, and some motion picture film. It accounts for only a small fraction of the volume of cellulose plastics. Cellulose nitrate materials are sometimes simply called *nitrates.*

A *celluloid* is a thermoplastic material made by the intimate blending of cellulose nitrate with camphor. Alcohol is normally used as a volatile solvent to assist plasticization and is subsequently removed. The type of cellulose nitrate used for celluloid manufacture usually contains 10.8–11.1 percent nitrogen.

Cellulose triacetate (*CT*) is a cellulosic material made by reacting purified cellulose with acetic anhydride in the presence of a catalyst. It is used in the form of film and fibers. Films and sheet are cast from clear solutions onto drums with highly polished surfaces. The film, which is of excellent clarity, has high tensile strength and good heat resistance and dimensional stability. Applications include book jackets, magnetic recording tapes, overhead projector film, and various types of packaging. Cellulose triacetate sheet has properties somewhat similar to those of the film and is used to make such articles as safety goggles and transparent covers of many kinds.

ASTM provides both test methods and specifications for products made from cellulosic polymers. The primary specifications and test methods are provided in Table C.2.

Table C.2 Primary Specifications and Test Methods for Cellulosics

Cellulosic	Test Method	Specification
Cellulose Acetate Butyrate	ASTM D817	ASTM D707 (molding, extrusion); ASTM D2411 (sheet and film)
Cellulose Acetate Propionate	ASTM D817	ASTM D1695
Cellulose Nitrate		ASTM D1695
Cellulose Propionate		ASTM D1695; ASTM D1562 (extrusion and molding)
Cellulose Triacetate		ASTM 1695

Major suppliers of cellulosic plastics include Akzo Nobel Chemicals Inc. (all); Eastman Chemical Co. (CA, CAB, CAP); FMC Corp. (CA, CAB); Raffi & Swanson, Inc. (all); Rotuba Extruders Inc. (CA, EC); RTP Co. (CAB, CAP); and Union Carbide Corp. (EC).

center-gated mold A center-gated mold is an *injection* or *transfer mold* in which the cavity is filled with resin through an orifice interconnecting the nozzle and the center of the cavity area. Normally, this orifice is located at the bottom of the cavity when forming items such as containers, tumblers, and bowls.

centipoise The centipoise is a unit of *viscosity*, conveniently and approximately defined as the viscosity at room temperature. Table C.3 provides approximate viscosities at room temperature, which may be useful for rough comparison.

See also apparent viscosity; viscosity.

centrifugal casting In the centrifugal casting process, a catalyzed resin is introduced into a rapidly rotating mold. The resin forms a layer on the mold surfaces and hardens. Vacuum is sometimes used to aid in bubble removal. Polyurethane, plastisols, other liquid elastomers, and epoxies can be used in this process. Conventional products formed by the centrifugal casting process include elastomer sheets, reinforced pipe, and rubber track.

With this process, reinforcing elements can be accurately placed. High-viscosity, rapidly curing materials can be used. Precise wall thickness is possible.

Disadvantages include the fact that fillers separate rapidly and the parts are limited to toroidal shapes.

Table C.3 Viscosity of Several Common Fluids

Liquid	Viscosity in Centipoise (cps)
Water	1
Kerosene	10
Motor oil; (SAE–10)	100
Castor oil; Glycerin	1,000
Corn syrup	10,000
Molasses	100,000

centrifugal coating A centrifugal coater is a self-contained unit. It consists of an inner basket, a dip coating tank, and exterior housing. Products are placed in the inner basket, which is dipped into the coating tank. The basket is withdrawn and spun at a speed high enough to remove the excess coating materials by centrifugal force. This causes the coating to be flung onto the inside of the exterior housing, from which it drains back into the dip tank.

The advantage of centrifugal coating is that large numbers of small parts can be coated at the same time. The disadvantage is that the appearance of the finish is a problem because the parts touch each other.

ceramic fiber Ceramic fibers are continuous fibers of *metal oxides*. The major advantages of these fibers are their very high temperature resistance (up to 1650°C) plus high modulus and compressive strength. They also have outstanding chemical resistance and can be woven into fabrics for use in various reinforced plastic structures. Typical applications are found in aircraft and aerospace, sport equipment, components requiring chemical resistance, and brake linings or friction materials.

One example of a recently introduced ceramic filler/reinforcement is short discontinuous fibers composed of approximately equal parts of *alumina* and *silica*. This filler has a melting temperature of 1795°C. It can be "engineered" for a specific set of physical properties by modifying fiber length, diameter, aspect ratio, and surface area.

In *unsaturated polyester*, a nominal 25 percent replacement of glass fiber with engineered ceramic fiber has shown improvement in flexural, tensile, and impact values. Further improvements are possible via the use of *coupling agents*. For example, flexural modulus of 2.3 million psi, notched Izod impact strength of 4.4 ft lb/in., tensile strength of 5610 psi, and flexural strength of 11,200 psi are possible.

chain extender In polyurethane materials, a chain extender is a short-chain diol that, along with diisocyanate, composes the hard segment in the polyurethane phase-separated block copolymers. The soft segment is prepared from an elastomeric long-chain polyol, generally a polyester or polyether, but other rubber polymers end-capped with a hydroxyl group could also be used.

See also polyurethane.

chain length

See degree of polymerization

chalking Chalking refers to a powder residue on the surface of a plastic material, often resulting from weathering. Chalking usually occurs because of the material's poor resistance to UV exposure and outdoor weathering conditions. Chalking is often among the early symptoms of weathering.

charge A charge is the amount or weight of a material used to load a mold at one time or during one cycle.

Charpy impact test The Charpy impact test is a destructive test of impact resistance, consisting of placing the specimen in a horizontal position between two supports and then striking the specimen with a pendulum striker swung from a fixed height. The magnitude of the blow is increased until the specimen breaks. The result is expressed in in.-lb or ft-lb of energy.

See also impact resistance.

chase As distinguished from the supporting mold base, the chase is the main body or heart of the mold, containing the cavity, mold pins, and other parts directly connected with the operation of the cavities.

A chase can be an enclosure of any shape used to (1) shrink fit parts of a mold cavity in place; (2) prevent spreading or distortion in *hobbing*; or (3) enclose an assembly of two or more parts of a *split cavity block.*

A *chase ring* is the ring placed around a *hob blank* to prevent it from spreading while the hob is being sunk.

chelating agent A chelating agent is a substance that, through chemical means, will form complexes with various ions and prevent them from exerting an influence on the system under study. Such ions are generally removed because they catalyze degradation reactions such as oxidation.

See also metal deactivator.

chemical resistance When polymeric materials are exposed to an aggressive chemical environment, the effects basically involve physical changes but chemical changes may also take place. In the case of physical changes the molecular structure of the polymer generally remains unchanged. In the case of chemical changes, the molecular structure of the polymer may or may not be changed.

Brief exposure to chemical media may cause surface tackiness, or, in severe cases, the chemical may truly dissolve the molecules in the case of thermoplastics and cause swelling and dimension change in the case of thermosets. In some cases, chemicals may have little effect on the pure polymer but will extract additives, with resulting degradation in performance.

Chemical effects are those involved in breaking and or forming chemical bonds. In some cases further polymerization may result, and in other cases molecular chain scission may result. These chemical reaction mechanisms may involve hydrolysis. *Hydrolysis* is the reversal of the condensation reaction in the presence of water molecules. *Oxidation* may result from the presence of oxidizing chemicals, and low- and high-energy radiation can also promote chemical changes.

A screening of polymeric materials considered for use in contact with a specific chemical can often be made through the use of published general ratings (i.e., excellent, good, fair, poor, and so forth). Performance-specified property tests on samples or test specimens after exposure to a chemical, comparing the results to the case of nonexposed samples, allow a quantitative assessment that can be expressed as a percent retention or percent loss of property. This type of testing is covered by ASTM D543.

chill roll The chill roll is a cored roll, usually temperature controlled with circulating water, which cools the *web* after thermal processing and before final winding. For chill rolls used on cast film, the surface of the roll is highly polished. In extrusion coating, either a polished or matte surface may be used depending on the surface desired on the finished coating.

Chill roll extrusion refers to the process of forming extruding film when it is cooled while being drawn between two or more highly polished chill rolls cored for water cooling for exact temperature control.

chlorinated hydrocarbon, plastic, rubber Chlorinated hydrocarbons are organic compounds having hydrogen atoms and, more importantly, chlorine atoms in their chemical structure. Trichloroethylene, methyl chloroform, and methylene chloride are chlorinated hydrocarbons. Chlorinated hydrocarbons are generally excellent solvents for many uncured thermosetting resins and thermoplastics.

Chlorinated plastics are polymers that have many chlorine atoms in their molecular chain. Good flame resistance and chemical inertness usually characterize these materials. Examples of such materials are chlorinated polyethylene, chlorinated polyether, chlorinated polyvinyl chloride, and chlorofluorocarbons.

Chlorinated rubbers are nonflammable, odorless, and nontoxic derivatives of rubbers containing about 65 percent chlorine. The manufacture of chlorinated rubber has traditionally been carried out by adding chlorine gas to a solution of rubber in a chlorinated solvent. Newer methods of producing chlorinated rubber involve the direct chlorination of latex or passage of chlorine over thin sheets of rubber swollen with a solvent such as carbon tetrachloride.

Chlorinated rubber is a thermoplastic material notable for its high resistance to corrosive chemicals as well as to gasoline, air, moisture, and mineral oils. In chlorinated solvents, chlorinated rubber makes a useful vehicle for modified alkyd resins formulated for air drying or low-bake enamels, as well as paints and lacquers.

Plasticized, it produces a film highly impermeable to water and water vapor. Chlorinated rubber is chiefly used in the production of heat- and chemical-resistant paints, varnishes, and lacquers. Films, impregnating solutions, adhesives, and (with the addition of plasticizers) molding powders can also be made.

chlorinated polyether Chlorinated polyether resins belong to the family of polyethers. They are linear, crystalline thermoplastics. Their monomer, a chlorinated oxetane, is synthesized from pentaerythritol and, under carefully controlled conditions, involving the use of catalysts such as BF_3 or BF_3-etherate, is polymerized into a very high-molecular-weight polymer.

Chlorinated polyether is characterized by high chemical and thermal stability resulting from its crystallized structure. Chlorine constitutes approximately 46 percent of the resin's weight. Other properties are not outstanding, so that chlorinated polyether is primarily chosen for its chemical-resistant qualities. It possesses resistance to both organic and inorganic agents at temperature up to 121°C or higher.

These resins are injection molded for components in chemical processing equipment. Low-cost metal components such as pipe, valves, and pumps, provide improved chemical resistance when lined with chlorinated polyether. Continuous, pinhole-free coatings of chlorinated polyether can be applied via a number of coating techniques.

chlorinated polyethylene (CPE) Chlorinated linear polyethylene (CPE) is produced by a simple chemical substitution of chlorine on the linear polyethylene backbone. The chlorination can occur by directly exposing the polymer to gaseous chlorine either in solution or in finely divided form. The presence of ultraviolet light or another activator is necessary for practical reaction rates. Materials offered commercially are in the 30–45 percent chlorine range and include amorphous as well as semicrystalline products. The materials are softer, more elastomeric, and more soluble than the unmodified polymer. Harder versions can be obtained by increasing the chlorine content to 50 percent or higher.

Chlorinated polyethylene has inherent oxygen and ozone resistance because of the saturated nature of the polymer. It also shows exceptionally high tear strength and heat aging characteristics and excellent oil and chemical resistance. To reduce cost, the base polymer can be heavily extended with processing oils and inert filler.

The significant advantages of products produced from chlorinated polyethylene are their improved resistance to chemical extraction, plasticizer volatility, and weathering. Products made from chlorinated polyethylene do not fog at higher use temperatures and can be made completely flame retardant. They do, however, exhibit chemical instability similar to that of polyvinyl chloride (PVC). They may be used as primary compounding materials or as blending resins with PVC, high- and low-density polyethylene, and other polymers. They are cross-linkable by irradiation or chemical means.

Applications include film and sheeting via standard extrusion, calendering, and molding techniques. Extruded sheet supported by foam is used for automobile dashboards, upholstery, and door liners. Flexible film is used for nursery, agricultural, and weather protection. Chlorinated polyethylene resins are blended with PVC for extruded pipe and building materials.

chloroprene
See polychloroprene.

chlorosulfonated polyethylene (CSM) Chlorosulfonated polyethylene is a saturated chlorohydrocarbon and contains about 20–40 percent chlorine and 1–2 percent sulfur as sulfonyl chloride in addition to polyethylene. The sulfonyl chloride groups are the curing or cross-linking sites. CSM properties are largely based on initial polyethylene and percent chlorine. A free radical-based polyethylene with 28 percent chlorine and 1.24 percent sulfur has a dynamic shear modulus range from 1000 to 300,000 psi. When the chlorine content is increased more than 30–35 percent the stiffness increases.

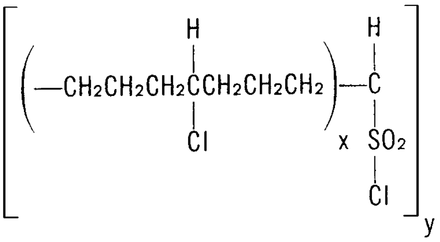

Figure C.3 General chemical structure of chlorosulfonated polyethylene (x is approximately 12 and y is approximately 17).

Hypalon (Du Pont) CSMs are specified by their chlorine and sulfur contents and their Mooney viscosity. CSM has an excellent combination of heat and oil resistance and oxygen and ozone resistance. CSM, like other polymers, is compounded to meet specific application requirements. Hypalon is used extensively for underhood wiring and fuel hoses because of its fuel and oil resistance.

chromatography—gas, liquid, paper, column, thin layer Chromatography is a physical method of separation in which the components to be separated are distributed between two phases. One of these phases constitutes a stationary bed of large surface area, and the other is a fluid or gas, which percolates through or along the stationary bed. This technique is used to identify constituents of a mixture qualitatively and quantitatively

See also gel permeation chromatography; high-pressure liquid chromatograph.

circuit boards
See printed circuit boards.

circumferential winding In filament winding, a circumferential winding is a winding with the filaments essentially perpendicular to the axis (90° or level winding). This type of winding would have the highest *hoop strength.*

clamping plate The clamping plate is a plate fitted to a mold and used to fasten the mold to a molding machine. *See* Fig. I.4.

clamping pressure Clamping pressure, as used in injection, compression, and transfer molding, is the pressure that is applied to the mold to keep it closed, in opposition to the fluid pressure of compressed molding material. In injection molding, clamping pressure varies from 3 to 10 ton/sq. in. to oppose the molding pressure. Compression and transfer molds use clamping pressures of 3–8 ton/sq. in.

In blow molding, the clamping pressure is the pressure exerted on the two mold halves by the locking mechanism of the blowing table. This pressure keeps the mold closed during formation of the container.

clarifying agent A clarifying agent is a reagent used in the production of high-clarity grades of polypropylene. An example is *Millard*, a proprietary compound from Milliken Chemical Co.

clay filler Clay fillers are used extensively in thermoset resins as a low-cost extender to reduce resin cost in the molded product. The mineral kaolinite is the source for clay filler called *kaolin*, a hydrous aluminosilicate mineral. Kaolin is used as a viscosity-modifying filler in liquid polyester for fiberglass molding. The increased viscosity tends to hold the glass fibers in the resin and eliminate show-through at the surface of the molded part. Very fine meshes of kaolin are used in thermoplastics.

Kaolin is the second most commonly used extender pigment in the plastics industry after calcium carbonate. It finds use in many polymers. The largest tonnage is used in wire and cable, polyester bulk molding compounds (SMC and BMC), and vinyl floor coverings.

Kaolin deposits are cored and analyzed before mining to determine quality. Mined clays are then either wet or dry processed by air floatation or water fractionation. Surface-modified clays can be made by treating standard, delaminated, and calcinated grades with surface modifiers. The treatment can be performed by either the supplier or the end user. These surface modifiers include silane, titanate, polyester, and metal hydroxide. The objective of these surface treatments is to increase filler loadings and/or improve physical properties such as melt viscosity, thermal stability, and modulus without loss of physical characteristics. Electrical applications represent the largest use of surface-modified kaolin in plastics.

Standard water-washed kaolins come in a variety of particle size distributions, ranging from 0.2 to 9.5 μm in median particle size. These wet-processed clays tend to have more uniform physical properties and are preferred for uniformity and specific properties such as increased loadings and improved molding characteristics. Water-washed clays can be used as rheological modifiers in conjunction with other extenders to optimize flow characteristics and reduce cost.

Delaminated kaolins differ from the standard water-washed grades in that they are thin platelets of varying widths, and they are devoid of stacks and ultrafines. Delaminated clays can be supplied in a variety of particle sizes and shapes. At comparable particle sizes or surface areas, delaminated clays result in about 30 percent higher tensile strengths and modulus than standard clays (in polyesters and styrene butadiene rubber formulations). Because of cleaner surfaces and different wetting characteristics, delaminated clays result in better color in polymer systems than standard kaolins.

Water-washed *calcined clays* vary in particle size and degree of calcinations. The primary use of calcinated clays is in wire and cable insulation. Use of small amounts of partially calcined clay in polyvinyl chloride (PVC) can double volume resistivity. A secondary use of calcined clays in PVC and other polymers is extending titanium dioxide (TiO_2). Calcined clay can replace up to 20 percent of the TiO_2 without loss of optical properties.

Major suppliers of kaolin clay include Akrochem Corp.; Englehard Corp.; Harwick Chemical Corp.; J. M. Huber Corp.; KMG Minerals, Inc.; NYCO Minerals Inc.; US Silica Co.; and Whittaker, Clark & Daniels.

cleaning Once machined, the plastic must be cleaned of any finishing lubricants and other contaminants before other secondary processes such as decorating or assembly can be considered. Simple cleaning of plastic parts is generally by solvent or alkaline cleaning. However, chemical treatments may be necessary to prepare the surface of the part for bonding, painting, or similar processes where another resin will have to wet its surface.

Solvent cleaning is generally the first (and often the only) surface preparation applied to plastic parts. Solvent cleaning removes organic release agents, such as silicone, that may coat the part during molding and any machine oil transferred to the part during finishing. Solvents such as methyl ethyl ketone, toluene, naphtha, acetone, trichloroethylene, and perchloroethylene are used for degreasing.

Selection of the solvent should be dependent on the plastic being cleaned. Certain solvents will aggressively attack certain polymeric surfaces, causing the surface to deform or exhibit stress crazing. Substrates can be wiped or sprayed with degreasing solvents, or they can be immersed in an agitated solution for about 5 min.

Vapor degreasing equipment using trichloroethylene vapor is very effective in eliminating mold release. This operation, however, is performed at a high temperature, thus requiring the substrate to be thermally stable.

Alkaline cleaning is effective for removing the water-dissolvable contaminants that may be difficult to remove with solvent wiping. Substrate immersion in an alkaline bath sometimes follows solvent degreasing. Parts are continuously agitated in a water solution maintained at 77–93°C and at an alkaline pH. As dirt, metal chips, and other contaminants are removed, more alkaline solution must be added to maintain the pH, and the bath must be replaced if contaminant levels become too high.

After alkaline cleaning, substrates are rinsed in water to remove all traces of the alkaline solution. The solution should not be allowed to dry on the part for cosmetic reasons or because it could result in a weak boundary layer in a painting or bonding operation. Some plastics are hygroscopic or absorb water, and a washing process, especially at elevated temperatures, could degrade the properties of the plastic. These plastics include nylons, ABS, polycarbonate, and thermoplastic polyesters.

The use of detergent-free *ultrasonic washing* may be the best method to clean small plastic parts. In this type of washer, clean water is placed in a tank that is subjected to ultrasonic (high frequency) vibrations. Thousands of small bubbles form from the ultrasonic agitation. These bubbles scrub the part's surface and clean it without the use of heavy detergents or solvents.

Often plastic parts will attract contaminants because of a static charge. Such static charging can also be a safety and a reliability concern. The charges can be large enough to be painful and result in bodily damage along a high-speed production line. Electrostatic charge can also cause circuit failure if near an integrated circuit. To render a plastic part less susceptible to static buildup, the plastic has to be made less of a dielectric insulator and more conductive. Three ways of doing this are by internal antistatic agents, by external antistatic agents, and by surface discharging. External antistatic agents are sprayed, wiped, or rubbed onto the plastic part to provide a short-term increase in surface conductivity. Water is the most common antistatic agent. (*See also* antistatic agents.)

Various surface treatment processes have been developed to ensure adhesion of adhesives, coatings, or print to polymeric surfaces. These treatments are both mechanical and chemical. They include abrasive cleaning, chemical etching, corona discharge, flame treating, plasma treatment, and laser pretreatment. (*See also* surface treatment.)

closed-cell cellular plastics Closed-cell cellular plastics are those plastics in which almost all of the cells are noninterconnecting. Closed-cell plastics are preferred over *open-cell plastics* for thermal- and sound-insulating properties.

See also cellular plastic; foamed plastic.

coated fabrics Coated fabrics may be defined as fabrics surfaced with a reasonably continuous film of oil, oil and resin, cellulose esters, rubber or synthetic rubber, vinyl, or other synthetic resins. Although some of the coating composition may penetrate the fabric, it is considered to be reinforced primarily on the surface.

There are four general types of synthetic coatings: (1) cellulose esters and ethyl cellulose; (2) vinyls and vinyl copolymers; (3) rubber and synthetic rubber; and (4) oil in resins. These are applied by one of four methods: (1) spreader or doctor knife (with cellulose nitrate); (2) calendering (with vinyls and rubbers); dipping (for oil in resin); and (4) rolling (for reversed coating and panel boards). Spraying is also used to a limited extent for special finishes.

coat hanger die The coat hanger die is one basic type of slot die for extrusion that is shaped internally like a coat hanger to gain better distribution across the full width of sheet extrusion.

coating cure Most of the organic coating resins are liquids, which cure or dry to form solid films. This mechanism will depend on the coating resins and the specific formulation prepared for the application. Coatings can be classified by their curing or drying mechanism as being-room temperature curing, sometimes called air drying; or heat curing, generally called baking or force drying, which uses elevated temperatures to accelerate air drying. Thermoplastic and thermosetting coating can be both air drying and baking.

Air-drying coatings will form films and cure at room or ambient temperature by mechanisms such as solvent evaporation, conversion, or coalescing. Baking coating will form films at room temperature but require elevated temperatures to cure. This is accomplished through either conversion or phase change.

Certain thermoplastic coating films will soften and flow to become smooth and glossy at elevated temperatures. This technique, called *reflow*, is used on acrylic lacquers by the automotive industry to eliminate buffing.

Certain films can be cured by bombardment with ultraviolet (UV) and electron beam radiation with little increase in surface temperature. Infrared radiation, on the other hand, increases the surface temperature of films and is therefore considered a baking process.

Vapor curing is essentially a crosslinking conversion method for two component coatings. The product is coated with one component of the coating in a conventional manner. It is then placed in an enclosure filled with the other component (the curing agent) in vapor form. It is in this enclosure that the reaction occurs.

coating process *See* specific types of coating such as curtain, dip, electrocoating, spray, powder, autodeposition, centrifugal, flow, and roll.

coating resin Because it is the polymer resin in the coating's formulation that determines performance properties, coatings are generally classified by their resin type. The most widely used resins for manufacturing modern coatings are acrylics, alkyds, epoxies, polyester, polyurethanes, and vinyls. They can be supplied in various forms including solvent-containing, high-solids, waterborne, and powder coatings.

The properties of various coating resins by polymer type are given in Appendix D. Tables C.4 and C.5 summarize the performance properties and available physical states of common coating resins.

Table C.4 Performance Properties of Common Coating Resins (Ref: lzzo, C.P., *Products Finishing Directory*, Gardner Publishing, Cincinnati, 1996)

Resin Type	Humidity Resistance	Corrosion Resistance	Exterior Durability	Chemical Resistance	Mar Resistance
Acrylic	E	E	E	G	E
Alkyd	F	F	P	G	G
Epoxy	E	E	G	E	E
Polyester	E	G	G	G	G
Polyurethane	E	G	E	G	E
Vinyl	E	G	G	C	G

Note: E = excellent, G = Good, F = Fair, P = Poor

Table C.5 Physical States of Common Coating Resins (Ref: lzzo, C.P., *Products Finishing Directory*, Gardner Publishing, Cincinnati, 1996)

Resin Type	Conv. Solvent	Waterborne	High Solids	Powder Coating	100% Solution Liquid	Two-component Liquid
Acrylic	x	x	x	x		
Alkyd	x	x	x			
Epoxy	x	x	x	x	x	x
Polyester	x		x	x	x	x
Polyurethane	x	x	x	x	x	x
Vinyl	x	x	x	x	x	

Acrylics are noted for color and gloss retention in outdoor exposure. They were used from the 1960s to the1980s in automotive finishes. Thermosetting acrylics are still used by the major appliance industry. Acrylics are used in electodeposition and have largely replaced alkyds. Their chemistry allows them to be used in radiation curing applications alone or as monomeric modifiers for other resins. Acrylic-modified polyurethane coatings have excellent exterior durability. (*See also* acrylic.)

Alkyd resin-based coatings offer the advantage of good durability at relatively low cost. They are used for finishing a wide variety of automotive and appliance products, either alone or modified with oils or other resins. They are not as durable in long-term outdoor exposure, and their color and gloss retention is inferior to that of acrylics. Alkyds are used for metal and wood finishing. Alkyd resins are used in fillers, sealers, and caulks for wood finishing because of their formulating flexibility. Alkyd-modified acrylic latex paints are excellent architectural finishes. (*See also* alkyd.)

Epoxy resins can be formulated with a wide range of properties. These medium- to high-priced resins are noted for adhesion, make excellent primers, and are used widely in the appliance and automotive industries. Their heat resistance permits them to be used for electrical insulation. When epoxy top coats are used outdoors they tend to chalk and discolor because of inherently poor ultraviolet light (UV) resistance. Two component epoxy coatings are used in extreme corrosion and chemical environments. Because of their adhesion, epoxy coatings are used extensively as primers over most substrates. (*See also* epoxy resin.)

Polyesters are used alone or modified with other resins to formulate coatings ranging from clear furniture finishes, replacing lacquers, to industrial finishes, replacing alkyds. These moderately priced finishes permit the same formulating flexibility as alkyds but are tougher and more weather resistant. Polyesters are also applied as powder coatings. Two component polyesters are well-known gel coats for glass-reinforced plastic bathtubs, boats, and automobiles. Polyester powder coatings are used as high-quality finishes in indoor and outdoor applications and as coil coatings. [*See also* polyester (thermosetting).]

Polyurethane resin-based coatings are extremely versatile. They are higher priced than alkyds but lower priced than epoxies. Polyurethane resins are available as oil modified, moisture curing, blocked, two component, and lacquers. Two-component polyurethanes can be formulated in a wide range of hardnesses. They can be abrasion resistant, flexible, resilient, tough, chemical resistant, and weather resistant. Urethane-modified acrylics have excellent outdoor weathering properties. Polyurethanes have become very important finishes in the transportation industry for aircraft, autos, railroads, trucks, and ships. (*See also* polyurethane.)

Polyvinyl chloride coatings are noted for their toughness, chemical resistance, and durability. They are available as solutions, dispersion, and lattices as well as powder coatings. Vinyls have been used in various applications including beverage can linings, automobile interiors, and office machine exteriors. They are also used as thick-film liquids and as powder coatings for electrical insulation. Due to their excellent chemical resistance, they are used as tank linings and as rack coatings in electroplating shops. (*See also* polyvinyl chloride.)

Other coatings resins that are used alone or as modifiers with other resins include aminos, cellulosics, chlorinated rubber, fluorocarbons, oleoresinous coating, phenolics, polyamides, polyolefins, polyimides, and silicones.

coating weight Coating weight is the weight of a coating per unit area. In the U.S, paper industry, usually coating weight is given as per ream, that is 500 sheets 24 in. × 36 in. (3000 sq. ft.) but sometimes 1000 sq. ft.

co-curing Co-curing is the act of curing a composite laminate and simultaneously bonding it to some other prepared surface. In filament winding, co-curing could refer to the curing together of an inner and outer tube of similar or dissimilar fiber resin combinations after each has been wound or wrapped separately.

coefficient of friction The coefficient of friction between two surfaces in contact is defined as the ratio of the frictional force to the force acting normally to the surfaces to maintain their contact. In the context of polymeric materials, two coefficients of friction are defined: the *static coefficient* and the *dynamic coefficient*.

The static coefficient of friction implies the force required to first move one substrate relative to the other, and the dynamic coefficient of friction refers to the force required to continue the movement. Methods of determining the coefficient of friction of some plastic materials are given in ASTM D1894 and ASTM D3028.

See also friction.

coefficient of thermal expansion The coefficient of thermal expansion (CTE) is the fractional change in length (sometimes volume if specified) of a material for a unit change in temperatures. Values for plastics range from 0.01 to 0.2 mil/in./°C. The value of the coefficient may not be the same when measured over different temperature ranges.

Methods of determining coefficient of thermal expansion include ASTM D696 (dilatometer method), ASTM E228 (dilatometer methods of plastics in the temperature range of −30°C to +30°C), and ASTM E831 (determination by thermomechanical analysis).

coextrusion Coextrusion is the process for extruding two or more materials in a single sheet or film. Two identical polymers may be laminated by coextrusion. In this process two different materials are extruded from two separate extruder barrels and then brought together in a complex die to achieve a laminate sheet or profile. Not many materials lend themselves to this process because temperature and chemical differences often preclude good bonding.
See also extrusion.

coextrusion blow molding Coextrusion blow molding is a process using a second, smaller extruder in combination with the main extruder to produce a parison that is a laminate consisting of a thick layer of body material and a thin layer of a barrier resin. A bonding agent is used to ensure adhesion between the two layers. In extruding the parison, the two melts are sent through a special coextrusion head that simultaneously applies the bonding agent between the two melts as they are extruded. Final blowing is done in a conventional manner.

Body materials that have been used include polypropylene, high density-polyethylene, or low-density polyethylene mixed with the bonding agent. The barrier material generally used is nylon, which may be either on the inside of the container or on the outside. Some of the advantages claimed for the coextrusion process are excellent aroma barrier, surface gloss, surface priming, scratch resistance (with the nylon on the outside), and chemical resistance and barrier to hydrocarbons (with the nylon on the inside).

See also blow molding.

cohesion Cohesion is the *intermolecular attractive forces* within a material that actually hold the molecules together. This is much different than adhesion, which is the state in which interfacial forces hold two surfaces together. Cohesion is the intermolecular forces within a substrate, and *adhesion* is the intermolecular forces between substrates.

These forces may consist of chemical bonds, valance forces, electrostatic forces, mechanical interlocking, polymeric diffusion, or a combination of these. However, the intermolecular forces acting in both adhesion and cohesion are primarily van der Waals forces.

cohesive failure Cohesive failure is failure within the main body of the material. Cohesive failure occurs primarily in the resin, adhesive, or substrate material and not at the interface between the adhesive and adherend or between the resin and the reinforcement particles. See Fig. A.4 for a schematic showing cohesive and adhesive failures.

See also adhesive failure; adhesion.

co-injection molding The co-injection molding process is a technique for the production of sandwich structures. It uses a low-pressure process and nonexpanding molds. In this process, two or three channel nozzles are used to inject two resins simultaneously. By injecting the two resins at very high rates, laminar flow is obtained and the core and skin resins remain separate. The result is a structure foam sandwich part with a solid skin, which has been produced at a rate comparable to regular injection molding.

Generally, two resins are used in the co-injection molding process. However, three resins may be used especially if the outer skin resin is not compatible with the inner foam core. In this respect the third resin is an intermediate layer for bridging the foam core and the skin.

See also injection molding; sandwich molding.

coin test The coin test is a simple and rather primitive nondestructive test used on laminates, composites, and adhesive-bonded structures to determine the presence of a void either within the laminate or bond line. In this test a coin is used to tap the sample in different spots to detect a change in sound or tone. A hollow sound would indicate the presence of a void or defect. It is a surprisingly accurate test in the hands of experienced personnel. Modern ultrasonic testing uses essentially the same principle.

See also ultrasonic testing; nondestructive testing.

cold drawing Cold drawing is a technique for using standard metalworking equipment and systems for forming thermoplastic sheet at room temperature. Acrylonitrile butadiene styrene (ABS) plastic is an example of a material that is well suited for cold drawing.

cold flow Cold flow is the continuing dimensional change that follows initial instantaneous deformation in a nonrigid material under static load. Cold flow is also known as *creep*.

See also creep.

cold molding Cold molding is a procedure in which a composition is shaped at room temperature and cured by subsequent baking. Also called *cold press molding*, this process is used where inexpensive plastic male and female molds can be used because of the lack of temperature and pressure and where limited runs are possible.

In the cold press molding process, resin and reinforcement are placed in the mold and it is then closed, developing a small amount of pressure (on the order of 50 psi). The resin and catalyst react to set the plastic. This results in an exothermic reaction. Cold press molding is a closed mold fill-in process that is limited to shapes that are not too complex. It is used with a long fiberglass-reinforced resin in the range of 15–25 percent glass content. It provides a modestly smooth surface that can be gel coated; however, considerable surface finishing may be necessary for an appearance surface without gel coating.

The minimum inside radius for cold press molded parts is 0.25 in. The range of wall thickness it can create is 0.080–0.500 in., with a normal wall thickness variation of ±0.20 in. A 100 percent wall thickness variation can be tolerated. For parts under 6 in. in depth, a 2° per side draft is required; beyond that depth, the draft should be 3–5°.

Cold pressing is a bonding operation in which an assembly is subjected to pressure without the application of heat.

cold runner molding Cold runner molding uses a mold in which the sprue and runner systems are insulated from the rest of the mold and the temperature is controlled to keep the plastic in the manifold fluid. This mold design eliminates scrap loss from sprues and runners.

cold slug The cold slug is the first material to enter an injection mold. It is so called because in passing though the sprue orifice, it is cooled below the effective molding temperature. The cold slug well is the space provided directly opposite the sprue opening in an injection mold to trap the cold slug.

cold stretch Cold stretch is the pulling operation, usually performed on extruded filaments, to improve tensile properties. It works by increasing the degree of orientation of the polymer molecules in the specimen.

colophony Colophony is the resinous, nonvolatile residue remaining after distillation of turpentine from oleoresin (the fresh secretion of pine and fir trees). The residue is a mixture of resin acids and resin acid esters, containing a high proportion of abietic acid. Colophony is often used as a synonym for *rosin*.

See also rosin.

color An important aspect of the optical properties of polymeric materials is that of color. Polymeric materials are often colored in the bulk through the use of appropriate colorants (pigments and dyes). The subject of color is especially important in the plastics industry for two reasons: (1) to be able to formulate a color of a defined and predetermined characteristic and (2) to measure differences in color that may occur because of processing, aging, etc. (i.e., *discoloration*).

See color measurement and control for a discussion on applying color quality standards (color evaluation, comparison, matching, and specification). However, a case of special interest is assoicated with the tendency for many initial colorless or white, transparent, or translucent polymers to develop undesirable yellowish color, with aging in particular. A standard method (ASTM D1925), based on the use of a recording spectrophotometer for transmittance and reflectance measurement, permits the determination of a *yellowness index (YI).*

See also optical properties.

colorant Colorants are added to plastic formulations to produce color in the polymeric part. They are separated into pigments and dyes. Pigments are insoluble in the polymer, whereas dyes are soluble in the polymer. The particular color desired and the type of polymer will affect the selection of the colorants.

Colorants come in several forms including liquids and dry concentrates. Color concentrates are typically used at a level of 3–4 percent. They are available in several forms including pellet, dice, chip, granular, or strand. The selection of the proper colorant form involves many factors: volume requirements, handling provisions, metering equipment, and labor and inventorying costs when comparing overall costs.

See also dyes; pigments

color measurement and control Instruments that measure and control color with a high degree of accuracy have been widely used in the industry for many years. They combine spectrophotometer and computer technology to do such jobs as quality control, color matching, initial formulation and batch corrections, shade sorting, inventory control and on-line monitoring.

The colorimeter and more advanced spectrophotometer evaluate the magnitude and direction of color difference for a given product by supplying numerical data for comparison with predetermined tolerances.

The *colorimeter* uses optical filters that determine the tri-stimulus values of the sample. Although these values adequately describe color, the instrument is limited to measurements under one illuminant and hence cannot detect color changes under different illuminants. Accuracy depends on the precise control of the spectral characteristics of the light source, filters, and photodetector.

The *spectrophotometer*, in comparison, describes color by measuring reflectance at several wavelengths and provides more accurate and reproductive measurement including the effect of different illuminants. There have been continual advances in computerized color quality control systems that use the spectrophotometer and more powerful and versatile software.

The principles and standard procedures used in the determination of color can be found in ASTM E308. Equipment is commercially available for measuring optical properties of polymers for these purposes. Major suppliers include Gardner (gloss meter for specular gloss, haze meter for haze and luminous transmittance, and clarity meter for specular transmission) and Hunter Lab (spectrocolorimeter).

combustion Combustion is the exothermic reaction of a substance with an oxidizing agent typically proceeding at a rate fast enough to manifest some or all of the following: flame, glowing, and/or evolution of smoke. Two ASTM publications provide extensive lists of combustion test methods: ASTM D3814 and a book on fire testing.

compatibilizer A compatibilizer is a mixing aid additive used in the production of a polymer alloy. It is functionally similar to a wetting agent in aqueous systems. Its presence promotes interfacial adhesion and, hence, intimate intermixing in the blending of polymers that are not otherwise compatible.

The identities of compatibilizers used in the production of commercial polymer alloys are generally considered proprietary. However, some are known to be block copolymers incorporating groups that are compatible with each of the components of the alloy.

compliance *Tensile compliance* is the reciprocal of Young's modulus. *Shear compliance* is the reciprocal of shear modulus. The terms are also used in the evaluation of stiffness and deflection.

composite A composite is a homogeneous material created by the synthetic assembly of two or more materials (a selected filler or reinforcing element and compatible matrix binder) to obtain specific characteristics and properties. Modern structural composites, frequently referred to as *advanced composites*, are a blend of two or more components, one of which is made up of long fibers and the other, for polymeric composites, a resinous binder or matrix that holds the fibers in place.

The fibers are strong and stiff relative to the matrix and are generally *orthotropic* (having different properties in two different directions). The fiber for advanced structural composites is long, with length-to-diameter ratios of over 100. The fiber's strength and stiffness are much greater, perhaps several times more than the matrix material. When the fiber and the matrix are joined to form a composite, they both retain their individual identities and both directly influence the composite's final properties. The resulting composite is composed of layers (laminae) of the fibers and matrix stacked in one or more directions to achieve the desired properties.

An advanced composite laminate can be tailored so that the directional dependence of strength and stiffness matches that of the loading environment. To do this, layers of unidirectional materials are oriented to satisfy the loading requirements. This allows for almost infinite variations in properties to cover individual needs.

The common commercially available fibers used in composites are fiberglass, graphite (carbon), aramid, polyethylene, boron, silicon carbide, and other ceramics such as silicon nitride, alumina, and alumina silica. Many matrix choices are available, both thermosetting and thermoplastic. Each type has an impact on the processing technique, physical properties, and environmental resistance of the finished composite. The most common resin matrices include polyester, vinyl esters, epoxy, bismaleimides, polyimides, cyanate ester, and triazine.

Polyester matrices have had the longest period of use, with application in many large structural applications. They will cure at room temperature with a catalyst (organic peroxide) that produces an exothermic reaction. The resultant polymer is nonpolar and very water resistant, making it an excellent choice for marine applications. [*See also* polyester (thermosetting).]

Epoxy resins are the most widely used matrices for advanced composites even though they are more costly than polyesters and do not have the high temperature capability of the bismaleimides or polyimide. They have excellent adhesion to fibers and to other resins. No by-products are formed during cure, and they have low shrinkage. Epoxy resins have good solvent and chemical resistance and good electrical properties. Physical properties can be varied over a very large range. (*See also* epoxy resin.)

Bismaleimides have found their niche in the high-temperature aircraft applications, where temperature requirements are in the 177°C range. Polyimides are the highest-temperature polymer in the general advanced composites area, with a long-term upper temperature limit of 232–326°C. (*See also* bismaleimides.)

Cyanate ester resins have shown superior dielectric properties and much lower moisture absorption than other structural resins for composites. *Phenolic triazine*

(PT) resins possess superior elevated-temperature properties, along with excellent properties at cryogenic temperatures. They are often used in filament winding or transfer molding applications. (*See also* cyanate ester).

compounding Compounding is the process of selecting and combining various ingredients to produce a plastic of desired properties. It is the combining of a base plastic resin with colors, modifiers, additives, reinforcements, filler, or other polymers to make the base resin perform better, cost less, process more easily, or look more attractive or to otherwise improve its characteristics.

The two major factors in compounding thermoplastics are (1) the selection and quantities of colorant, plasticizers, fillers, stabilizers, and lubricants necessary to impart the desired physical and chemical properties; and (2) the mechanical means of incorporating them in the base plastic. There are many mechanical methods for blending the various ingredients into a homogeneous mass. Broadly speaking, they all fall into one of three categories: (1) those that depend on solvents; (2) those that use heat and pressure to fuse the ingredients; and (3) those that rely on mechanical dry mixing in combination with atomization of the liquid ingredients.

The compounding of thermosetting materials involves processing thermosetting resins with fillers, hardeners, lubricants and color agents so that the molded products will have the desired physical properties. In general, the amount of filler used varies between 30 and 70 percent. Thermosetting molding materials are compounded by either wet or dry processes.

The segments of the plastics industry that perform most of the compounding today generally fall into three separate categories: resin suppliers, independent compounders, and processor/fabricators. *Independent compounders* are either *proprietary compounders* or *custom compounders*. Proprietary compounders compound and sell their own special formulation. Custom compounders do compounding for someone else. They may supply processors or fabricators with compounds not available "off the shelf" from resin suppliers or proprietary compounders. Or they may supply compounding for resin suppliers on a toll basis or under a fee arrangement; in these cases they are referred to as *toll compounders*.

compression molding Compression molding is one of the oldest methods of polymer processing. Compression molding is a technique of thermoset molding in which the molding compound (generally preheated) is placed in the open mold cavity, the mold is closed, and heat and pressure (in the form of a downward-moving ram) are applied until the material has cured (see Fig C.4).

The necessary pressure and temperature vary considerably depending on the thermal and rheological properties of the polymer. For a typical compression molding thermoset material, they may be between 120 and 200°C and 1000 and 3000 psi. A slight excess of material is usually placed in the mold to ensure its being completely filled. The rest of the polymer is squeezed out between the mating surfaces of the mold in a thin, easily removed film known as *flash*.

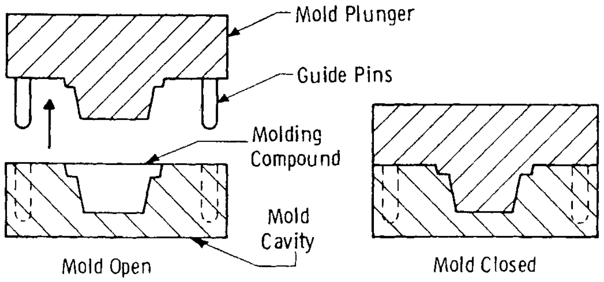

Figure C.4 Simplified illustration of the compression molding process. (Ref: Meier, J.F., "Fundamentals of Plastics and Elastomers", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Compression molding has a long history of processing wet materials such as unsaturated polyesters in combination with reinforcing materials such as fiberglass. Newer wet materials like bulk (BMC), sheet (SMC), and thick (TMC) molding compounds allow faster processing and many processing options. The matrix resins are usually polyesters, but recently resol phenolics, vinyl esters, hybrid resin systems, and epoxies have been introduced. Compression molding is also being used more often with various *prepreg* materials for structural composite applications. Cost reduction from labor-intensive processes is the primary consideration.

A variation of compression molding suitable for some thermosetting materials is *cold molding* or *preforming*, in which the polymer mix is formed into shape by the application of pressure alone. It is then baked in an oven to give the cross-linked product. Another variation is *transfer molding*, in which the thermosetting polymer is heated hot enough to flow but not to cross-link in the premolding chamber and then is transferred to a hot mold, where cross-linking takes place at a higher temperature and under pressure.

The compression mold is used in the various types of compression molding. It is a mold that is open when the material is introduced and that shapes the material by head and by pressure on closing. A compression mold is best for molding thermosetting materials into parts of large areas or deep draw such as cabinets, business machine housings, lighting reflectors, and telephone bases. More cavities can be operated with a given tonnage press because less pressure is required on the material. A standard material requires only 2–3 tons/sq. in. for compression molding as compared to 4–5 tons sq. in. for transfer molding. Some disadvantages of compression molds are (1) the flash varies from part to part because of variations in load and closing of the press, (2) the thickness of the part cannot be as closely controlled as in some other types of molds, and (3) the part requires longer cure in heavy sections.

Compression molding presses are generally classified according to method of operation (i.e., hand, manual, semiautomatic, and fully automatic). They may be classified also according to their source of power (i.e., mechanical, hydraulic, and combination). Sometimes they are classified by type of construction: single opening, multiple platen, tilt head, angle, inverted ram, and double ram.

Compression presses may be configured to use an upward (*upacting*)- or downward (*downacting*)-moving platen depending on size and application. Larger machines are usually downacting. Downacting machines are very common in SMC, BMC, and thermoplastic stamping in all sizes. Automated compression molding processes often use downacting machines because the fixed height of the lower platen facilitates material loading, part removal, and radio frequency preheating and eases use of vacuum chambers around the mold.

The process is generally used for high-volume production because the cost of a modern semiautomatic press of modest capacity (50 to 70-ton clamping force) may be as much as $100,000 and a moderately sophisticated self contained multicavity mold may cost $50,000. Typical applications include melamine dinnerware; toaster legs and pot handles; and electrical outlets, wall plates, and switches.

Although compression molding is used principally with thermosetting compounds, the process is occasionally used with thermoplastic materials, often thermoplastic composites. If a thermoplastic material is being molded, the mold is cooled, the pressure is released, and the molded article is removed. Most recently, compression molding has seen major growth as the process of choice in high-strength reinforced thermoplastics. This trend is known in Europe as *GMT* and in the United States, as *thermoplastic stamping*.

Molding thermoplastics requires mold cooling rather than mold heating. The material is put into the cavity while the mold is hot enough to melt the charge, enabling the melt to flow adequately to fill the cavity. Cooling water is then circulated through the mold cooling channels to cool the plastic below its melt temperature. Thermoplastic toilet sets are an example of this process. A thick cross-section can be molded in cycle times of 4–5 min.

Major suppliers of compression molding machines include Cannon USA Inc.; Gluco, Inc.; Johnson Machinery Co., Inc.; Hull Corp.; Modern Hydraulic Corp.; Savage Engineering Inc.; Timberline Machinery Inc.; and Wabash MPI.

compression ratio The compression ratio, as related to an *extrusion screw*, is the ratio of volume available in the first flight at the hopper to the last flight at the end of the screw. Compression ratios available in current commercial equipment are in the range of 1.5–4.5 to 1, with the general-purpose screw usually having a compression ratio of 2.5–3.0 to 1.

Generally, screws with a high compression ratio should be operated at slower screw speeds (e.g., 10–50 rpm), whereas screws having a compression ratio of less than 3:1 can be operated at higher screw speeds (50–150 rpm).

compression set Compression set is generally a property measured for elastomers. It is the permanent distortion that remains after the rubber has been held at either constant strain or stress and in compression for a given time. Constant strain is most generally used and is reported as a percentage of the permanent creep divided by the amount of original strain. In elastomer testing, a strain of 25 percent is most common.

compressive strength The compressive strength is the crushing load at the failure of a specimen divided by the original sectional area of the specimen. Compressive strength is expressed in pounds per square inch of the original cross-section. Except for foams, plastic products rarely fail from compression alone. Consequently, the compressive strength is of limited value.

For compressive strength determination, ASTM D695 and D649 use a molded or machined specimen for a specified slenderness ratio. The specimen is compressed in a suitable test machine at a specified loading rate, generally 0.05 in./min until failure occurs. A wide range of specimen sizes is permitted for this test.

condensation polymer Condensation polymers are those formed by a condensation reaction such as alkyd, phenol formaldehyde and phenol resins. In condensation polymers the molecular formula of the repeat unit of the polymer lacks certain atoms present in the monomer from which it is formed.

These polymers are formed by a condensation reaction. For example, a phenolic is formed by typical condensation reactions between bifunctional monomers with the eliminated molecule of water. *Addition polymers* are those in which this loss of a small molecule does not take place.

condensation polymerization Condensation polymerization is a chemical reaction in which two or more molecules combine, with the separation of water or other simple substance. This reaction is called a *condensation reaction*.

conditioning Conditioning is the introduction of a material to a stipulated treatment so that it will respond in a uniform way to subsequent testing or processing. The term is frequently used to refer to the treatment given to specimens before testing. Usually the temperature, relative humidity, and conditioning time period are specified.

conductive filler and reinforcement The most common type of *conductive plastic* is one that uses *carbon black* to decrease the volume resistivity. This is widely used for parts that must bleed off static charges, as in applications in which there is danger of a spark-generated explosion and in wire and cable shielding. Plastic structures are sometimes also made conductive with *carbon mat*, for instance, so the part can be electrostatically painted without special priming.

All carbon blacks are semiconductive, but certain grades are preferred where composite conductivity is desired. The degree of effectiveness is determined by four factors: particle size, structure (shape), porosity, and surface chemistry.

Conductivity in carbon black filled composites increases as the number of contacts (or near contacts) between aggregates increase. Small size and high structure (porosity) grades can offer equivalent resistivity at one-half the loading of conventional blacks by greatly increasing surface area. The best carbon blacks for conductive fillers are the furnace type, which have very low levels of chemisorbed oxygen groups on the surface. Increasing levels of carbon black loading show little effect on composite resistivity until the level rises above 15 percent. At levels above

40 percent, resistivities of less than 10 ohm-cm have been measured. (*See also* carbon black.)

Very high levels of conductivity can be realized in some highly metal-filled polymeric systems. The highest levels can be obtained with *silver*, *bronze*, or *stainless steel strand* fillers if cost is not an objective. However, these composites are expensive and not suitable for use in thin-walled, complex geometries. The high level of conductivity needed in many applications requires sufficient filler to establish conductive pathways in the plastic. The loading levels required by powdered or spherical fillers are too high to accomplish this. A high-aspect- ratio approach is needed.

More recently, several novel conductive plastics have been introduced to provide shielding against electromagnetic interference (EMI). Filler and reinforcing materials contending for these applications include carbon fibers; metallized microspheres; aluminum fibers, flakes, and ribbon; and aluminum-metallized glass fibers.

Carbon fibers, 1/2 in. in length, are being evaluated widely in injection molding applications, and a few commercial compounds for EMI applications (phenolics, nylon) have been introduced commercially. Carbon fibers are presently being used for electrostatic discharge and electrostatic painting applications.

Carbon fibers electroplated with electroless nickel or other metals have also been developed for EMI applications. The plating increases the conductivity of the fibers about 30 times and adds magnetic properties. These metallized carbon fibers are generally in the size range of 2–8 μm. (*See also* carbon fiber.)

Metallized glass fibers are less expensive than carbon fibers and can produce stronger composites than carbon black. Metallized glass fibers are more effective in shielding compression-molded parts. Injection molding of thermoplastics or BMC containing metallized glass fiber poses several problems such as breakage of the fibers, difficulty in processing high loadings, and fiber orientation. However, 2–5 percent loadings of fibers are sufficient in injection-molded parts for static bleed-off and probably for most electrostatic painting. *Silver-coated glass fibers* are available for EMI/RFI shielding applications.

Silver-coated solid and hollow spheres find wide acceptance in applications in which EMI/RFI and ESD control is required. Silver-coated spheres can provide high compressive strength and excellent processing durability for applications requiring conductive thermoplastics. Other uses include conductive thermosets, adhesives, coatings, caulks, and composites.

Pure aluminum conductive materials are available in several forms for compounding including flakes and fibers. These materials are much less brittle than metallized glass fibers. They give higher conductivity vs. volume loading in comparison to carbon blacks and carbon fibers and show the typical drastic reduction in resistivity at a certain loading point. The flake form is recommended for injection molding; either flake or fiber is effective in compression molding.

Finely drawn *stainless steel wire fibers* have also been used for conductive filler. They are effective in low concentrations because of their high conductivity as well as their resilience in injection molding processes. They can provide EMI shielding at loadings as low as 1 percent and thus do not adversely affect physical properties, surface quality, colorability, or paintability. Woven fabric and nonwoven mat forms have recently been introduced as well.

conformal coating A conformal coating is an insulating coating applied to a printed circuit board wiring assembly that covers all of the components and provides protection against moisture, dust, and dirt.

consistency Consistency is the resistance of a material to flow or permanent deformation when shearing stresses are applied to it. The term is generally used with materials whose deformations are not proportional to applied stresses. *Viscosity* is generally considered to be a similar internal friction that results in flow in proportion to the stress applied.

See also viscosity.

contact cement or adhesive Contact cements or adhesives are resins that thicken or cross-link on heating and, when used for bonding laminates, require little or no pressure. Phenolic or nitrile phenolic adhesives are good examples of *contact adhesives*.

Contact adhesives are applied to both substrates by spray or roll coating. Usually the solvent is allowed to evaporate under ambient conditions, but sometimes heat is applied to accelerate drying. After some portion of the solvent evaporates, the adherends are joined and the adhesive rapidly bonds or knits itself with the application of only contact pressure. There is a window of time in which there is just enough tack exhibited by the adhesive to bond.

Contact adhesives have relatively high shear and peel strengths. Strength and durability approach those of structural thermosetting adhesives. A typical contact adhesive application is the bonding of decorative surface materials to wood for kitchen countertops. Parts must be correctly positioned before bonding because repositioning is difficult or impossible after the bond is made.

contact pressure Contact pressure is the application of little or no pressure on a lamination or bonded assembly. Generally, contact pressure is just enough pressure to ensure that the plies of the laminate are well mated together and that air is eliminated within the structure.

continuous chain injection molding Continuous chain injection molding is a proprietary process patented by the American Can Company. Considerably increased production rates (up to 30,000 parts/h) are claimed for this process.

In this technique, a rotary mold is used and parts are ejected as a continuous chain, which is later broken up or fed to machines for further processing. (See Fig. C.5.) The entire process can be completely automated for small precision parts and, with the use of hot runner molds, is said to result in considerable savings over conventional methods.

See also injection molding.

Figure C.5 Continuous chain injection molding. (Ref: Schwartz, S.S. and Goodman, S.H., *Plastics Materials and Processes*, van Nostrand Reinhold Company, New York, 1982, p. 558)

continuous laminate Continuous or *contact pressure laminates*, as distinguished from *high-pressure laminates*, can be made continuously in any length but only in flat sheets. Gauges generally range from 5 mil to about 100 mil. The largest application of continuous low-pressure laminates is in decorative covering and tabletop applications.

As an example of the method of production of these materials, the decorative grade will be described. Paper in continuous lengths is thoroughly impregnated with liquid resin. Heat is then applied to the assembly while it is being carried between layers of dry paper or plastic film. These cover layers are subsequently stripped from the solidified paper and resin laminate. Only moderate heat and pressure are used.

continuous tube process The continuous tube process is a blow molding process that uses a continuous extrusion of tubing to feed into the blow molds as they clamp in sequence.

continuous-use temperature The continuous-use temperature of a plastic is the highest temperature at which that plastic can be reliably used with minimal changes in mechanical and/or electrical properties. These tests are based on short-term laboratory testing. Sometimes continuous-use temperatures can be very unreliable because of modes of degradation or stress that occurs in service that is not represented in the laboratory.

See also thermally stable plastics.

convergent die A convergent die is a die in which the internal channels leading to the orifice are converging (only applicable to dies for hollow bodies).

cooling channel Cooling channels are channels or passageways located within the body of a mold through which a cooling medium can be circulated to control temperature of the mold surface. Cooling channels may also be used for heating a mold by circulating steam, hot oil, or other heated fluid through the channels, as in the molding of thermosetting and some thermoplastic materials.

cooling fixtures A cooling fixture (or shrink fixture) is a block of metal or wood having the shape of a molded piece that is used to maintain the proper shape or dimensional accuracy of a part after it is removed from the mold. Generally, the part stays on the cooling fixture until it is cool enough to retain its shape without further appreciable distortion.

copolyester elastomer Thermoplastic copolyester elastomers are segmented block copolymers with a polyester hard crystalline segment and a flexible, soft amorphous segment with a very low glass transition temperature (T_g). These materials are known as COPs. The copolymers are also called thermoplastic etherester elastomers (TEEEs).

COPs differ from simple polyester thermoplastics, which are typically hard crystalline polymers of organic dibasic acids and diols. COPs have an excellent combination of properties and are accordingly priced higher than thermoplastic elastic olefins (TEOs) or thermoplastic vulcanizates (TPVs).

The morphology of COPs is that shown in Fig. C.6. These materials perform as TPEs if structures A and B are chosen to give rubbery properties to the copolymer over a useful temperature range. The glass transition point of the soft segment defines T_g for the COP and should be low enough to prevent brittleness at the lowest temperature to which the working material will be exposed. The structure of this segment provides the flexibility and mobility needed for elastomeric performance. The melting point of the hard segment should be high enough to allow the material to maintain a fabricated shape at the highest temperature experienced, but low enough to allow processing on standard thermoplastics equipment.

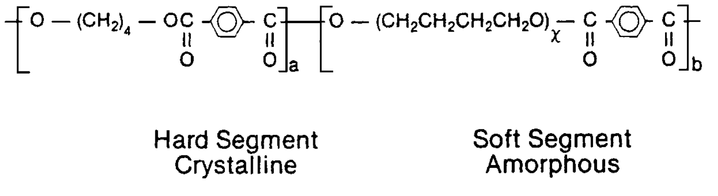

Figure C.6 Structure of commercial copolyester thermoplastic elastomer: a = 16, x = 10 to 50, and b = 16 to 40. (Ref: Rader, C.P., "Thermoplastic Elastomers", *Handbook of Plastics, Elastomers and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

The copolyester elastomer's mechanical properties are between those of rigid thermoplastics and thermosetting hard rubber. Copolymer properties are largely determined by the soft-to-hard segment ratio; however, as with any commercial resins, final properties are determined by compound formulations. These polymers combine flexural fatigue strength, low-temperature flexibility, good apparent modulus (creep resistance) and heat resistance, resistance to hydrolysis, and good chemical resistance to nonpolar solvents at elevated temperatures. The impact resistance of the COPs is excellent. They are also resilient, with low hysteresis and heat buildup for uses requiring rapid, repeated flexing.

COPs have a useful service temperature range from −40° to 150°C. The lower limit is set by the soft segment T_g and the upper limit by oxidative attack of the polymer chains. Retention of physical properties measured at elevated temperature is quite good. They also have very good resistance to a wide range of fluids: aqueous salt solutions, polar organics, and hydrocarbons. The ester linkages in the polymer backbone, however, render them susceptible to hydrolysis in both acids and bases.

Copolyester elastomers can be processed by conventional thermoplastic melt processing methods such as injection molding and extrusion. They require no vulcanization. These polymers can be processed successfully with low-shear processes such as laminating, rotational molding, and casting.

Typical products are automotive exterior trim, fascia components, spoilers, window track tapes, boots, bellows, underhood wire covering, connectors, hoses and belts, appliance seals, power tool components, ski boots, and camping equipment.

COPs have a material cost higher than that of most thermoset rubber compounds and 50–150 percent higher than that of the TPVs and TEOs. This higher cost can be more than offset by the high strength and modulus of the COP, which permits thinner parts and markedly lower part weights. The efficiency of the thermoplastic's processing can combine with the lower part weight to give pronounced cost savings relative to a thermoset rubber. Thus COPs have been quite successful in replacing thermoset rubber in the fabrication of numerous articles.

Major suppliers and copolymer materials include Du Pont (*Hytrel*), Ticona (*Riteflex*), and DSM (*Arnitel*).

copolymer A copolymer is a polymer whose molecules are made up of more than one type of *monomer*. A copolymer is not a mixture of polymers, but a chemical compound that may have entirely different properties from those of either of the pure polymers. The copolymer of styrene and butadiene (*styrene butadiene*), for example, is different from both polystyrene and polybutadiene; it is a synthetic rubber whose hardness and wear qualities depend on the relative proportion of styrene and butadiene in it.

Because three, four, or even more monomers can be copolymerized, it is possible to synthesize a great many polymers from a few monomeric materials. By varying the kind and relative amounts of the monomers, materials with a wide range of mechanical and chemical properties can be produced. Many of the plastics in use today are copolymers.

Copolymerization is a chemical reaction in which two or more different monomers polymerize together to yield a new compound, called a copolymer.

copper-clad laminate Copper-clad laminates are laminates (generally thermoset) with copper bonded to one or both sides for use as printed wiring boards. More than 90 percent of all copper-clad laminates used in the industry are NEMA-grade laminates, and more than 80 percent are grade FR-4 (a grade of glass fabric reinforced with flame-retardant epoxy). The NEMA grades used as copper-clad laminates are XXXP, XXXPC, FR-1, FR-2, FR-3, FR-4, FR-5, G-10, G-11, CEM-1, and CEM-2. Table C.6 gives typical properties of copper-clad laminates.

Common laminating resins used are phenolic and epoxy, although cyanate esters, polyimides, and other resins are used in specialty applications. The copper foil used is 99.5 percent pure and may contain some silver. Generally, electrodeposited foil is used rather than rolled copper, and the foil is usually treated to improve the adhesion of the laminating resin to the foil surface.

See also NEMA laminates; printed circuit.

core In materials construction the core is the central part of a sandwich construction (can be honeycomb material, foamed plastic, or solid sheet) to which the faces of the sandwich are attached. For example, the core can be the central member of a plywood assembly.

In mold design, the core is (1) a channel in a mold for circulation of heat transfer media or (2) a part of a complex mold that molds undercut parts. In the latter case the cores are usually withdrawn to one side before the main sections of the mold open (also called a *core pin*). Cores are usually withdrawn before the main sections of the mold are opened. A *core drill* is a device for making cooling channels in the mold.

corona Corona, an undesirable condition that occurs at sufficiently high voltage levels, is ionization of air in the high-voltage assembly. This ionized air, called a plasma, greatly deteriorates plastics in the assembly by erosion or decomposition of the base polymer. Corona often originates within voids or at sharp edges of an insulator's geometry.

A current passing through a conductor induces a surrounding electrostatic field. When voids exist in the insulation near the conductor, the high-voltage electrostatic field may ionize and rapidly accelerate some of the air molecules in the void. These ions can then collide with other molecules ionizing them, thereby "eating" a hole in the insulation. This process is called *partial discharge* and is manifested by corona.

See also high-voltage resistant plastic; dielectric strength

corona resistance Corona resistance is the resistance of insulating materials, especially plastics, to failure under a high-voltage state known as partial discharge. Failure can be erosion of the plastic material, decomposition of the polymer, thermal degradation, or a combination of these three failure mechanisms. Corona resistance

Table C.6 Typical properties of copper cold laminate. (Ref: Sanyson, R.N., “Laminate and Reinforced Plastic Materials and Processes,” *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper (Ed.), McGraw-Hill, New York, 1996)

Property[*]	Type of Laminate						
	Paper, Phenolic	Paper, Fire-retardant Phenolic	Paper, Epoxy	Glass Fabric, Epoxy	Glass Fabric, Fire-retardant Epoxy	Glass Fabric-paper, Epoxy	Glass Fabric-glass mat, Epoxy
Flexural strength, lb/in^2	12,000	12,500	14,000	55,000	65,000	55,000	62,000
Peel strength, lb/in (1 oz cu)	6	6	8	10	10	10	10
Water absorption, % 24 hr	0.75	0.75	0.65	0.10	0.10	0.17	0.10
Volume resistivity, Ω·cm	10^{11}	10^{11}	10^{12}	10^{14}	10^{14}	10^{13}	10^{14}
Surface resistivity, Ω	10^{6}	10^{6}	10^{7}	10^{12}	10^{12}	10^{12}	10^{12}
Dielectric constant	4.6	4.8	4.6	5.2	5.5	4.5	4.8
Dissipation factor	0.040	0.038	0.035	0.020	0.022	0.025	0.021
Electric strength, kV parallel to lam.	20	10	40	50	50	60	60
Arc resistance, s	20	20	50	120	120	90	115
Flammability	Burns	V-1	V-1	Burns	V-0	V-0	V-0

[*] Based on 0.059-in laminates tested by IPC-TM-650.

is especially poor if there are gas pockets or voids within the polymer that can ionize in the presence of a high electric field.

corona surface preparation Corona discharge treatment is a popular method for dry surface preparation of polymer films. The purpose of the treatment is to make the polymer surface more receptive to inks or coatings; however, it has also been used effectively as a pretreatment for adhesives. The treatment is believed to oxidize the surface of the polymer so that the ink, coating, or adhesive can permeate the roughness of the thin oxidized layer. The most common methods of treating surfaces by oxidizing are corona treatment and flame treatment. For film, corona treatment is the preferred method of the two.

The schematic in Fig. C.7 illustrates a basic arrangement for treating film or coated paper with corona treating equipment. The electric equipment consists basically of a high-frequency generator (10–20 kHz), a stationary electrode electrically connected to the generator, and a dielectrically covered treater roll that serves as the grounded electrode. The material to be treated is carried over this roller for continuous processing. A suitable voltage, typically 20 kV, is developed between the electrodes and produces a spark or corona discharge by ionizing the air in the gap between the electrodes. These ionized particles in the air gap bombard and penetrate into the molecular structure of the substrate. This electrical discharge causes oxidation and polar group formation in the surface molecules, which in turn raises the surface energy of the treated material.

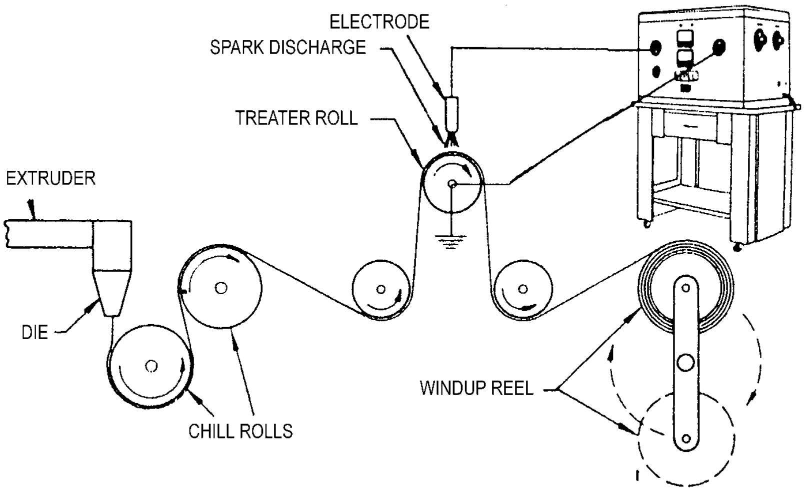

Figure C.7 Basic arrangement for corona surface treatment of plastic film. (Courtesy Lepel High Frequency Laboratories)

Corona treating equipment is inexpensive, clean, and easily adapted to in-line operations. Parameters that positively affect the efficiency of the treating process include power input and temperature, whereas line speed and humidity negatively affect efficiency. Stored film is generally considered more difficult to treat than film that is just processed (e.g., exiting an extruder). The opportunity for low-molecular-weight additives and contaminants to migrate to the surface is greater for stored film. These surface contaminants degrade the treating efficiency of the corona.

Corona treatment is mainly suitable for films, although thin containers have been treated by nesting them on a shaped electrode and rotating the part adjacent to a high-voltage electrode. Approximately 25 mil is the maximum thickness of sheet that can be treated by the corona discharge method. However, high-frequency arc treatment has been applied to automotive trim parts of up to 1/8 in. thick. Significant bond strength improvements were noted on talc-filled polypropylene parts bonded with hot melt adhesives.

Corona discharge treatments have commonly been used to treat substrates such as films or polymer coated paper for printing. The polymers commonly treated in this way are polyethylene, polypropylene, and polyethylene terephthalate or Mylar®. Fluorocarbon film surfaces have also been treated with corona in environments other than air. Metal foil surfaces have been treated with corona, but the effect is only moderate, probably because of removal of organic contaminants by the oxidizing exposure.

corrosivity index The corrosivity index of a plastic is the mean specific conductance of an aqueous extract of a plastic or filler determined under specific conditions (ASTM D4350). The index may be regarded as a reflection of the probability that, in humid conditions, metal surfaces in contact with the material could suffer galvanic corrosion or direct chemical attack.

cotton, linen Fabrics made of cotton or linen are used as reinforcements in several grades of laminate. These are usually impregnated with a phenolic resin, but they could be impregnated with other resins as well.

Laminates made with these fabrics have better water resistance than paper-based laminates. They also machine well and have good physical properties, particularly their impact strength and abrasion resistance. The electrical properties, however, are poor. These cotton laminates are used for gears and pulleys. In chopped or macerated form, cotton or linen can be used in molding compounds.

coupling agent Coupling agents are additives used in reinforced and filled plastic composites to enhance the plastic-filler reinforcement interface to meet increasingly demanding performance requirements.

In general there is little affinity between inorganic materials used as reinforcements and fillers and the organic matrices in which they are blended. With silicate reinforcements (glass fiber or wollastonite) silane coupling agents act by changing the interface between the dissimilar phases. This results in improved bonding and upgraded mechanical properties of the composites. By chemically reacting with the resin and the filler or reinforcement components, coupling agents form strong and durable composites. Coupling agents significantly improve mechanical and electrical properties for a wide variety of resins, fillers, and reinforcements. In addition, they act to lower composite cost by achieving higher filler loading.

Fiberglass reinforcement for plastics is the major end use of coupling agents. Thermoset resins, such as polyester and epoxy, account for approximately 90 percent of coupling agent consumption. Kaolin clay, wollastonite, and glass fiber are the leading fillers or reinforcements chemically treated with coupling agents. Coupling agents are both purchased and applied by the glass fiber or inorganic filler manufacturer or by the compounder for incorporation into the composite system.

Another important market for silane coupling agents is in the cross-linking of polyolefins. In this market, silanes are growing at the expense of organic peroxides. Silanes and titanates along with several minor product types make up the coupling agent market.

Silanes comprise more than 90 percent of the plastic coupling agent market. They can be represented chemically by the formula $Y—Si(X)_3$ where X represents a hydrolyzable group such as ethoxy or methoxy and Y is a functional organic group that provides covalent attachment to the organic matrix. The coupling agent is initially bonded to the surface hydroxy groups of the inorganic compound by the $Si(X)_3$ moiety. It attaches either directly or, more commonly, via its hydrolysis product $Si(OH)_3$. The Y function group (amino, methoxy, epoxy, etc.) bonds to the matrix when the silane-treated filler or reinforcement is compounded into the plastic, resulting in improved bonding and upgraded mechanical and electrical properties. Table C.7 lists four different silane chemistries and their related composite systems.

Table C.7 Silane Chemistries With Appropriate Filler and Resin Matrices

Silane Type	Resin	Filler or Reinforcement
Amino	Phenolic	Alumina
	Phenolic	Silicon carbide
	Acrylic	Clay
	Nylon	Clay
	Nylon	Wollastonite
	Furan	Sand
Epoxy	Epoxy	Alumina trihydrate
Methacrylate	Polyester	Mica
Vinyl	PVC	Clay
	PVC	Talc
	EPDM	Clay

Titanates are used primarily as dispersing aids for fillers in polyolefins to prevent agglomeration. Titanium-based coupling agents react with free protons at the surface of the inorganic material, resulting in the formation of organic monomolecular layers on the surface. Typically, titanate-treated inorganic fillers or reinforcements are hydrophobic, organophillic, and organofunctional and, therefore, exhibit enhanced dispersibility and bonding with the polymer matrix. When used in filled polymer systems, titanates claim to improve impact strength, exhibit melt viscosity lower than that of virgin polymer at loadings above 50 percent, and enhance the maintenance of mechanical properties during aging.

Zirconate coupling agents have a structure very similar to the titanates. Zirconium propionate is used as an adhesion promoter in printing ink formulations for polyolefins that have been treated by corona discharge. The coupling agent is believed to form from hydrogen bonds with the nitrocellulose in the ink. Surface COOH groups seem to be the most likely attachment site to the polyolefin surface. Like the titanates, zirconate coupling agents are useful in improving the dispersion characteristics of fillers in polymer systems.

The leading suppliers of silane coupling agents in North America are Witco and Dow Corning. Other major suppliers include Degussa, Nippon Unicar, PCR, Rhodia, Shin-Etsu Chemical, and Sivento for silanes and Kenrich Petrochemicals and Rhodia for titanates.

See adhesion promoter; wetting agent.

crack growth Crack growth is the rate of propagation of a crack through a material due to a static or dynamic applied load. Tough materials are generally more resistant to crack growth than brittle materials.

cratering Cratering is the appearance of depressions on a coated plastic surface, often caused by excess lubricant. Cratering results when the coating is too thin and later ruptures, leaving pinholes and other voids. Use of less thinner in the coating can reduce or eliminate cratering, as can less lubricant on the part.

crazing Crazing is fine cracks that may extend in a network on or under the surface or through a layer of a plastic material. Crazing usually occurs in highly stressed regions of thermoplastic molded parts, especially when they come into contact with a strong solvent. Crazing is often caused by exposure to an environment or chemical.

Many molded plastics, such as acrylic, will show crazing when cleaned with solvent if they have residual stresses in the molded part. *Annealing* is a way of removing the internal stresses to minimize crazing. (*See also* anneal, environmental stress cracking.)

In the context of glass-reinforced plastics, crazing is a series of fine cracks just at or under the surface of the laminate. A standard for classification may be found in ASTM D2563.

creep Creep is the dimensional change with time of a material under load, after the initial instantaneous elastic deformation. It is the time-dependent part of strain resulting from an applied stress. *See* ASTM D674, “Recommended Practices for Testing Long Time Creep and Stress Relaxation of Plastics Under Tension or Compression Loads at Various Temperatures.” Creep at room temperature is sometimes called *cold flow*.

Creep rate is the slope of the creep-time curve at a given time. *Creep recovery* is the time dependent decrease in strain in a solid after the removal of force. *Creep* *rupture strength* is the stress that causes fracture in a creep test at a given time, in a specified constant environment. This is sometimes referred to as the *stress-rupture strength*. In glass technology, this is termed the static fatigue strength.

crosslinking Crosslinking is the process by which chemical links occur between molecular chains of a plastic. In thermosets, crosslinking makes one infusible "super molecule" of all the chains. Crosslinking contributes to strength, rigidity, and high temperature resistance. Thermoplastics, such as polyethylene, can also be crosslinked by irradiation or chemically through the formulation to produce three-dimensional structures that are thermoset in nature and offer improved tensile strength and stress-crack resistance.

A *crosslink* is a bond, chemical or ionic, or bridging atom or group of atoms that joins two polymer chains or two parts of the same chain. Crosslinks form a three-dimensional (crosslinked) polymer structure. In rubbers, crosslinking is also called *vulcanization*. (*See also vulcanization.*)

A *crosslinking agent* is a reagent that promotes or regulates crosslinking. Some examples are peroxides that promote formation of crosslinks in unsaturated polyester resins and sulfur in the crosslinking (or vulcanization) of rubber.

crowfoot mark or crowsfeet

See weave.

cryogenic temperature Cryogenic temperatures are temperatures that are very cold, generally considered to be near or below the temperature of liquid nitrogen. Cryogenic temperature resistance is usually measured by immersing a specimen in liquid nitrogen or liquid helium. Plastics, adhesives, laminates, etc. generally become very brittle and lose all elongation at cryogenic temperatures.

However, certain polymers with very low glass transition temperatures (polyurethanes) or glass transition points at both high and low temperature (polybenzimidazole, epoxy-nylon, epoxy-amide) have good retention of both tensile strength and elongation at cryogenic temperatures and are usually the only materials that will work well at these temperatures.

Very often it is not the low temperatures themselves that cause cryogenic strength degradation but the fast rate of excursion from a moderate temperature to cryogenic temperatures that causes problems. Stresses caused by thermal contraction and mismatch of thermal expansion coefficients often lead to failures of products at very low temperatures.

crystalline Crystalline polymer structure or *crystallinity* in polymers refers to an arrangement of molecules that denotes uniformity and compactness of the molecular chains. Normally, it can be attributed to the formation of solid crystals having a definite geometric form. In some resins, such as polyethylene, the degree of crystallinity indicates the degree of stiffness, hardness, environmental stress-crack resistance, and heat resistance. (See Fig. C.8.)

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Figure C.8 Classification of the expected properties of materials on the basis of molecular weight and crystallinity. (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 9)

A major factor in determining whether a polymer will form crystalline regions is the occurrence of successive units in the chain in a configuration of geometric regularity. If all the substituents on each chain are small, or if all are alike, the polymer can tightly pack into an ordered structure and *crystallinity* can be highly developed. Examples of *crystalline polymers* include polyethylene, nylon, polyvinylidene foramide (PVF), and acetal.

The properties of an *amorphous* (noncrystalline) *polymer* are determined by the degree of restriction of molecular motion of its chain. A highly crystalline polymer such as nylon 6 is much stronger and tougher than amorphous polymers. No “crystalline polymer” is completely crystalline, but it has crystalline regions dispersed among amorphous structure. Thus the more correct term for “crystalline” polymers is “semicrystalline.”

The *crystalline melting point* is the temperature at which the crystalline structure in a material is broken down by molecular movement and begins to take on amorphous characteristics.

crystallite Because of their length and complex configuration, polymer molecules can align themselves in an amorphous matrix so that select areas become more ordered than the surrounding environment. Such ordered regions are called crystallites. The *crystallinity* of a polymer refers to the degree to which such ordered crystalline regions are present.

The typical crystallite has dimensions less than the length of the extended polymer molecules so that a given molecule can traverse more than one crystallite region, as well as the amorphous region in between.

The relative percentages of the crystalline regions vary widely with the nature of the polymer and the history of the sample being examined. There are no known commercial polymers that are 100 percent crystalline.

See also spherulite.

cull In transfer molding, the cull is the material remaining in a transfer chamber after the mold has been filled. Unless there is slight excess in the charge, the operator cannot be sure that the cavity is filled. The charge is generally regulated to control thickness of the cull.

cup flow test The cup flow test is a test for measuring the flow properties of thermosetting materials. In the cup flow test, a standard mold is charged with preweighted material and the mold is closed with sufficient pressure to form a required cup. The minimum pressures required to mold a standard cup and the time required to close the mold fully are determined.

cup viscosity test The cup viscosity test is a test for making flow comparisons under strictly comparable conditions. The cup viscosity test uses a cup–shaped gravity device that permits the timed flow of a known volume of liquid passing through an orifice located at the bottom of the cup. Because of the simplicity of the test and its ability to be used alongside mixing equipment, the cup viscosity test is ideal for mixing resinous solutions or making adjustments of solvent to existing solutions to obtain a specified viscosity.

See also Zahn viscosity cup.

cure Cure is the process of changing the physical properties of a material by chemical reaction. Curing generally applies to thermoset polymers. The reaction can be condensation, polymerization, or vulcanization. It is usually accomplished by the action of heat and catalyst, alone or in combination, with or without pressure.

The *cure cycle* is the schedule of time periods of specified conditions to which a reacting thermosetting material is subjected to reach a specified property level. The *curing temperature* is the temperature at which a cast, molded, or extruded product, a resin-impregnated reinforcing material, an adhesive, etc. is subject to curing. The *curing time* is the interval of time that it takes the thermoset material to cure under specific conditions. (See Fig. C.9.)

curing agent The curing agent is a chemical used to bring about the curing of a prepolymeric or polymeric composition. The function of a curing agent may include regulation as well as promotion of the curing process. Curing agents vary widely depending on the nature of the polymer and the process by which cure will take place. Sometimes curing agents are also known as *hardeners*.

See also epoxy resin curing agent; polyurethane catalyst; hardener.

curtain coating Curtain coating, which is similar to *flow coating*, is used to coat flat product on conveyorized lines. The coating falls from a slotted pipe or flows over a dam in a steady stream or curtain while the product is conveyed through it. Excess material is collected and recycled through the system. Film thickness is controlled by coating composition, flow rates, and line speed.

Curtain coating may be used with low-viscosity resins or solutions, suspensions, or emulsions of resins in which the substrate to be coated is passed through and

Figure C.9 Effect of cure time on the physical properties of elastomers. ΔT is the heat buildup in a compression-flex test. (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 539)

perpendicular to a freely falling liquid curtain. The flow rate of the falling liquid and the linear speed of the substrate passing through the curtain are coordinated in accordance with the thickness of the coating desired.

The advantage of curtain coating is uniform coating thickness on flat products with high transfer efficiency. The disadvantage is the inability of curtain coatings to uniformly coat three-dimensional objects.

cutting In the fabrication of plastic materials, the primary cutting operations are sawing, blanking, punching, knife cutting, slitting, and shearing. The selection of a cutting process will depend on the nature of the polymer as well as the production requirements. The same is true of the secondary cutting operations such as routing, milling, drilling, tapping, and lathe and screw machine operations. In those cases where more than one technique is applicable, the choice is determined by cost factors.

See also sawing, cutting, shearing.

cyanate ester The cyanate esters are a family of aryl dicyanate monomers and their prepolymer resins that contain the reactive cyanate functional group. When heated, this cyanate functionality undergoes an exothermic cyclotrimerization reaction to form triazine ring connecting units, resulting in gelation and formation of thermoset polycyanurate plastics. Cyanate ester monomers range from low-viscosity liquids to meltable solids. They cure by the catalytic action of solutions of zinc, cobalt, or copper carboxylates or acetylacetonate chelates in nonylphenol.

Cyanate esters also function as epoxy converters. Incorporating 50–65 percent epoxy resin will provide essentially complete conversion at 177°C.

Cyanate esters are used in the manufacturing of structural composites such as filament winding, resin transfer molding, and pultrusion. The cyanate ester resins have shown superior dielectric properties and much lower moisture absorption than any other structural resin used for composites. The glass transition temperature of cyanate esters is relatively high (250°C), but it requires cure temperatures greater than 177°C.

Cyanate esters are used in circuit boards because of their low dielectric constant of 2.91 and a high T_g of 290°C. Prepregs and laminates are made with conventional technology, and they are tougher and more moisture resistant than FR-4 copper clad. Laminates are also used in radomes, antennas, and aerospace structures.

AroCy L-10 is a low-viscosity (140 cP at room temperature) cyanate ester resin available from Ciba-Giegy. Cure requires 3 h at 177°C and a postcure of 225–250°C.

cyanoacrylate adhesive Methyl and ethyl cyanoacrylate monomers are an extremely powerful adhesives. The first cyanoacrylate adhesives were known commercially as “super-glues.” Cyanoacrylate adhesives were first developed by the Eastman Chemical Company, but now there are many suppliers and commercial products can be found in any hardware store or supermarket.

Adhesion occurs very rapidly (generally a matter of seconds) when the liquid monomer is spread in a thin layer between the surfaces to be bonded. Traces of bases (even as weak as alcohol or water) on the surfaces catalyze polymerization by an anionic mechanism. Adhesion arises in part from mechanical interlocking between polymer and surface and in part from strong secondary bond forces.

The bonds formed with cyanoacrylate adhesives, although fast and having high tensile strength, are brittle and do not have great toughness or peel strength. They are also adversely affected by moisture, solvents, and high temperatures.

cyclic compound Organic compounds are called *cyclic* when their two end carbon atoms are linked to each other directly as in benzene or through another atom. The term was devised to distinguish cyclic compounds from open-chain compounds.

cyclic thermoplastic General Electric Co. has developed a series of experimental low-molecular-weight cyclic thermoplastics. When reaction-molded polycarbonate, for example, is first heated to about 200°C, it becomes a low-viscosity liquid. Further heating between 250 and 300°C with anionic catalyst produces a 50,000- to 100,000-molecular-weight plastic. This can be used for pultrusion and in making parts that are too large for conventional injection molding. The cyclic oligomer carbonate can be cross-linked with epoxies and other resins to produce a higher molecular weight with enhanced properties.

Polyacrylate, polyetherketone, polyethersulfone, and polyetherimide have been processed in the same way. The polymer melt readily wets glass fibers. These materials have been used in resin transfer molding, filament winding, and casting.

cyclized rubber When rubber is heated slowly or treated with acidic reagents, it becomes hard and brittle. Its unsaturation is reduced, but the empirical formula $(C_5H_8)_x$ remains unchanged. The changes are thought to result from the condensation of isoprene residues in pairs to give cyclic structures.

Cyclized rubbers are made commercially by treating rubber in this manner with sulfuric acid, various sulfonyl chlorides, or chlorostannic acid. The products are nonelastic. They are used primarily as compounding ingredients in shoe soles and heels and for rubber-to-metal bonding adhesives.

cyclohexanone Cyclohexanone, $CO(CH_2)_4CH_2$, is a *ketone* widely used as a solvent for cellulosic plastics and for polyvinyl chloride and its copolymer with vinyl acetate. It is synthesized from phenol.

cyclo-olefin Cyclo-olefin is a term applied to *thermoplastic olefin* (*TPO*) *copolymers*. These polymers are usually based on ethylene with typically 25–50 percent of a cyclic olefin comonomer. Cyclo-olefins are produced with the aid of *metallocene catalysts*.

See also thermoplastic elastomer.

D

dacron Dacron is a tradename for a synthetic fiber made by Du Pont from the polyester of ethylene glycol and terephthalic acid (dimethyl terephthalate).

See also polyester (thermoplastic).

damping Damping is the ability in a material to absorb energy to reduce vibration. Damping usually refers to a *viscoelastic* material's (e.g., elastomer) inability to transfer mechanical or acoustical energy from one surface to the other. Polymeric materials with good damping characteristics are used to insulate against noise and vibration.

daylight opening Daylight opening is a term used to describe the clearance between two platens of a press in the open position. The opening must be large enough to allow a part to be ejected when the mold is in the fully open position. In the case of a multiplaten press, the daylight opening is the distance between adjacent platens.

debond A debond, or disbond, is a deliberate separation of a bonded joint or interface, usually for repair or rework purposes. However, it is also a term used to describe an unbonded or nonadhered region due to damage to the joint or poor quality control measures. In reinforced plastics, debond refers to a separation at the fiber/matrix interface due to strain incompatibility or to a void existing between plies in the laminate.

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deckle rod The deckle rod is a small rod, or similar device, inserted at each end of the extrusion coating die, which is used to adjust the length of the die opening.

decorating Several decorating processes can be accomplished with plastic parts—during processing of the part, directly afterward, or before final assembly and packaging. The most inexpensive method of providing decorative designs on plastics is to incorporate the design into the mold or to apply the decoration as part of the molding operation. However, often this is not possible because of mold complexity, the need to apply decorations to the customer's specification, or other reasons.

The most widely used decorating processes in the plastic industry are painting, hot decorating (hot stamping, in-mold decorating, heat transfer), plating, printing, and application of lapels, decals, etc. Table D.1 rates the characteristics of the most common of these decorating methods.

Table D.1 Various Decorating Methods (Ref: Satas, D., "Pad Printing", *Plastics Finishing and Decoration*, D. Satas, ed., van Nostrand Reinhold, New York, 1986)

	Pad Printing	Mask Spray Painting	Screen Printing	Hot Stamping
Comparative equipment costs	P	E	G	F
Comparative tool costs	G	P	E	F
Ink costs	E	F	G	P
Ease of setup	F	E	G	P
Suitability for various jobs:	E	P	G	E
Small, flat areas				
Fine detail	E	P	G	G
Large areas	P	E	E	P
Opaque coverage	P	E	E	G
Convex surfaces	E	G	F	F
Concave surfaces	E	P	P	P
Single, multicolor application	E	P	P	G
Low-volume application	F	G	E	F
High-speed production	E	F	E	G

Note: P = poor, F = fair, G = good, E = excellent.

As with adhesive bonding, surface treatment and cleanliness are of primary importance when decorating plastic parts. Before decoration, the surface of the plastic part must be cleaned of mold release, internal plastic lubricants, and plasticizers. Plastic parts can also become electrostatically charged and attract dust. This could disrupt the even flow of a coating or interfere with adhesion. Solvent or destaticizers may be used to clean and eliminate static from plastic parts before decorating. Cleaning of the plastic part requires an understanding of the plastic material to be cleaned and the effect of the solvents on that plastic. (See also cleaning.)

Some plastics may need to be surface roughened or chemically treated to promote adhesion of the decorating medium. Molded and extruded plastic parts tend to have glossy resin-rich surfaces. This is desirable if the part is used in the "as-is" molded condition, but the glossy surface may require abrading or etching to hold paint or printing media or before application of an adhesive. Polyolefins, polyacetals, polyamides, fluorocarbons, and other low-energy surfaces that are difficult to wet might require special surface treatments before decorating processes can be completed satisfactorily. Many of the cleaning methods and surface treatments that are used for promoting adhesion are also applicable before decorating.

See also painting plastics; hot decorating; plating; printing on plastics.

decorative laminate Decorative laminates are high-pressure laminates with a paper base, similar in many respects to industrial laminates except for the special attractive surfaces. These laminates have a core of sheets of phenolic resin-impregnated kraft paper. On top of this is placed a special grade of paper with a decorative pattern printed on the surface and impregnated with a clear melamine resin. The decorative pattern may be wood grain, solid color, or any other design. On top of this is placed another sheet of paper called an overlay that is impregnated with melamine having an index of refraction that is similar to that of the cellulose in the paper. This overlay protects the decorative sheet and provides the unique abrasion and stain resistance required of these laminates. The stack then goes into large, multiple-opening presses. Here the sheets are bonded together at a temperature of up to 150°C and pressures of up to 1500 psi. The sheets are trimmed, and the back is sanded to achieve tolerances and provide for adhesive bonding.

Decorative laminates, available in several grades, can be used for different applications. Postforming grades are capable of being bent to produce curved surfaces. They must be rapidly heated to about 160°C and pressed to shape in a form or mold with moderate pressure. The resistance of these laminates to household chemicals is excellent.

These laminates are usually bonded to a substrate such as plywood, chipboard, or composition board. It is recommended that a *balancing sheet* be used when these laminates are bonded. This sheet consists of several layers of phenolic-impregnated paper similar to the core in the decorative laminate. When it is bonded between the laminate and the substrate, the balance sheet prevents moisture absorption and minimizes warpage of the structure. Adhesives that are used include urea formaldehydes, phenolic, casein, epoxy, and polyvinyl acetate.

Decorative laminates are not structural materials and should be treated as veneers except when they are bonded to structural cores. Although the face wears well in abrasive environments, the materials are handled as brittle, rigid, thin structures. The grain direction and dimensional stability of the laminates are similar to those of wood. With varying humidity, the width of the laminate changes twice as much as the length; therefore, in critical applications, the machine or grain direction should be established.

Decorative laminates are standardized in NEMA publications LD3, *High Pressure Decorative Laminates*, and LD3.1, *Performance*, *Applications*, *Fabrication and Installation of High Pressure Decorative Laminates*.

deflashing Many plastic parts formed in molding operations will have some excess material, called *flash*, at the parting lines and on molded-in inserts. *Gates* are also excess resin material resulting from the flow path of the plastic into the mold. It usually is necessary to remove this excess material for cosmetic or functional reasons. This process is called deflashing.

No single method is universally applicable for the removal of flash and gates. Each part geometry and material will have its specific requirements and individual problems. The techniques generally used for removal of flash and gates are hand deflashing (filing, sanding, machining, and tumbling). For removal of flash, tumbling is generally preferred. However, the shape, size, or contours of the article may require filing to remove heavy flash, gate sections, or burrs that may be left by machining operations such as cutting and drilling. Other methods of deflashing parts that are less common are chemical deflashing and water honing.

hand deflashing The ease of filing will depend on the type of file chosen. The file characteristics must be carefully matched to the plastic's properties (hardness, brittleness, flexibility, and heat resistance). The size, shape, and contour of the article being filed determine the size and shape of the file to use. For removal of flash, files should have very sharp, thin teeth that will hold their edge, well-rounded gullets to minimize the tendency to clog, and the proper rake for clearing of the chips.

Thermoplastics on which files are used include those that are relatively soft as well as those that are hard. However, some materials (e.g., nylon), because of their toughness and abrasion resistance, are not easily filed. Thermoset flash should be filed off in such a way as to break it toward a solid portion of the part rather than away from the main body, to prevent chipping. The file is pushed with a firm stroke to break off the flash close to the body, and then filing is continued to smooth the surface. (*See also* filing, grinding, and sanding.)

tumbling Tumbling is a simple, high-volume process to deflash rigid plastics. The tumbler is usually a metal drum or cylinder that is perforated in such a way that the plastic parts will not fall through the perforations. The tumbler is then placed on a rotating mechanism. The plastic parts are loaded in the tumbler so that at least half of the tumbler space is empty. The tumbler is set in motion, allowing the parts to slowly roll and impact against one other. The constant impacting removes the brittle, external flash in a relatively fast time (10–15 min). The limitations of tumbling are that the parts must be robust, they must be molded with rigid, brittle material, and only external flash will be removed. Tumbling can also be used to round corners and apply a surface finish to plastic parts. Tumbling does not produce as high a finish as polishing, but for many articles a very high polish is not necessary and is not worth the higher costs involved.

For more thorough flash removal, moderately abrasive material is added to the tumbling method described above. This *media deflashing* allows both internal and external flash to be removed. The parts to be deflashed are loaded into a container. Once the tumbling starts an abrasive media material (ground walnuts, hard nylon, polycarbonate pellets, etc.) is directed at the parts under air pressure and at high velocity. Modern deflashers recycle the blast media and use dust collectors to minimize air pollution.

Cryogenic deflashing uses cold temperatures to make the plastic rigid and brittle. It uses essentially a sealed tumbler with either liquid nitrogen or expanding carbon dioxide (−40 to −40°C) to cool the parts. At these temperatures, even elastomers will become rigid, thus allowing even tough flash to be removed in a conventional tumbling process.

See also abrasive finishing; tumbling.

deflection temperature

See heat distortion temperature.

defoamers The function of defoamers is to facilitate the removal of air entrained in a mix (usually a liquid mix) during compounding. In applications like potting and encapsulation, this air could cause bubbles on the surface of the plastics. Bubbles or voids in an insulation material can cause arcing that could limit the plastic's effectiveness.

Accordingly, after high-speed mixing, vacuum or dryers are used to release air. The purpose of the defoamer or air release agent is to speed up and optimize the removal of air. Some can help prevent air entrapment. The agents also serve as *lubricants* for the fillers, as *wetting agents*, and as *surface tension depressants* —all of which contribute to the air release function.

Silicones and related blends of silicones and other materials are among the most popular types of air release agents in use in liquid resin compounding. A typical base for defoaming is alcohol/silicone. However, one must be careful when using silicone defoamers. The presence of the silicone could cause a surface on the part that will not be amenable to coatings or adhesives.

Major suppliers of defoamers and deaerating agents are American Ingredients Co., Harwick Chemical Corp., Wacker Silicones Corp., and Witco Corp.

degassing The process of degassing is to remove air that may be entrained in a mix (usually a liquid mix) during compounding. When fillers, additives, or catalysts are mixed into a liquid at high speeds, air is entrained in the mix. A typical application is the compounding of liquid polyurethanes or epoxies. Without degassing, the mixed liquid resin may retain air bubbles, which would remain in the cured part and contribute to a reduction in properties.

Accordingly, after high-speed mixing, vacuum is used to release air. The mixed resin is generally placed in a vacuum chamber and subjected to several vacuum cycles until there is no noticeable bubbling from the mix.

degradability agent Degradability agents are additives that are added to a plastic to aid its *biodegradation* or *photodegradation* processes. To make plastics degradable, it is necessary first to break them down into very small particles with large surface area, and second to reduce their molecular weight. Biodegradable products accomplish this differently from those that are photodegradable.

Additive-based biodegradable materials usually incorporate a natural degradable polymer, such as corn, rice, or potato starch, with a nonbiodegradable synthetic polymer, such as polyethylene, polypropylene, polystyrene, or polyurethane. It generally requires an accelerator additive to facilitate the breakdown of the polymer chain to the point at which it can be metabolized by microorganisms.

Photodegradable products are based on various technologies: ketone carbonyl systems, ethylene/carbon systems, ethylene/carbon monoxide systems, antioxidant/photoactivator systems, and masterbatches based on proprietary additive systems. The addition of an ultraviolet (UV)-absorbing material will also act to enhance photo-degradation. An example is the addition of *iron dithiocarbamate*. Two problems exist with photodegradable material. It must be exposed to light for degradation to occur (if buried in a landfill, degradation will not occur). There is also potential toxicity due to the additives used to impart photosensitivity. However, photodegradable products can be made with no loss of physical properties.

Major suppliers of biodegradable agents include Ampacet Corp. and Fully Compounded Plastics Inc. Major suppliers of photodegradable agents include the above and Colortech Inc., Ecolyte Atlantic Inc., and Polymer Materials Inc.

See also biodegradable plastic.

degradation Degradation of a polymer or plastic is an irreversible detrimental alteration of the chemical structure. This is often due to polymer chain scission or oxidative breakdown. Typically these chemical changes are associated with permanent changes in the physical properties such as a loss of strength and extensibility, and embitterment and in many cases with changes in appearance such as discoloration, darkening, and cracking (*See also* aging; hydrolysis; oxidation.)

A *degradable plastic* generally refers to a plastic that has been purposefully designed to degrade in certain environments as, for example, biodegradable plastics or photodegradable plastics. (*See* degradable agents; biodegradable plastic.)

degree of polymerization The degree of polymerization is the number of structural units or *mers* in the average polymer molecule in a particular sample. In most plastics the degree of polymerization must reach several thousand if worthwhile physical properties are to be had. There is positive correlation between the degree of polymerization and the *molecular weight* of a polymer.

delamination Delamination is the separation of the layers in a laminate, either locally or in a large area, caused by the failure of the resin holding the laminate together. In fabric-reinforced composites delamination occurs when one group of plies separate from another group. With adhesion bonding, delamination occurs when one adherend separates cleanly from another because the bond is broken.

Delamination can occur during cure (often because of entrapped gases) or during the part's operational life (often due to degradation of the resin, excessive stress on the laminate, or out-gassing due to continued cure).

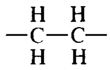
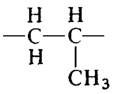
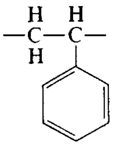
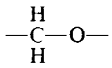
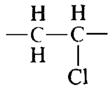
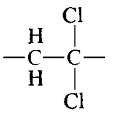
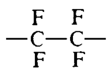
dendrimer A dendrimer is a polymer whose molecules are not linear but highly branched in a radial fractal pattern. Dendrimer polymers have an overall shape that is substantially spherical. Other relatively simple molecules may be physically accommodated in the spaces among the branches. As a result, dendrimer polymers can provide a basis for controlled release agents. Early examples of dendrimers include the hydrocarbon $C_{1134}H_{1146}$.

denier Denier is a unit in a numbering system for fibers or filaments. It is the weight in grams of 9000 meters of synthetic fiber in the form of continuous filament. The lower the denier, the finer is the fiber.

density Density is the weight per unit volume of a substance, expressed in grams per cubic centimeter, pounds per cubic foot, etc. For practical purposes, density may be regarded as numerically equal to relative density (sometimes called *specific gravity*). ASTM D1505 describes a test method to determine the density of plastics.

Density is a direct function of the polymer's chemical composition. The specific gravity of carbon/hydrogen polymers is about 1.0 (similar density to water). Most other atoms produce higher density, such as the fluoropolymers. The specific gravity of typical polymers is shown in Table D.2.

Table D.2 Specific Gravity of Polymers (Ref: Driver, W.E., *Plastics Chemistry and Technology*, van Nostrand Reinhold, New York, 1979, p. 46)

Polymer	Structure	Specific Gravity
Polyethylene	 $-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-$	0.92–0.96
Polypropylene	 $-\underset{H}{\overset{H}{C}}-\underset{CH_3}{\overset{H}{C}}-$	0.9
Polystyrene		1.05
Acetal	 $-\underset{H}{\overset{H}{C}}-O-$	1.4
Polyvinyl chloride	 $-\underset{H}{\overset{H}{C}}-\underset{Cl}{\overset{H}{C}}-$	1.4
Polyvinylidene chloride	 $-\underset{H}{\overset{H}{C}}-\underset{Cl}{\overset{Cl}{C}}-$	1.7
Polytetrafluoroethylene	 $-\underset{F}{\overset{F}{C}}-\underset{F}{\overset{F}{C}}-$	2.2

Polyethylene is denser than polypropylene because of its closer packing. Polystyrene is somewhat denser because the ring is denser than the linear —C—C— system and has fewer hydrogen atoms per carbon. Oxygen, chlorine, fluorine, and bromine are dense atoms, which increase the density of polymers that have such atoms in their molecular configuration.

See also apparent density; bulk density; specific gravity.

deodorants Deodorants are additives for plastics that prevent the development of odor. Different from deodorants, *odorants* are generally defined as additives that produce a fragrance or odor (in the positive sense) in plastics. There is a gray area, however, in which odorants mask distasteful odors and thereby serve as deodorants. (*See* odorants.)

Deodorants prevent microorganisms from reacting with organic matter to produce odors. Two major microorganisms that initiate such reaction are bacteria and fungi. In the presence of heat and moisture, for example, bacteria from the skin could react through perspiration with product like clothing with synthetic polymer fiber to develop odor unless an *antimicrobial agent* is present. *(See* biocides.) Similarly, in the presence of heat and moisture, fungi could grow and react with a product to create odor. The most popular antimicrobial agents used as deodorants are the *organometallics*. These agents are used primarily with polyvinyl chloride (PVC) and polyethylene in trash bags.

Major suppliers of deodorants include Dorman Materials Co., Harwick Chemical Corp., International Flavors & Fragrances Inc., Keystone Aniline Corp., and Polyad Co.

depolymerized rubber Hardman, Inc. produces liquid polymers that can be vulcanized to rubbers. They are cured with *p*-quinone dioxime and lead dioxide at room temperature and with sulfur at elevated temperature. Ultraviolet initiators can also be used.

Trademarked *Kalene,* this material is a depolymerized virgin butyl rubber, which is similar to butyl LM rubber. The properties are similar to those of conventional butyl rubber such as the lowest vapor transmission rate of any elastomer, resistance to degradation in high-humidity, high-temperature environments (very little change after 120°C steam for 1000 h), excellent electrical properties (volume resistivity of 5.5×10^{15} ohm-cm and a dielectric constant of 3.1), resistance to soil bacteria, excellent weathering, and resistance to chemicals and oxidation.

Because of the high viscosity of the rubber, oil or solvent must be added to produce a pourable compound. This material is useful in applications in which it can be applied under pressure and protected from physical abuse. Its uses include roof coating, reservoir liners, aquarium sealants, and conformal coatings.

Cis-1,4-polyisoprenes are produced by depolymerizing polyisoprene or natural rubber. The material is used as a reactive plasticizer for adhesive tape, abrasive and friction products such as grinding wheels, and automobile brake linings, wire and cable sealants, and hot melt adhesives. The natural rubber product serves as a base for cold molding compounds for arts and crafts, asphalt modifier, as potting, or in molds.

desiccant A desiccant is a chemical substance that will remove moisture from materials, usually due to adsorption of the moisture onto the surface of the substance. This is also known as a *drying agent*. A *desiccator* is a heat-resistant glass container having an airtight lid and a lower compartment that houses a desiccant. Hot test specimens are placed in a desiccator to prevent moisture pickup before they are tested, weighed, etc.

destaticization Destaticization is the process of treating plastic materials to minimize their accumulation of static electricity and consequently the amount of dust picked up by plastics because of such charges. It can be accomplished either by treating the surface with specific materials or by incorporating additive materials (*antistatic agents* or *antistats*) in the molding compound.

See antistatic agent; static electricity.

detergents Detergents are substances with a high surface activity so they can remove contaminants from surfaces as part of a cleaning process. Generally detergents are good for removing non-organic contaminates such as dirt and dust. Often solvents are needed to remove organic contaminates from surfaces. Detergents are made synthetically to a large extent, although detergents based on naturally occurring materials are also commercially available.

See also chemical cleaning.

dextrin Dextrin is a group of compounds with the same empirical formula as *starch* $(C_6H_{10}O_5)_x$ but with a smaller value of x. Dextrin is a white, amorphous, odorless powder that dissolves in water to form a syrupy liquid. It is made by moistening starch with a mixture of dilute nitric and hydrochloric acids and then exposing to a temperature of 100–125°C.

Dextrin compounds have strong adhesive properties and are used as pastes, particularly for envelopes, gummed paper, and postage stamps. Dextrin adhesives can bond to many different substrates. Paper and paperboard are the most common substrates. Laminating adhesives are usually made from highly soluble white dextrins and contain fillers such as clay.

diallyl phthalate (DAP) Diallyl phthalate is a thermosetting ester polymer resulting from the reaction of allyl alcohol and phthalic anhydride.

See also allyl.

diaphragm gate In injection and transfer molding, a diaphragm gate is a gate (orifice through which the melt enters the mold cavity) used in molding annular or tubular articles.

See also gate.

dibutyltin dilaurate (DBTDL) Dibutyltin dilaurate (DBTDL) is an organotin compound used as a catalyst in formations for polyolefin materials crosslinked with vinyltrimethoxy silane. The materials are made into such products as cable coverings and heat shrink tubing. Other applications of DBTDL are in formulations for certain kinds of polyurethane foams and as a heat stabilizer for polyvinyl chloride (PVC).

die The die is the element at the end of the extruder or molding machine that determines the shape of the product being produced. The dies for each type of product are different.

The *die block* is the part in an extrusion die that retains the forming bushing and core. In an injection mold, it is the part that contains the cavity or plug (force). The *die adaptor* is the part of an extrusion die that holds the *die block*.

In the extrusion of pipe or tubing, the *die bushing* is generally the female part of the die and is attached to the die body by adjustable screws. Thus small changes can be made in the wall thickness if required.

A divergent die is a die in which the internal channels leading to the orifice are diverging (applicable only to dies for hollow bodies).

Used in coating processes, *die blades* are deformable member(s) attached to a die body, which determines the slot opening. The die blades are adjusted to produce uniform thickness across the film or sheet produced. The *die gap* is the distance between the metal faces forming the die opening.

See also extrusion die.

die cutting Also known as *blanking*, die cutting is a process of cutting shapes from sheet stock by striking the stock sharply with a shaped knife edge known as a *steel rule die*. *Clicking* and *dinking* are other names for die cutting of this kind.

See also blanking.

dielectric A dielectric is a substance or medium in which an electric field can be maintained with little supply of energy from an external source. Dielectrics are nonconductors of electricity. All insulating plastics are dielectrics.

dielectric breakdown Dielectric breakdown or *dielectric strength* is the measure of the electrical strength of a material as an insulator. It is the passage of sudden excessive current through a part that is meant to be an insulator. Dielectric breakdown can be verifed by instruments and by visible damage to the specimen.

See also dielectric strength; high-voltage resistant plastics.

dielectric constant Dielectric constant (ASTM D150) is the ratio of the capacitance of a capacitor, which uses the given plastic (or other insulating material) as the dielectric, to the capacitance of an identical capacitor, which uses air as the dielectric. It is a measure of the ability of a plastic to store electrostatic energy when subjected to an electric field. Dielectric constant is important in the study of capacitive effects and in calculation of the electrical stress distribution in composite insulators.

This term is also sometimes called *permittivity*. Dielectric constant values have no units because they are mathematical ratios. Low dielectric constant values, desirable for electronic plastics, would be below 3.0 or 4.0.

See also dielectric properties.

dielectric curing or heating Dielectric curing of a synthetic thermosetting resin can be accomplished by simply placing the part in a high-frequency electric field. Such a field is produced by radio frequency or microwave ovens. Dielectric curing is very difficult to control, and there is a significant risk of overheating and burning the part.

Dielectric heating can be used to preheat powder, pellets, or preforms to remove water before processing the material. Dielectric heating can also be used to generate the heat necessary for curing polar, thermosetting adhesives, and it can be used to quickly evaporate water from a water-based adhesive formulation.

Dielectric processing of water-based adhesives is commonly used in the furniture industry for very fast drying of wood joints in furniture construction. Common wood adhesives, such as polyvinyl acetate emulsions, can be dried in seconds with dielectric heating processes.

dielectric heat sealing/welding Dielectric sealing can be used on most thermoplastics except those that are relatively transparent to high-frequency electric fields. This method is used mostly to seal vinyl sheeting such as automobile upholstery, swimming pool liners, and rainwear. An alternating electric field is imposed on the joint, which causes rapid reorientation of polar molecules. As a result, heat is generated within the polymer by molecular friction. The heat causes the polymer to melt, and pressure is applied to the joint. The field is then removed, and the joint is held until the weld cools. The main difficulty in using dielectric heating as a bonding method is in directing the heat to the interface. Generally, heating occurs in the entire volume of the polymer that is exposed to the electric field.

Variables in the bonding operation are the frequency generated, dielectric loss of the plastic, the power applied, pressure, and time. The materials most suitable for dielectric welding are those that have strong dipoles. These can often be identified by their high electrical dissipation factors. Materials most commonly welded by this process include polyvinyl chloride, polyurethane, polyamide, and thermoplastic polyester. Because the field intensity decreases with distance from the source, this process is normally used with thin polymer films.

There are basically two forms of dielectric welding: radio frequency welding and microwave welding. Radio frequency welding uses high frequency (13–100 MHz) to generate heat in polar materials, resulting in melting and weld formation after cooling. The electrodes are usually designed into the platens of a press. Microwave welding uses high-frequency (2–20 GHz) electromagnetic radiation to heat a susceptor material located at the joint interface. The heat generated melts thermoplastic materials at the joint interface, producing a weld on cooling. Heat generation occurs in microwave welding through absorption of electrical energy similar to radio frequency welding.

Polyaniline doped with an aqueous acid, such as hydrochloric acid, is used as a susceptor in microwave welding. This introduces polar groups and a degree of conductivity into the molecular structure. It is these polar groups that preferentially generate heat when exposed to microwave energy. These doped materials are used to produce gaskets, which can be used as an adhesive in dielectric welding.

Dielectric welding is also commonly used for sealing thin films such as polyvinyl chloride for lawn waste bags, inflatable articles, liners, and clothing. It is used to produce high-volume stationery items such as loose-leaf notebooks and checkbook covers. Because of the cost of the equipment and the nature of the process, industries of major importance for dielectric welding are the commodity industries.

dielectric monitoring Dielectric monitoring is an analytical method that involves tracking the changes in the electrical properties, such as dielectric constant and dissipation factor, of a thermo-setting polymer as it cures. Generally, these properties change rapidly with time as the material cures and then begin to stabilize as gellation takes place. These properties are relatively constant after the specimen is fully cured. Dielectric monitoring is sometimes used along with or as an alternative to gel point determination as a quality control method to determine the reactivity of certain resin mixtures.

In the preparation of certain laminates (e.g., polyimide) dielectric monitoring is used to determine the stage in the processes at which laminating pressure can be increased so as not to extrude excessive resin out of the laminating stack and yet not have voids and poor interlaminar adhesion because the resin is too far advanced when pressure is finally applied. Dielectric monitoring in this manner is also called *dielectrometry* or *dielectric spectroscopy*.

dielectric properties A dielectric is an insulating material generally of polymeric composition. Several parameters define the dielectric properties of a given material. Of course, the dielectric material must be able to withstand the maximum voltage that will be seen in service, but, in AC dielectric applications, good resistivity as well as low energy dissipation are also desirable characteristics. The dissipation of electrical energy results in inefficiencies in an electronic component and causes heat buildup in the plastic part that acts as the dielectric.

Figure D.1 illustrates these dielectric properties and how they are tested. The relationship of the specimen, the electrode, and the electric field is shown.

The *dielectric constant* is that property of a dielectric that determines the electrostatic energy stored per unit volume for a unit potential gradient. For practical purposes, the dielectric constant is the ratio of capacitance of an assembly of two electrodes separated solely by a plastic insulating material to its capacitance when the electrodes are separated by only vacuum.

The dielectric constant of plastic materials is measured as specified in ASTM D150. It is a dimensionless factor derived by dividing the parallel capacitance of the system with a plastic material by that of an equivalent system with a vacuum as a dielectric. The lower the number, the better the performance of the material as an insulator.

In an ideal insulator, such as a vacuum, there is no energy loss to dipole motion of molecules. In solid materials, such as plastics, the dipole motion becomes a factor. A measure of the inefficiency is the dielectric constant or relative permittivity.

Dielectric heating of a material occurs when high-frequency voltage is applied to the material that forms the dielectric of a condenser. Dielectric heating results from the *dielectric loss* in the material. The dielectric loss is determined by how easily

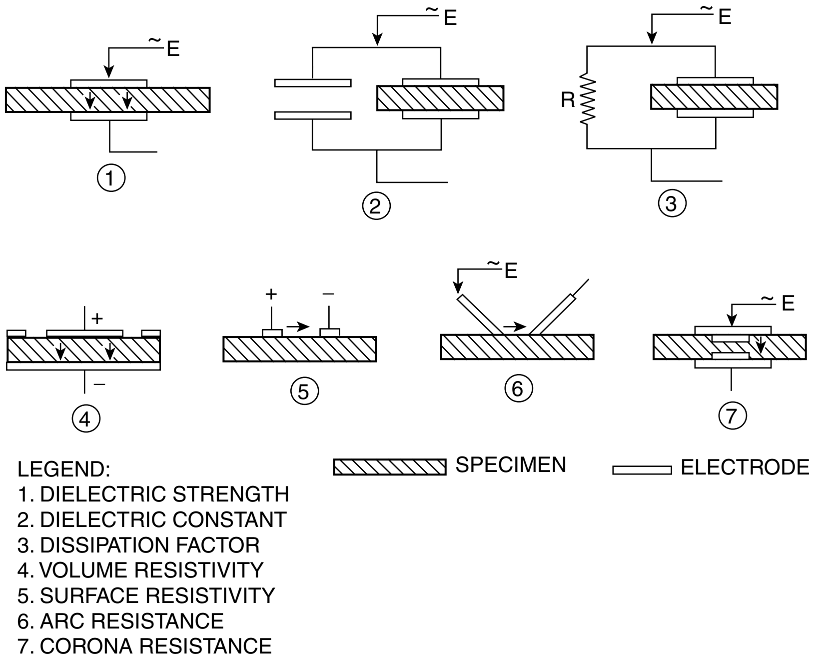


Figure D.1 Schematic illustration of electrical properties. (Ref: Craig, C.L., "Electrical Properties of Plastics" *Plastics Design and Processing*, Lake Publishing Co., Libertyville, Il, February 1962)

polar molecules can rotate in an alternating electric field. The relative motion of the molecules against one another causes heating.

Dielectric heating is the process used for sealing vinyl films and for preheating thermoset and thermoplastic molding compounds to remove moisture. If a polymer's dielectric loss increases significantly with temperature, a runaway condition could result that will lead to thermal degradation of a dielectric insulation (i.e., the high temperature causes the dielectric loss to rise which causes internal heating in the polymer leading to higher temperature and further increase in loss).

The *dielectric loss* in a material is the time rate at which electric energy is transformed into heat in a dielectric when it is subjected to a changing electric field. As the polar parts of a molecular chain continually try to align themselves with the alternating electric field, internal friction within the material causes heating.

The *dielectric loss factor* (*loss factor*) of a material is the product of the dielectric constant and the tangent of the dielectric loss angle for a material. This is a measure of how easily the material will heat up in a high-frequency field such as a radio frequency or microwave frequency oven.

Dissipation factor (*loss tangent*, *loss angle*, *tan dèlta*, *approximate power factor*) is the tangent of the loss angle of the insulating material. The dielectric power factor is the cosine of the dielectric phase angle (or sine of the dielectric loss angle). In a perfect dielectric, the voltage wave and the current are exactly 90° out of phase. As the dielectric becomes less than 100 percent efficient, the current wave begins to lag the voltage in direct proportion. The amount the current wave deviates from being 90° out of phase with the voltage is defined as the dielectric loss angle. The tangent of this angle is known as the loss tangent or dissipation factor.

A low dissipation factor is important for plastic insulators in high-frequency applications such as radar equipment and microwave parts; smaller values mean better dielectric materials with less dielectric heating. A high dissipation factor is important for polymers that are to be heated in a radio frequency or microwave oven for welding, drying, etc.

Dissipation factor is measured as specified in ASTM D150. Relative permittivity and dissipation factor are measured by the same test equipment.

The *power factor* is the cosine of the angle between the voltage applied and the current resulting. The *dielectric phase angle* is the angular difference in phase between the sinusoidal alternating potential difference applied to a dielectric and the component of the resulting alternating current having the same period as the potential difference. The *dielectric loss angle* is the difference between 90° and the dielectric phase angle.

Dielectric strength is the maximum voltage gradient that an insulating material can withstand before breakdown occurs, usually expressed as a voltage gradient, such as volts per mil. The applied voltage just before breakdown is divided by the specimen thickness to give the value in kV/mm. The surrounding area can be air or oil. Breakdown occurs when the material is punctured ("arced through").

The value obtained for the dielectric strength will depend significantly on the thickness of the materials being tested, the method of conditioning the materials before test, and the method of testing. Other factors that will influence dielectric strength values are homogeneity and moisture content of the specimen; dimension and thermal conductivity of the test electrode; frequency and waveform of the applied voltage; ambient temperature, pressure, and humidity; and electrical and thermal characteristics of the ambient medium. ASTM D149 measures dielectric strength. (*See also* dielectric strength.)

The *insulation resistance* is a measure of the resistance a plastic provides to current flow when two terminals are placed in contact with it. It is the ratio of the applied DC voltage on the electrodes to the total current between them. Insulation resistance is often reported as the ohms resistance generated between the two electrodes but is, in fact, a composite of volume and surface resistivity.

- *Volume resistivity* represents the extent to which current can pass through the bulk of the plastic and is dependent on the nature of the plastic itself.
- *Surface resistivity* is more a function of the nature of the plastic surface, its cleanliness, purity, and freedom from contamination. Surface resistivity is the ratio of the potential gradient parallel to the current along the surface to the current per unit width of surface. The most important factor about this measurement is the presence of moisture, which will significantly lower the surface resistance.

If an electric arc passes over the surface of a plastic, there is a tendency for *tracking* to occur. The arc initially passes through the air, but the surface of the plastic decomposes along the line of the arc. The result of the decomposition is a carbon track, which can conduct current. This causes further decomposing and increases the size of the current carrying track until the current passes completely along the surface. The value of arc resistance depends on the ease of decomposition of the plastic and the nature of the decomposition products.

dielectric strength Dielectric strength (ASTM D150) is the electrical property of insulating materials that indicates the level of voltage at which dielectric breakdown of the material begins to occur. This is especially critical for plastics. Dielectric strength is expressed in volts per mil, which indicates the voltage level that will cause dielectric breakdown through 1 mil of thickness. Thicker plastic sections will withstand higher voltage levels, but not proportionately higher. At sufficiently high voltage levels, corona and/or carbon tracking can occur. Cleanliness of the environment and contamination of the plastic are also factors.

As the thickness of an insulator increases, so does the voltage necessary to cause breakdown. However, this relationship is not linear. Importantly, the voltage gradient (volts/mil) at breakdown decreases as the thickness of the sample increases. Therefore, it is necessary to know the sample thickness in comparing dielectric strength values (usually given in volts/mil).

See also dielectric properties; high-voltage-resistant plastic.

die line In blow molding, die lines are vertical marks on the *parison* caused by damage of die parts or contamination. In pultrusion, a die line is the lengthwise flash or depression on the surface of a pultruded plastic part. The line occurs where separate pieces of the die join together to form the cavity.

die swell and die swell ratio The passage of polymer melt though an extrusion die normally involves constriction of the flow, because the cross-sectional area of the die is less than that of the melt-filled space behind it. The flow constriction imposes compression and shear on the melt. Because of its viscoelastic nature, the melt undergoes some elastic extension in the die. The net result of this is a degree of lateral expansion of the emerging extrudate known as die swell.

In blow molding, the *die swell ratio* is the ratio of the outer *parison* diameter (or parison thickness) to the outer diameter of the die (or die gap). Die swell ratio is influenced by polymer type, head construction, land length, extrusion speed, and temperature.

differential scanning calorimetry (DSC) Differential scanning calorimetry is a quality control method that measures the energy absorbed (endotherm) or produced (exotherm) during a specified time and temperature cycle. This technique can be used to determine whether a polymer cures in the same way from batch to batch. It can also be used to show the glass transition temperature of a polymer (generally as a break in the slope of the endothermic curve as a function of temperature).

Differential scanning calorimetry is an alternative to differential thermal analysis (DTA) for measurement of transition temperatures of polymers, especially where a determination has a quantitative aspect.

See also thermal analysis; differential thermal analysis (DTA).

differential thermal analysis (DTA) Differential thermal analysis is a process for measuring the difference in temperature between a specimen of the test substance and a specimen of a reference material. This is accomplished generally as a function of temperature or time. The test results are recorded in the form of a plot on which the temperature difference should be plotted on the ordinate with endothermic reactions downward and exothermic reactions upward.

Differential thermal analysis is widely used for determining exotherm and endotherm of reactive substances. It can also be used for determining transition temperatures, such as the glass transition temperature and the melt temperature of polymers (ASTM D3418). ASTM D472 provides directions for reporting thermoanalytical data.

See also thermal analysis; differential scanning calorimetry (DSC).

diffusion Diffusion is the mixing or self-dispersion of gases, liquids, or solid materials without outside influence. It is the transport of components from one part of the system to another. In plastics, the system most often consists of a polymer and a diffusant of much smaller molecular size. The diffusant is generally a gas, vapor, or liquid. In a polymer/penetrant system, the rate of transfer of the penetrant across a unit area of a section taken through the system should be proportional to the penetrant concentration gradient measured normal to the section. The *diffusion coefficient*, sometimes also called the *diffusivity*, is a measure of the diffusion.

The diffusion rate will depend heavily on the molecular size of the diffusion species and on the size of the gaps between polymer molecules. Crystalline structures have an ordered arrangement of molecules, and diffusion can occur in amorphous regions or through regions of imperfections. The crystalline regions in a polymer can thus be considered almost impermeable. Amorphous polymers exist in the rubbery state where there is an abundance of “free volume” so that diffusion can occur relatively easily.

diluent A diluent is an ingredient usually added to a formulation to reduce the concentration of the resin. Diluents are also used primarily to reduce the viscosity and to modify the processing conditions of some resins. Diluents will allow higher filler loadings.

There are *reactive* and *nonreactive diluents*. The reactive diluents become part of the final molecular structure of the polymer by reacting with the base resin during cure. The nonreactive diluents do not become part of the polymer but act as plasticizers or discrete regions surrounding the main polymer. Diluents do not evaporate as do solvents but become part of the final material.

Reactive diluents, such as *butyl glycidyl ether* or *cresyl glycidyl ether*, are often used in epoxy resin formulations. In epoxy formulations a reactive diluent is a compound containing one or more epoxy groups that functions mainly to reduce the viscosity of the mixture.

dimensional stability Dimensional stability is the ability of plastic parts to retain the precise shape in which they were molded, fabricated, or cast. Dimensional stability problems usually occur when the plastic part shrinks excessively when coming out of the mold or when it is undercured and continues to cure and shrink in the operating environment. Heat aging generally manifests itself as shrinkage caused by the polymer continuing to cure. The shrinkage of various thermoset molding compounds as a result of heat aging is shown in Fig. D.2.

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Figure D.2 Shinkage of various thermosetting molding materials as a result of heat aging. (Ref: Chottiner, J., "Dimensional Stability of Thermosetting Plastics", *Materials Engineering*, February 1962)

Dimensional stability problems also occur with plastics having high moisture absorption. These plastics will change their dimensions depending on the relative humidity of the environment. Plastics that most notably show this effect are cellulosic polymers and nylon, although most polymers are affected in some way.

Maximum dimensional stability is afforded by mineral-filled phenolics. Although the thermoplastics as a whole are weak in this respect, polystyrene, acrylic, rigid vinyls, and ethyl cellulose are exceptions, having satisfactory dimensional stability for many applications where the requirements are not of the severest order.

dimer A dimer is a substance comprising molecules formed from two molecules of the same monomer. The molecule progresses through the polymerization process in stages from *monomer* to *dimer* to *trimer* and onward.

dimethyl silicone polymer
See silicone rubber.

dip coating Dip coating is a simple coating process in which products are dipped in a tank of coating material, withdrawn, and allowed to drain in the solvent-rich area above the resin pool and then allowed to dry. The film thickness is controlled by viscosity, flow, percent solids by volume, and rate of withdrawal. This simple process can also be automated with the addition of a drain-off area, which allows excess coating material to flow back to the dip tank.

Dip coating is a simple, quick method that does not require sophisticated equipment. The disadvantages of dip coating are film thickness differential from top to bottom, resulting in a so-called wedge effect; fatty edges on lower parts of products; and runs and sags. Although this method coats all surface areas, solvent reflux can cause low film build. Light products can float off the hanger and hooks and fall into the dip tank. Solvent-containing coatings in dip tanks and drain tunnels must be protected by fire extinguishers and safety dump tanks. Using waterborne coatings can eliminate the fire hazard.

dip molding Dip molding, or *dip casting*, is a process of applying a protective coating as well as producing an article by repeated immersions of a mold or form into a solution, gel, paste, or melt. The mold plus the coating or the coating alone, stripped from the mold, may be the final product. In the latter case, dipping is especially useful to make shapes of intricate design that it would be impossible to make by other molding techniques or for which the die cost would be prohibitive. Typical products made by dip molding are toys, bathing caps, and vials.

Products that have to be stripped from the mold are made of an elastomeric material. If solvent is present it can be volatilized in an oven after each dipping period. Resins that have been used for dip molding include vinyl copolymers, vinylidene chloride, polyvinyl butyral, nylon, polyvinyl alcohol or acetal, and modified acrylics. For rigid products, cellulosic plastics, styrene, and similar resins can be used.

direct gate The direct gate is a large gate at the end of the *sprue*.

See also gate.

dishing Dishing is a symmetrical, more or less spherical distortion in a plastic, generally noted as a circular indentation in the surface of the molded part. Dishing is the opposite of *doming*.

dispersant In an *organosol* or other liquid suspension, a dispersant is a liquid component that has a solvating or peptizing action on the resin so as to aid in dispersing and suspending it.

dispersion A dispersion is a two-part system comprising a material in a state of fine division distributed through a continuous matrix of another material. The term *polymer dispersion* is most commonly applied to dispersions in which the disperse phase is a polymeric material and the dispersion medium is water. Stable colloidal aqueous dispersions of rubber and of certain other polymers are commonly known as *lattices*.

See also latex.

dispersion coating A dispersion coating is a coating consisting of a resin in a colloidal rather than a true solution or the process of applying such a coating. A common dispersion coating is that based on fluorocarbon materials such as polytetrafluoroethylene (PTFE). Dispersions of PTFE in water may be used to coat metallic or other smooth surfaces. After coating and drying, the surface must be heated above the gel point to fuse the polymer particles and produce a smooth coating.

displacement mold Combining compression and transfer mold design, a displacement mold is used to produce long tubelike sections with a closed end. A preform is loaded at the end of a plunger, and, as the mold closes, the compound extrudes down the plunger. The material is entrapped in the mold by a positive parting line design.

dissipation factor Dissipation factor is the electrical property of insulating materials that is a measure of the power loss in a plastic or other electrical insulating material. It is a mathematical term defined as the ratio between the permittivity and the conductivity of an electrical insulating material. In simple terms, it is an indicator of the power lost in the operating system and is essentially identical to power factor for low losses.

Quantitatively, lower dissipation factors result in higher-quality, higher-performance electrical or electronic systems, having lower electrical losses. Dissipation factor values have no units because they are mathematical ratios. Low dissipation factor values, desirable for electronic plastics, would be below 0.01 and 0.001. Two other terms for dissipation factor are *loss tangent* and *tan delta*. A related term is *quality factor* or *Q factor*, which is the reciprocal of the dissipation factor.

See also dielectric properties; electronic plastic.

doctor roll, doctor blade, doctor bar A doctor roll, also known as a doctor blade or doctor bar, is a device for regulating the amount of liquid material on the roller of a spreader. It accomplishes this by maintaining an offset to the roll that picks up the coating from the tank or by having a fine wire wound around the doctor roll so that the spaces between the wires act as metering points by which the coating material is applied. The doctor roll can be used to spread and control the amount of resin applied to roving, tow, tape or fabric as well as to coat a continuous film or sheet.

domain Domain is a morphological term used in noncrystalline systems, such as block copolymers. It describes regions in which chemically different sections of the molecular chain separate, generating two or more amorphous phases.

dome, doming In reinforced plastics, the dome is the end of a filament-wound cylindrical container (i.e., that portion that forms the integral ends of the container).

In general, doming is a symmetrical, more or less spherical distortion of a flat or cured part of a plastic, which causes it to be more or less cup-shaped. Doming may be due to warping. Doming is the opposite of *dishing*.

double-backed tape Double-backed tape is tape having adhesive on both sides. It is usually made from a polymeric film with *pressure-sensitive adhesive* coated on both sides. The formulation of the adhesive is very important to provide a sufficient degree of adhesion yet allow the double-backed tape to be unrolled from a roll of product. The film is generally only a carrier for the adhesive.

Double-backed tape is generally used in laminating one substrate to another. Often the carrier film and adhesive are transparent to allow parts to be viewed through the tape. Certain office product tapes are double-backed tape having a clear carrier and a clear pressure-sensitive adhesive on both sides of the carrier.

double gate When one gate does not allow the plastic to flow in rapidly enough to fill out the mold in the required time, two or more gates are provided for in the mold design. Double gating is sometimes used to minimize *knit lines*.

See also gate.

double-shot molding Double-shot molding is a process of turning out thermoplastic parts having two colors by successive molding operations.

draft The draft is the degree of taper of a sidewall or the angle of clearance of the vertical surface of a mold. The draft is designed to facilitate removal of a part from a mold. The *draft angle* is the angle of taper on a mold or mandrel that facilitates removal of the finished part.

drape Drape is the bending or droop in a prepreg or fabric. Drape is tailored to the specific application. A worker making a hand layup on a sharp bend needs plenty of drape, but the press laminator making flat laminates does not need any drape at all.

Thermoset prepregs can be formulated and processed to have various degrees of drape. Thermoplastic prepregs are very “woody” and have little drape; therefore, they generally need to be heated to form around sharp mold sections.

drape assist frame In sheet thermoforming, the drape assist frame is a frame shaped to the peripheries of the depressed areas of the mold and suspended about the sheet to be formed. During forming, the assist frame drops down, drawing the sheet tightly into the mold and thereby preventing webbing between high areas of the mold. The drape assist frame also permits closer spacing in multiple molds. The drape assist frame can be made of anything from thin wires to thick bars.

drape forming Drape forming is a method of thermoforming thermoplastic sheet in which the sheet is clamped into a movable frame and then is draped over the high point of a male mold. Vacuum is then pulled to complete the forming process.

See also thermoforming.

drawing Drawing is the process of stretching a thermoplastic sheet or rod to reduce its cross-sectional area. Drawing is generally done to shape the plastic into its final form, but often the term is used to describe the process of creating a more orderly arrangement of polymer chains with respect to each other.

See also orientation.

draw ratio The draw ratio is reflective of the amount of stretching undergone by a plastic material in a stretching or drawing process. It is the ratio of the cross-sectional area of the material before and after stretching.

The *draw down ratio* is the ratio of the thickness of the extruder die opening to the final thickness of the product.

drilling Thermoplastics and thermosets may be drilled with any standard drill used for metals. However, there are drills specifically designed to drill plastic materials. Drills that are not made of high-speed steel or solid carbide should be carbide or diamond tipped. For drilling plastics, drills should have highly polished flutes and chrome-plated or nitrided surfaces. Drills should be ground with a 70–120° point angle and a 10–25° lip clearance angle. The rake angle on the cutting edge should be zero or several degrees negative. Highly polished, large, slowly twisting flutes are most desirable for good chip removal.

Normal feed rates are in the range of 0.001–0.012 in./rev for holes of 1/16- to 2-in. diameter with speeds of 100–250 ft/min, using lower speeds for deep and blind holes. Generally, the plastic supplier can provide suggested drill sizes and speeds for thermosets and thermoplastics.

Holes drilled in most thermoplastics and some thermosets are generally 0.002- to 0.004-in. undersized because of thermal expansion effects. To alleviate this effect, drilling could be accomplished in two stages. A small pilot drill should be used first, followed by the required size drill. The drill should be lifted frequently to prevent overheating. Thermoplastics may require external cooling to reduce frictional heat and gumming. Compressed air blown into the hole will help remove chips and provide some cooling effect.

The part must be held firmly during drilling to counter the tendency for the tooling to grab and spin the work. Circle cutters are often preferred for making holes in thin materials.

drop impact test The drop impact test measures the impact resistance of plastics. A predetermined weight is allowed to fall freely onto the specimen from varying heights until the specimen or product fails. The energy absorbed by the specimen is measured and expressed in in.-lb or ft-lb.

The drop impact test is ideal for measuring impact resistance of materials or parts that will be used in a fashion in which they could either be hit with a sharp object (a hammer, for example) or dropped (a plastic container, for example). ASTM D2463 describes a drop impact test for a blow-molded container.

dry blend Dry blend is a free-flowing dry compound prepared without fluxing or additions of solvent. Dry blend is also called *powder blend.* A dry blend contains all the necessary ingredients mixed in a way that produces a dry, free-flowing particulate material. The term is commonly used in connection with polyvinyl chloride compounds.

Dry coloring is a method commonly used by fabricators for coloring plastics by tumble blending uncolored particles of the plastic material with selected dyes and pigments.

Table D.3 Suggested Drying Conditions for Generic Thermoplastic Resins (Ref: Barry, C.M.F. and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

Material	Water Absorption, %	Maximum Water, %	$T_{\text{extrusion}}$, °C	$T_{\text{inj. molding}}$, °C	T_{drying}, °C	t_{drying}, h
Acrylonitrile butadiene styrene (ABS)	0.25–0.40	0.20	225	260	88	3–4
Acetal	0.25	—	—	200	93	1–2
Acrylic	0.20–0.30	0.08	190	235	82	1–2
Polyamide-6 (nylon) (PA-6)	1.60	0.15	270	290	82	4–5
Polyamide-6, 6 (nylon) (PA-6,6)	1.50	0.15	265	265	82	4–5
Polycarbonate (PC)	0.20	0.02	290	300	120	3–4
Polybutylene terephthalate (PBT)	0.08	0.04	—	240	125	2–3
Polyethylene terephthalate (PET)	0.10	0.005	250	255	160	4–5
Polyetherimide (PEI)	0.25	—	—	370	155	4–5

High-density polyethylene (HDPE)	<0.01	—	210	250	—	—
Low-density polyethylene (LDPE)	<0.01	—	180	205	—	—
Linear low-density polyethylene (LLDPE)	<0.01	—	260	220	—	—
Polyphenylene oxide (PPO)	0.07	—	-250	275	100	2–3
Polypropylene (PP)	<0.01	—	235	255	—	—
Polystyrene (PS)	0.03	—	210	220	—	—
High-impact polystyrene (HIPS)	0.10	—	235	230	—	—
Polyphenylene sulfide (PPS)	—	—	—	330	140	2–3
Polysulfone (PSU)	0.30	0.05	345	360	135	3–4
Polyurethane (PU)	0.10	0.03	205	205	82	2–3
PU (elastomers)	0.07	0.03	200	205	100	2–3
r-PVC (polyvinyl chloride)	0.10	0.07	185	195	—	—
p-PVC (polyvinyl chloride)	0.02	—	175	150	—	—
Styrene acrylonitrile (SAN)	0.03	0.02	215	245	82	3–4

drying Plastics, when exposed to the atmosphere, will pick up moisture. How much moisture will depend on the type of polymer, the humidity of the surrounding air, and several other factors. If the amount of moisture pickup is excessive, it may affect the performance of the processing machine, the cosmetic qualities of the product being produced, or even the physical and structural properties of the product. It is therefore generally understood that the processing of both thermosets and thermoplastics that contain high concentrations of moisture normally results in the production of unacceptable products.

Surface moisture on nonhygroscopic polymers can be removed easily by a simple hot air dryer with a single-pass air circuit. Table D.3 shows suggested drying conditions for certain thermoplastic resins. Effective control of moisture in hygroscopic polymers (e.g., ABS and nylon) almost always requires a dehumidifying air dryer. The moisture content in hygroscopic polymers will depend on the type of polymer, the length of time the polymer is exposed to the atmosphere, the humidity of the atmosphere, and the temperature.

Plastic materials, generally molding compounds or wet sheets, are dried by equipment that uses gas, steam, or electricity or infrared rays as a source of heat. Dielectric heat is most commonly used for preheating, as opposed to drying.

The two types of dryers are static trays and conveyors, which are often vibrated as they move along. Atmospheric tray dryers are not suitable for some materials, notably nylon molding powder that oxidizes in air and requires vacuum drying. A commonly used variant of the tray type is the truck dryer. Here the loaded trays are placed on trucks and rolled into the drying enclosure. Continuous conveyor drying systems are extensively used where the product must be dried from the wet solid state and where production requirements are high.

dry spots In reinforced plastics, a dry spot is an area of incomplete surface film. A *dry fiber* is a condition in which fibers are not fully encapsulated by resin during pultrusion. A *dry laminate* is a laminate containing insufficient resin for complete bonding of the reinforcement.

dry strength In adhesive bonding, dry strength is the strength of an adhesive joint determined immediately after drying under specified conditions or after a period of conditioning in the standard laboratory atmosphere. This is as opposed to *wet strength*, where the adhesive joint is tested immediately after conditioning in a moist environment.

dry winding In filament winding, dry winding is a term used to describe filament winding using preimpregnated roving, as differentiated from *wet winding* where the roving is impregnated in a liquid resin bath immediately before winding on a mandrel.

ductility Ductility is the amount of plastic strain that a material can withstand before fracture. It is also used to describe the ability of a material to deform plastically before fracturing. Thus ductile polymers are generally tough, elastic polymers that can deform readily and have a moderately high degree of elongation (e.g., elastomers, toughened thermoplastics).

duplicate cavity plate The duplicate cavity plate is a removable plate that retains cavities. It is used where a two-plate operation is necessary for loading inserts.

durometer hardness Durometer hardness is a measurement of the indentation hardness of a plastic material. It is the extent to which a spring-loaded steel indenter protrudes beyond its pressure foot into the sample material. Hardness is measured by a *Shore durometer.*

See also hardness.

dwell The dwell is a pause in the application of pressure to a mold, made just before the mold is completely closed. The dwell allows the escape of gas from the molding material.

In filament winding, dwell is the time that the traverse mechanism is stationary while the mandrel continues to rotate to the appropriate point for the traverse to begin a new pass.

In a standard autoclave cure cycle, dwell is an intermediate step in which the resin is held at a temperature below the cure temperature for a specified period of time sufficient to produce a desired degree of cross-linking. It is used primarily to control resin flow.

dyeing (fibers) The dyeing of fibers is a complex art in itself. A successful dye must either form strong secondary bonds to polar groups on the polymer or react to form covalent bonds with functional groups on the polymer.

Because the fibers are dyed after spinning, the dye must penetrate the fiber and diffuse into it from the dye bath. The size of the dye molecule is such that it cannot penetrate crystalline areas of the polymer, so it is mainly the amorphous regions that are dyed. This often conflicts with the requirement of high crystallinity in the fiber. To counteract this effect, highly crystalline polymers (e.g., polyacrylonitrile) usually contain minor amounts of plasticizing comonomers to enhance dye penetration.

On the other hand, nonpolar and nonreactive fibers, such as acrylic fiber, have no sites on which the dye can bond even if it could penetrate. This is overcome by incorporating a finely divided solid pigment into the polymer before melt spinning. Copolymers of propylene and a monomer with dye-accepting sites are also now available.

dynamic mechanical analysis (DMA) Dynamic mechanical analysis (DMA) measures a compound's modulus (stiffness) as its temperature is raised. It is a technique in which a material is subjected in a suitable mode to an oscillatory load under an appropriately controlled temperature program. The dynamic modulus and/or damping of the material is determined as a function of temperature.

This instrument has provided interesting insights into properties of phenolics as well as those of diallyl phthalate, thermoset polyester, silicones, and epoxies, by indicating the ability of thermosets to retain their modulus at elevated temperatures.

See also thermal analysis.

dynamic mechanical spectrophotometer (DMS) The dynamic mechanical spectrophotometer measures the viscoelastic properties of polymers, thus determining a compound's viscosity and elastic modulus following the change of these properties over time and changes in temperature.

dynamic testing Dynamic testing refers to the test of a polymeric specimen when subjected to sudden or repeated (cyclic) loads that are not intended to cause failure. Dynamic testing is of special importance in the case of polymeric materials because of their well-known sensitivity to the speed of loading (*see* impact strength), a characteristic of viscoelastic materials.

The analysis of dynamic loads, particularly those involving repeated loads (sinusoidal testing) is complex and requires a mathematical base. Quantities such as the storage and loss moduli and the loss tangent or loss factor are defined, measured, and often reported in graphic form.

Besides providing useful information for applications involving dynamic loading (high strain rates, shock and vibration damping, etc.) dynamic testing is widely used as a convenient way of assessing temperature effects, and even for the elucidation of the chemical and physical structure of polymeric systems.

See also fatigue; endurance.

E

E-glass E-glass, also called electrical-grade glass, belongs to a family of glasses with low alkali content, usually under 2.0 percent. It is a *borosilicate* type of glass most suitable in *electrical-grade laminates*. Electrical properties remain more stable with these glasses because of the low alkali content. E-glass is also the glass type most widely used for reinforced plastics because of its low cost, easy handling quality, and generally good properties. Laminates made from E-glass have generally good resistance to water, fair resistance to alkali, and poor resistance to acid.

See also glass fiber.

Ebonite Ebonite is hard *natural rubber* that is vulcanized to its maximum degree. It is the final product of the reaction of rubber with an excess of sulfur. Ebonite is a hard, inextensible solid containing about 32% combined sulfur. Low-cost fillers and extenders are used primarily to minimize difficulties in handling the rubber-sulfur mix before vulcanization. It has been produced on a commercial scale since about 1860.

Ebonite stocks may be prepared for vulcanization by calendering or extrusion. Vulcanization, as with soft rubber, is affected by heat and pressure. In some cases the rubber may be given a soft cure, formed into a desired shape, and then cured to the final hard rubber state.

Ebonite can be machined and is often produced in bar, tube, or sheet stock for this purpose. Major applications make use of its chemical inertness and corrosion resistance as well as its electrical and thermal insulating properties. The material softens at about 50°C and, hence, is not suitable for high-temperature applications.

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eight-harness satin weave
See weave.

ejector assembly mold hardware The *ejector pin* (or *sleeve*) is a pin or thin plate that is driven into a mold cavity from the rear as the mold opens, forcing out the finished piece. This is also known as a *knockout pin*. The *ejector plate* is a plate that backs up the ejector pins and holds the *ejector assembly* together. The *ejector return pins* are projections that push the ejector assembly back as the mold closes. These are also called *surface pins* and *return pins*. The *ejector rod* is a bar that actuates the ejector assembly when the mold is opened.

Ejector pads are plates that, in essence, are used as knockout pins. They form part of the molding surface, which eject cold molded products from a mold, the material being too soft to withstand small area knockout pins. Such steel pads may cover the entire bottom surface of the mold or form substantial areas of the molded piece.

elastic deformation The elastic deformation is that part of the deformation of an object under load that is immediately recoverable when the load is removed. *Elastic recovery* is the fraction of a given deformation that behaves elastically. A perfectly elastic material has an elastic recovery of 1; a perfectly plastic material has an elastic recovery of 0.

elasticity Elasticity is that property of a material by virtue of which it tends to recover its original size and shape after deformation. If the strain is proportional to the applied stress, the material is said to exhibit *Hookean* or *ideal elasticity*. Sometimes materials with this property are also said to be *viscoelastic materials*.

See modulus of elasticity; Hook's Law.

elastic limit The elastic limit is the extent to which a material can be stretched or deformed before taking on a permanent set. *Permanent set* occurs when a material that has been stressed does not recover its original dimension, as when a 12-in. piece of rubber that has been stretched becomes 13-in. long when relaxed.

elastic memory Elastic memory or *plastic memory* is the phenomenon by which cast plastic sheets that are heated above a certain temperature (generally the *heat distortion temperature*) have a strong tendency to revert to their original flat shape. Thus a flat sheet that has been thermoformed to a new shape reverts to a flat sheet if sufficiently heated.

Although this limits the maximum service temperature of a material, it allows the fabricator to reheat and reform a sheet without loss if he happens to make a mistake in shaping it. Molded parts exhibit the same tendency. In attempting to relieve the strains incurred in molding, they tend to distort. As in sheet fabrication, this also limits the top service temperature in a molding.

elastomer ASTM defines an elastomer as a macromolecular material that returns rapidly to approximately its initial dimensions and shape after substantial deformation by weak stress and release of the stress. Elastomers (or *rubbers*) are an important group of polymers that may be either thermosetting or thermoplastic. This group of materials includes thermoplastic elastomers, melt-processable rubbers, thermoplastic vulcanizate, synthetic rubbers (e.g., butyl, neoprene, nitrile, and silicone rubbers), and natural rubber.

An elastomer is a material that at room temperature stretches under low stress to at least several times in length and snaps back to the original length on release of stress. The properties of typical elastomers are defined by the following requirements:

a. They must stretch rapidly and considerably under tension, reaching high elongations (200–1000%) with low damping (i.e., little loss of energy as heat).
b. They must exhibit high tensile strength and high modulus (spiffiness) when fully stretched.
c. They must retract rapidly, exhibiting a phenomenon of snap or rebound.
d. They must recover their original dimension fully on the release of stress, exhibiting the phenomena of resilience and low permanent set.

The molecular requirements of elastomers may be summarized as follows:

a. The material must be a high polymer.
b. It must be above its glass transition temperature (T_g) to obtain high local segment mobility (most thermoplastics and thermoset plastics operate below their T_g).
c. It must be amorphous in its stable (unstressed) state for the same reason.
d. It must contain a network of cross-links to restrain gross mobility of its chains.

The process by which a network of cross-links is introduced into an elastomer is called *vulcanization*.

Up until World War II, almost all elastomers were based on natural rubber. During the war, synthetic rubbers began to replace the scarce natural rubber. Since that time production of synthetics has increased until it now far surpasses that of natural rubber. There are thousands of different elastomer compounds. Not only are there many different classes of elastomers, but also individual types can be modified with a variety of additives, fillers, and reinforcements. In addition, curing temperatures, pressures, and processing methods can be varied to produce elastomers tailored to the needs of specific applications.

There are roughly 20 major classes of elastomers. Two basic specifications provide a standard nomenclature and classification system. The ASTM standard D1418 categorizes elastomers into compositional classes. A joint ASTM-Society of Automotive Engineer (SAE) specification, ASTM 2000/SAE J200, provides a classification system based on material properties.

The nomenclature for elastomers, common names, ASTM designations, and general properties and characteristics are summarized in Appendix C. A listing of representative tradenames, suppliers, and characteristics of specific elastomers may be found under the name of the elastomer.

See also specific elastomers by name.

electrical laminate The electrical and electronic industries use large quantities of laminated materials for primary and secondary insulations. Laminate reinforcements include paper, fabrics, and glass mats. Resins include phenolic, melamine, silicone, epoxy, and polyester. There are generally two classes of laminates used in the electrical and electronic industries: copper-clad laminates that are covered with copper foil for use in printed wiring boards and unclad laminates that are used without foil for insulation.

The National Electrical Manufacturers Association (NEMA) has organized and maintained standards on the manufacture, testing, and performance of laminated thermosetting products in the form of sheets, rods and tubes. NEMA material descriptions and the properties of NEMA-type laminates are provided in Appendix E.

The available thicknesses of laminates are a function of the type of resin binder and the thermal conductivity of the reinforcement. Cotton-based laminates can be molded up to 10 in. thick, whereas some glass-based grades are limited to 4 in.

Key physical properties are highly influenced by the reinforcing form. Paper-based laminates have a higher water absorption than do glass fabric-based grades. Phenolic resin-based grades have higher water absorption than do epoxy resin-based grades. Izod impact strengths are highest for those laminates based on glass fibers, and the same is true for flexural strengths. In most applications the dimensional stability of laminates is important. Laminates may contain considerable internal strain that can result in deformations called *warp* and *twist*.

The electrical strength of laminates is strongly affected by humidity. The electrical strength of paper-based grades decreases dramatically as humidity increases; sometimes by a factor of eight. That of the glass fiber grades also decreases, but only slightly. NEMA Laminate Grades G-5, G-7, and G-9 are used in arcing applications and all excel 180 s in the ASTM D495 arc resistance test.

electric discharge machining Electric discharge machining (EDM) is a metal working process applicable to mold construction in which controlled electrical sparking is used to erode the workpiece and form shapes.

electric insulation The term electrical insulation applies to any material that can retard the flow of electricity. Electrical insulators are used to prevent the passage or escape of electric current from conductors.

See also dielectric; dielectric properties.

electrocoating Electrocoating is a sophisticated dipping method of coating that was commercialized in the 1960s to solve severe corrosion problems in the automotive industry. In principle it is similar to electroplating, except that organic coatings, rather than metals, are deposited on products from an electrolytic bath.

Electrocoating can be either anodic (deposition of coatings on the anode from an alkaline bath) or cathodic (deposition of coatings on the cathode from an acidic bath). The bath is aqueous and contains very little volatile organic solvent. The phenomenon called *throwing power* causes inaccessible areas to be coated with uniform film thickness. Electrocoating is gaining a significant share of the primer and one-coat enamel coating market.

Advantages of electrocoating include environmental acceptability owing to decreased solvent emissions and increased corrosion protection to inaccessible areas. It is less labor intensive than other methods, and it produces uniform film thickness from top to bottom and inside and outside for products with a complex shape. Disadvantages are the high capital equipment costs and higher material costs, and more thorough pretreatment is required. Higher operator skills are also required.

electroformed mold An electroformed mold is a mold made by electroplating metal on the reverse pattern of the cavity. Molten steel may then be sprayed on the back of the electroformed mold to increase its strength.

electroless and electrolytic-plated plastics
See metallization of plastics; plating.

electromagnetic shielding Electromagnetic shielding (EMS) is the presence of a conductive, protective encasement around an item of electrical or electronic equipment or some of its components. Electromagnetic shielding is installed to exclude or reduce electric and/or magnetic flux within or beyond the equipment or one or more of its elements. EMS is often provided by conductive plastics.

EMS shields equipment that can produce *electromagnetic interference* (EMI) or that is affected by it (e.g., computers, television sets, telephones, etc.). Metal housings provide excellent shielding. However, conductive plastics offer lower part weight and greater facility of production. Very high conductivities have become achievable at low loading levels with some conductive metal fillers such as stainless steel fibers.

electromigration Electromigration is a detrimental effect of uncontrolled, or migrating, current on a plastic or insulating material. A common example is electromigration between conductors on a printed wiring board. This electromigration allows undesired current flow between adjacent conductors, resulting in permanent surface deposits called *dendrites* or *trees*. These deposits cause deterioration of the circuit function for which the printed wiring board has been designed.

electronic plastic Electronic plastics are defined as that group of plastic materials having certain electrical properties, which provide high performance in specific electronic product applications. This term has come into use in recent years as plastic suppliers have sought to develop and produce a wide variety of controlled-property and higher-purity plastics that better meet the requirements of high-performance and advanced electronic devices, assemblies, and systems. In addition, military and space agencies have sponsored major programs to achieve specific improvements in plastics not available in commercial plastics.

The property improvements sought cover a wide range of electrical and electronic performance requirements, such as:

- lower electrical losses for high-speed circuitry used with advanced semiconductors for high-speed computer systems
- Lower thermomechanical stresses for sensitive semiconductor devices and fine metallic interconnections in microelectronics
- Lower-thermal-expansion printed circuit boards for fine-featured solder joints in high-density interconnection circuitry
- Greater resistance to carbon tracking during arcing in high-voltage systems
- Greater resistance to electrical interference effects of electrostatic discharges (ESD) in electrical and electronic systems
- Improved resin flow control around closely spaced high-density semiconductor assemblies
- Many more specific property improvements for plastics used in advanced and high-performance electrical and electronic systems.

Low-electrical-loss plastics are those having reduced dielectric constant and/or reduced dissipation factor. There is a constant and continuing effort to achieve these electrical property improvements for high speed circuitry used in high-speed computer systems and electronic data transmission systems, because the speed of electronic signals is greatly affected by these electrical loss characteristics of plastics. For instance, the speed of an electronic signal is delayed in a mathematical relation to the increased dielectric constant of plastics used in the electrical assembly, whether the plastic is used as a substrate for circuitry interconnections or as a coating or molding used to cover or encapsulate electrical or electronic devices in the assembly.

Thus the lower the dielectric constant of the plastic, the greater the signal speed. Dielectric constant values of plastics are controlled by such parameters as polymer structure, plastic formulation and additives, polymer purity, and operating temperature and frequency of the electrical system. Therefore, lowest electrical losses require not only high-performance plastics, but also achieving the lowest operating temperature by thermal management techniques and/or use of plastics whose properties are more stable as operating temperatures rise.

Certain classes of plastics, such as silicones, fluoropolymers, and others, have more stable electrical properties than many other plastics and polymer structures. In plastics having less stable electrical and electronic properties, these properties worsen as operating conditions worsen. For instance, dielectric constant and/or dissipation factor increase as temperature or humidity increase, with this increase often being dramatic or even destructive at the glass transition temperature of the plastic. Those property values are also affected by the frequency of the electrical system. (*See also* dielectric constant; dissipation factor.)

High-thermal-conductivity plastics are those that have been formulated to provide higher thermal conductivity while maintaining good electrical insulating properties. This is increasingly critical because of the increasing heat dissipation requirements of electronic systems. Thermally stable plastics are also important for the same reason. (*See also* high-thermal-conductivity plastics; thermally stable plastics)

electrostatic discharge (ESD) Electrostatic discharge (ESD) is the undesirable generation of electricity under various conditions, often caused by mechanical movements such as handling of plastic parts or walking on plastic carpets. Electrostatic discharges can create voltage levels sufficient to be physically and uncomfortably felt and to damage sensitive electronic components such as semiconductors.

High-resistivity materials such as certain plastics are specifically susceptible to the generation of ESD. This problematic property of certain plastics is often improved by incorporating certain conductive additives and fillers called *antistats* to the plastic to reduce the resistivity of the plastic material.

See also static electricity; antistatic agent.

electrostatic powder coating

See powder coating.

elongation Elongation is the deformation of a material caused by stretching. It is a measure of the elasticity or toughness of a material. As a rule of thumb, a rubber with less than 100 percent elongation will usually break if doubled over on itself.

Specifically, elongation is the increase in gauge length of a tension specimen within the elastic limit when it is subjected to a tensile stress. Elongation is usually expressed in percentage of the original length and is often called *percentage elongation*. It is also expressed in units of in./in.

The *elongation at break* is the elongation recorded at the moment of rupture of a specimen, also expressed as a percentage of the original length.

embossing Embossing is the process for decorating plastic sheets or molded products generally with mating dies or rolls that produce a raised design on one side and a corresponding depressed design on the opposite side of the part. Generally, embossing is a technique used to create depression of a specific pattern on plastic film or sheeting. Such embossing, in the form of surface patterns, can be achieved on molded parts by the treatment of the mold surface with photoengraving or another secondary process.

Embossing may be applied to continuous rolls of material or to single sheets or pieces. The design may be raised on one side and the other side remains flat, as in the embossing of belts, handbag materials, etc. Embossing may also be carried out by a rotating cylinder, when it is sometimes referred to as *calendering*. The process of imprinting or decorating plastics by means of a depressed design is also, although incorrectly, called embossing. Such a marking is caused by a heated die under pressure.

See also hot decorating.

emulsifier An emulsifier is a substance that is surface active and allows two immiscible liquids to remain intimately mixed and stable. An *emulsion* is a suspension of fine droplets of one liquid in another.

Emulsifiers impart stability to an emulsion by lowering the interfacial tension between the two immiscible liquids that make up the emulsion (one dispersed in the other in the form of droplets). In the plastics industry emulsifiers are used with any product that is in the form of an emulsion, or they can be used in the emulsion polymerization of various polymers.

Although small amounts are used, emulsifiers that act as surface-active agents or surfactants can have a significant effect on the surface behavior of the system in which they are placed. The chemistry of the emulsifying action generally involves the use of a material that has a molecule, or ion, that contains a hydrophilic group at one end and a hydrophobic group at the other end.

There are three basic types of emulsifiers: anionic, cationic, and nonionic. Choice of an emulsifier is dependent on the system to be emulsified, the degree of stability required, and the end use conditions.

Major suppliers of emulsifying agents include Akzo Chemicals Inc.; Ashland Chemical Inc.; Dow Chemical; Du Pont; Emery Group; Mobay Corp.; and Witco Corp.

emulsion polymerization Emulsion polymerization is one of the four basic methods of producing a polymer: bulk, solution, emulsion, and suspension polymerization. If a monomer can be polymerized in a water emulsion, then one can retain the low viscosity needed for good heat control without the hazards associated with the handling of solvents. Such a procedure is called emulsion polymerization. Polyvinylidene fluoride is an example of a polymer that can be produced in this way.

Reactant rates and molecular weights are usually higher with this method than with mass or solution polymerization. The molecular weight distribution is also often quite narrow, water is cheaper and less hazardous than solvent, and recovery steps are not complex. However, ingredients must be added to aid emulsification. This added contamination and the requirement of a drying step constitute significant disadvantages for the process.

enamel Enamel is a coating that on hardening has an enameled or glossy face. The word enamel in the paint industry refers to glossy varnishes with pigments or to paints of oxide or sulfate pigments mixed with varnish to give a glossy face. They vary widely in composition, in color and appearance, and in properties. As a class, enamels are hard and tough and offer good mar and abrasion resistance. They can be formulated to resist attack by the most commonly encountered chemical agents and corrosive atmospheres.

Because of their wide range of useful properties, enamels are one of the most widely used organic finishes in industry and are especially used as household appliance finishes. Enamels are generally baked, which drives off the solvent and fuses the resin into a uniform vitreous layer. Modified phenol melamine and alkyd melamine synthetic resins produce tough and resistant enamel coatings. Quick-drying enamels are cellulose lacquers with pigments.

encapsulation Encapsulation (also called *potting*) is a process in which parts, mainly electronic units or assemblies, are coated with any one of a variety of plastic materials to provide electrical insulation, resistance to mechanical and thermal shock, and protection of the part from the effects of moisture and chemical attack. There are a number of techniques for encapsulation of parts, and because many of them are similar to *casting*, the encapsulation process can be considered an offshoot of the casting process.

Encapsulation is often performed with resins containing fillers such as mica, aluminum oxide, milled glass fibers, and many others. Although epoxies are the resins most generally used, polyesters, filled and unfilled silicones, urethanes, and polysulfides are also used. By the proper choice of fillers it is possible to match expansion rates of the electronic part and the encapsulant, increase the thermal conductivity of the part, and considerably upgrade the electrical and mechanical properties of the assembly.

In some assemblies where a transparent encapsulant is necessary to see the part, filled materials cannot be used. In these cases a clear elastomeric material, such as silicone, is normally used. The gel-like structure of the encapsulant then absorbs the thermal stresses simply by deforming, thus not stressing the electronic component. When transparent encapsulants are used, the job of locating and replacing a damaged or defective component is simplified.

The encapsulation operation may be as simple as pouring the filled, catalyzed resin over the part, or it may be improved by the use of a vacuum to remove all the air from the component and the resin. The part to be encapsulated is usually placed in a temporary container, the resin is introduced under vacuum conditions, and the entire assembly is cured. After curing the container may or may not be removed.

The above technique is usually applied when small quantities of parts and assemblies must be encapsulated or for very large parts where automatic equipment may not be practical. For large quantities of parts (e.g., resistors, capacitors, transistors) *transfer molding* is generally used. Current techniques use transfer molding with liquid resins. These resins can be injected at considerably lower pressures than the molding powders that were formerly used. The advantages of the lower pressures are that part deformation is reduced, lower clamping pressures are required, and somewhat less expensive tooling may be used. These liquid resins can be one- or two-component materials. Polyester resins are the materials in widest use, but epoxies, silicones, and urethanes are also used.

See also transfer molding.

endothermic reaction An endothermic reaction is a reaction in which heat is absorbed.

engineering plastic Engineering plastics are high-stability, high-performance thermoplastics that lend themselves to engineering design, for example, gears and structural members. They have a sufficiently high set of physical properties to be used in engineered products. In many applications engineering plastics can be considered as alternatives to metals. These plastics are usually suitable for applications up to 125°C, well above the thermal stability of many commercial plastics. The next higher grade of plastics, so-called *high-performance plastics*, is usually suitable for product designs requiring stability above 175°C.

Included in the term engineering plastics are several structural plastics with or without fillers or reinforcements. The following properties are associated with "engineering" plastics: (1) high strength-to-weight ratio, (2) retention of mechanical properties at elevated temperature, (3) low creep, (4) low coefficients of thermal expansion, (5) good electrical properties, and (6) good chemical resistance.

Generally included under the classification of engineering plastics are:

- Acrylonitrile butadiene styrene
- Acetal
- Acrylic
- Fluorocarbon
- Nylon
- Phenoxy
- Polybutylene
- Polyaryl ether
- Polycarbonate
- Polyether (chlorinated)
- Polyether sulfone
- Polyphenylene oxide
- Polysulfone
- Polyimide
- Rigid polyvinyl chloride
- Polyphenylene sulfide
- Thermoplastic urethane elastomers
- Many reinforced plastics

engraved roll coating Engraved roll or *gravure* coating is a coating process by which the amount applied to the web is metered by the depth of the overall engraved pattern on a print roll. This process is frequently modified by interposing a resilient offset roll between the engraved roll and the web.

Engraved roll coating is a common method of printing on plastic film. The gravure (also called *rotogravure*) transfers ink from cells etched or engraved on a copper- and chrome-plated cylinder to the material being printed. The cylinder rotates in an ink fountain, and the cells pick up the liquid ink. A doctor blade wipes excess ink from the roller, leaving ink only in the cells. The low-viscosity liquid inks used in this process contain a volatile solvent.

Gravure is mainly used when the design requires good continuity of sharp pattern details and rich color effects. It is a high-speed process; however, it can be expensive for short runs because of the cost of the cylinders.

environmental stress cracking Environmental stress cracking (ESC) is the susceptibility of a thermoplastic article to crack or *craze* under the influence of certain chemicals, aging, weather, or other stress. Environmental stress cracking and crazing are significant and frequent modes of failures for plastic products.

Whether a particular substance will act as a stress cracking agent for a particular polymer depends primarily on their respective chemical natures. For example, many normally glassy polymers are susceptible to various organic liquids and their vapors, whereas environmental stress cracking agents for polyethylene include solutions of surface-active agents.

Several standard ASTM test methods include requirements for environmental stress cracking. ASTM D1693 is a test for environmental stress cracking ethylene plastics, ASTM F484 for acrylic plastics, and ASTM F791 for transparent plastics. ASTM D1939 is a test for environmental stress cracking for extruded or molded ABS parts, ASTM D2561 for blow-molded polyethylene containers, ASTM D5419 for threaded plastics, and ASTM F1248 for polyethylene pipes.

Environmental stress cracking effects are generally more prevalent in noncrystallizing or amorphous polymers. Semicrystalline polymers can also be affected through their amorphous regions in particular. In general, environmental stress cracking effects are more severe at higher temperatures. This is probably assoicated with the higher mobility of the molecules involved.

epichlorohydrin (ECH, ECO) Epichlorohydrin polyether elastomers are homopolymers (ECH) and copolymers (ECO): chloromethyloxirane homopolymers and chloromethyloxirane copolymer with oxirane. Chloromethyl side chains provide sites for cross-linking.

Epichlorohydrin rubber posseses a blend of the good properties of neoprene and nitrile. Epichlorohydrins have excellent resistance to swelling when exposed to oils and fuels; good resistance to acids, alkalis, water, and ozone; and good aging properties. High chlorine content provides inherent flame retardance, and, as with other halogenated polymers, flame-retardant enhancers may be added to increase UL 94 flammability rating.

ECH and ECO can be blended with other polymers to increase high- and low-temperature properties and oil resistance. Modified polyethers have potential use for new, improved synthetic rubbers. ECH and ECO derivatives, formed by nucleophilic substitution on the chloromethyl side chains, may provide for better processing.

epoxy—glass
See laminates

epoxy resin Epoxy resins are characterized by the epoxide group (oxirane rings), which make these resins cross-linkable. The most widely used resins are *diglycidyl ethers of bisphenol A* (*DGEBA*). These are made by reacting epichlorohydrin with bisphenol A in the presence of an alkaline catalyst. By controlling the operating conditions and varying the ratio of the epichlorohydrin to bisphenol A, products of different molecular weights can be made. For liquid resins, *n* (see Fig. E.1) is normally less than 1; for solid resins, *n* is 2 or greater. Solids with very high melting points have *n* values as high as 20.

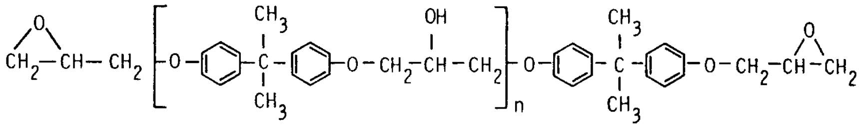


Figure E.1 General chemical structure of epoxy (diglycidyl ether of bisphenol A).

The resins in this group range from low-viscosity liquids to solid resins melting up to 175°C. Generally the higher the melting point, the less curing agent is needed. The cured properties of all these resins are similar, but the toughness increases as the melting point increases. Although most of the DGEBA epoxies are light amber, transparent, colorless epoxies are available for optical embedments.

The electronic industry demands epoxy resins with minimum ionic contamination, particularly sodium and chlorine. Most manufacturers supply DGEBA epoxy with less than 100 ppm ionic contaminants and some with less than 1 ppm chlorine and sodium.

Chlorinated or *brominated bisphenol A* is used to produce flame-resistant epoxies. As the halogen content increases, the viscosity generally increases. Epoxies have also been synthesized that contain high weight percents of fluorine. They can be used with silicone amines to yield products with very low moisture pickup, 0.25% at 20°C. These materials are extremely stable on high temperature exposure and during outdoor weathering.

Epoxy resins based on *biphenyl F* have some important advantages over the bis A epoxies. Compared with bis A epoxies, bis F epoxies have a lower room-temperature viscosity; a crystallization time twice as long; better resistance to sulfuric acid, acetone, and methanol; but at twice the price. The cured epoxy bis F is generally tougher than bis A epoxy cured with the same curing agent, but it will have a lower glass transition temperature, (T_g).

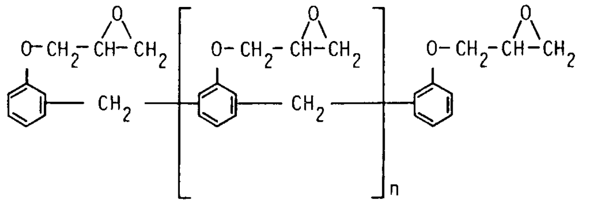
Another class of epoxy resins is the *novolacs*, particularly the epoxy cresols and the epoxy phenol novolacs. These are produced by reacting a novolac resin, usually formed by the reaction of *o*-cresol or phenol and formaldehyde with epichlorohydrin. These highly functional materials are particularly recommended for transfer molding powders, electrical laminates, and parts in which superior thermal properties, high resistance to solvents and chemicals, and high reactivity with hardeners are needed.

The novolacs cure more rapidly than DGEBA resins and have higher exotherms. The cured novolacs have higher heat deflection temperatures than DGEBA resins. They have excellent resistance to solvents and chemicals. Novolacs also have excellent electrical properties, which are retained at high service temperatures.

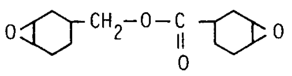
Another group of epoxy resins, the *cycloaliphatics*, is particularly important when superior arc track and weathering resistance are necessary requirements. A distinguishing feature of cycloaliphatic resins is the location of the epoxy group(s) on a ring structure rather than on an aliphatic chain. Cycloaliphatics can be produced by the peracetic epoxidation of cycle olefins and by the condensation of an acid such as tetrahydrophthalic anhydride with epichlorohydrin, followed by dehydrohalogenation.

Cycloaliphatic epoxy resins have superior arc-track resistance, good electrical properties under adverse conditions, good weathering properties, high heat deflection temperatures, and good color retention. Some members of this group are low in viscosity and serve as reactive diluents in laminate structures. Properties of these materials can be modified by blending flexible and rigid resins. Massive castings have been made with cycloaliphatic epoxies.

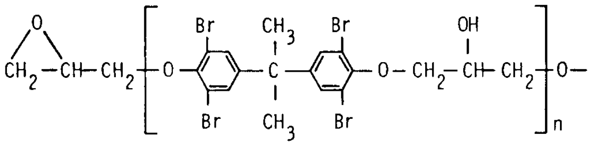
Brominated epoxies have all the other characteristics of the resins in the epoxy family, and in addition they are relatively flame resistant because of the bromine constituents in the molecular structure.



Epoxy Novolac



Cycloaliphatic Epoxy



Brominated Epoxy

Figure E. 2 General chemical structures of epoxy novolac, cycloaliphatic epoxy, and brominated epoxy.

Epoxies are one of the most versatile and widely used thermosetting resins, especially in the electrical/electronic industries. This is primarily because of the wide variety of formulations possible and the ease with which these formulations can be made and utilized with minimal equipment requirements. Formulations range from flexible to rigid in the cured state and from thin liquids to thick pastes and molding powders in the uncured state. Conversion from uncured to cured state is made by use of hardeners, heat, or both.

The largest application of epoxies is in embedding applications (potting, casting, encapsulating, and impregnating), in molded parts, and in laminated constructions such as metal-clad laminates for printed circuits and unclad laminates for various types of insulating and terminal boards. Molded epoxy parts have excellent dimensional stability.

ASTM D1763 offers a standard specification for epoxy resins. ASTM D3013 offers a standard specification of epoxy molding compounds.

Major suppliers of epoxy resins include Akzo Nobel Chemical Inc.; Ciba Specialty Chemicals; Cytec Fiberite Inc.; Dow Plastics; Epic Resins; Magnolia Plastics Inc.; Resyn Corp.; Shell Chemicals; Thermoset Plastics, Inc.; Union Carbide Corp.; and United Resin Corp.

epoxy resin curing agent Epoxy resins must be cured with *crosslinking agents* (*hardeners*) or *catalysts* to develop desirable properties. The epoxy and hydroxyl groups are the reaction sites through which cross-linking occurs. Careful selection of the proper curing agent is required to achieve a balance of application properties and initial handling characteristics. Major types of curing agents are aliphatic amines, aromatic amines, catalytic curing agents, and acid anhydrides. These are shown in Table E.1.

Basically, there are two general types of epoxy curing agents: active hydrogen compounds that react with the epoxies to cure them by polyaddition reaction and ionic catalysts. Among the first group are the aliphatic polyamines and their derivatives.

Aliphatic amine curing agents produce a resin-curing agent mixture that has a relatively short working life but cures at room temperature or at a low baking temperature in a relatively short time. These curing agents include *diethylene triamine* (*DETA*), which provides fast room-temperature cure for rigid epoxy, and *polyamides*, which can be used for flexible to rigid applications, potting, adhesives, and coatings. Resins cured with aliphatic amines usually develop the highest exothermic temperatures during the curing reaction; thus the amount of material that can be cured at one time is limited because of possible cracking, crazing, or even charring of the resin systems if too large a mass is mixed and cured. Physical and electrical properties of epoxy resins cured with aliphatic amines tend to degrade as the operating temperature increases. Epoxies cured with aliphatic amines find their greatest usefulness where small masses can be used, where room-temperature curing is desirable, and where the operating temperature required is below 100°C.

Epoxies cured with *aromatic amines* have a considerably longer working life than those cured with aliphatic amines, but they require curing temperatures of 100°C or higher. Resins cured with aromatic amines can operate at a temperature considerably above the temperature possible for those cured with aliphatic amines. However, aromatic amines are not as easy to work with as aliphatic amines, because of the solid nature of the curing agents and the fact that some (such as metaphenylene diamine) sublime when heated, causing stains and residue deposition. Typical aromatic amines are *metaphenylene diamine* (*MPDA*) for rigid, high-temperature resins that go into laminates, potting, etc. and *4,4′*-methylene dianiline (MDA), with the same types of applications as MPDA.

Acid anhydride curing agents, especially the liquid anhydrides, are particularly important for epoxy resins. They cure at elevated temperatures but offer long pot life, good electrical properties, and heat resistance. Typical of these agents are *phthalic anhydride* and *nadic methyl anhydride*. The high-temperature properties of resin systems cured with these materials are better than those of resin systems cured with

Table E.1 Curing Agents for Epoxy Resins (Ref: Meier, J.F., "Fundamentals of Plastics and Elastomers", *Handbook of Plastics*, *Elastomers*, *and Composites*, 3rd ed, C.A. Harper, ed. McGraw-Hill, New York, 1996)

Curing-agent Type	Characteristics	Typical Materials
Aliphatic amines	Aliphatic amines allow curing of epoxy resins at room temperature, and thus are widely used. Resins cured with aliphatic amines, however, usually develop the highest exothermic temperatures during the curing reaction, and therefore the mass of material which can be cured is limited. Epoxy resins cured with aliphatic amines have the greatest tendency toward degradation of electrical and physical properties at elevated temperatures	Diethylene triamine (DETA) Triethylene tetramine (TETA)
Aromatic amines	Epoxies cured with aromatic amines usually have a longer working life than do epoxies cured with aliphatic amines. Aromatic amines usually require an elevated-temperature cure. Many of these curing agents aresolid and must be melted into the epoxy, which makes them relatively difficult to use. The cured resin systems, however, can be used at temperatures considerably above those which are safe for resin systems cured with aliphatic amines	Metaphenylene diamine (MPDA) Methylene dianiline (MDA) Diamino diphenyl sulfone (DDS or DADS)
Catalytic curing agents	Catalytic curing agents also have a working life better than that of aliphatic amine curing agents and, like the aromatic amines, normally require curing of the resin system at a temperature of 200°F or above. In some cases, the exothermic reaction is critically affected by the mass of the resin mixture	Piperidine Boron trifluoride ethylamine complex Benzyl dimethylamine (BDMA)
Acid anhydrides . .	The development of liquid acid anhydrides provides curing agents which are easy to work with, have minimum toxicity problems compared with amines, and offer optimum high-temperature properties of the cured resins. These curing agents are becoming more and more widely used	Nadic methyl anhydride (NMA) Dodecenyl succinic anhydride (DDSA) Hexahydrophthalic anhydride (HHPA) Alkendic anhydride

aromatic amines. Some anhydride-cured epoxy resin systems retain most electrical properties to 150°C and higher and are little affected physically, even after prolonged heat aging at 200°C.

In addition, the liquid anhydrides are extremely easy to work with; they blend easily with the resins and reduce the viscosity of the resin systems. Also, the working life of the liquid acid anhydride systems is long compared with that of the mixtures of aliphatic amine and resin, and the odors are slight. *Accelerators* used with the anhydrides are usually *tertiary amines* such as *benzyl dimethylamine* (*DBMA*) or *DMP-30*. They are used to promote the curing of mixtures of acid anhydride and epoxy resin. The thermal stability of epoxies is improved by anhydride curing agents.

Catalytic curing agents also have longer working lives than the aliphatic amine materials and, like the aromatic amines, catalytic curing agents normally require curing of the epoxy system at 100°C or above. Resins cured with these systems have good high-temperature properties compared with epoxies cured with aliphatic amines. With some of the catalytic curing agents, the exothermic reaction becomes high as the mass of the resin mixture increases. Among the catalytic curing agents are such groups as *benzyldimethylamine* (*BDMA*), which is the tertiary amine used as an accelerator with the anhydrides, and *boron trifluoride monethylamine complex*, which is used for rigid epoxies, coatings, adhesives, and laminates. These catalysts generally have long room-temperature pot life, rapid cure at high temperature, and heat resistance.

Latent curing agents such as *dicyandiamide* are used to produce one-part systems that have long room-temperature shelf lives but cure rapidly at elevated temperatures. They are used in potting compounds, laminates, and adhesives. Dicyandiamide-cured epoxies are commonly used as one-component elevated-temperature curing adhesives for high-temperature, structural applications. A new class of latent curing agent is being used that is insoluble in the epoxy at room temperature but goes into solution at moderate temperature to effect a rapid cure.

Amino and phenoplast resins (like melamine, urea, and phenolic) can also be used for elevated temperature curing. They are cross-linked through the hydroxyl group of the epoxy and produce products with good chemical resistance.

Flexibilizing curing agents are generally long aliphatic chains containing amino groups. *Ancamides* (Pacific Anchor) and the *Versamids* (Henkel) are members of this group. They cure slowly at room temperature to produce tough, water-resistant products. Adhesion is excellent, and the ratio of curing agent to resin is not critical. The electrical properties are better than those of other flexibilized systems, and the cured epoxies are usable over a very wide temperature range.

Major suppliers of epoxy curing agents include Ashland Chemical Inc.; Ciba Geigy Corp.; Dow Chemical; Epic Resins; Hexcel Corp.; Shell Chemical Co.; Thermoset Plastics Inc.; Union Carbide; and Uniroyal Chemical Co.

epoxy resin modifier Epoxies can be modified with other resins to provide physical properties suited for the end use application. *Reactive diluents* such as butyl glycidyl ether reduce the viscosity of the epoxy mixture. There is relatively little change in the cured properties when these diluents are used in concentrations of up to 5 parts per hundred resin. Above this concentration there is a deterioration of electrical, mechanical, and chemical resistance properties.

Reactive flexibilizers such as polysulfides, urethanes, polybutadienes, and polyesters are copolymerized with epoxies to increase flexibility, improve adhesion, modify electrical properties, and improve resistance to chemicals. *Nonreactive extenders* such as thermoplastics, asphaltums, and waxes are used to modify properties and reduce the cost of the compounds. Polyarylene ether sulfone as an extender in epoxy resins increases the fracture toughness fivefold with only a slight drop in T_g.

equivalent weight Reactivity of epoxies and other resins is expressed as equivalent weight, defined as molecular weight per reactive group. For example, the simplest form of bis-A epoxy has a molecular weight of 340. There are two epoxide groups, and therefore the equivalent weight is 170. When formulating a resin system, the equivalent weight of the resin should be balanced with the equivalent weight of the curing agent.

ester Esters are chemical compounds formed by the reaction of an alcohol and an organic or inorganic acid. Many esters are useful as solvents, especially methyl acetate, ethyl acetate, butyl acetate, and amyl acetate. These have low boiling points ranging from about 60 to 150°C. Esters with high boiling points can be used as plasticizers.

etching Etching refers to a chemical surface treatment of a plastic material usually for the purpose of (1) modifying the surface for better adhesion or (2) decorative effects.

For improved adhesion, the chemical modification of low-energy polymer surfaces may be carried out by treatment with chromic acid, sulfuric acid, metallic sodium complex dispersions, and other mixtures. The chemicals used and the treating conditions are dependent on the type of polymer being treated and the degree of adhesion required.

Liquid etchants can be used for chemical modification or dissolving surface contamination. Etchants effectively treat irregularly shaped objects that are difficult to treat by other adhesion-promoting processes such as corona or flame treatment. A number of etching solutions and procedures have been developed for specific polymeric surfaces. The choice of the liquid etchant depends on the polymers. Polyolefins are usually treated by oxidizing acids such as chromic, sulfuric, nitric, or mixtures of these. Fluorocarbons are usually treated by sodium-napthalene etching solution.

To facilitate the etching process, removal of organic surface contaminants must first be accomplished by passive chemical cleaning. Sometimes solvent degreasing is used before etching to gently soften and swell the polymer surface. Chemical etching solutions for polymeric substrates can be recipes that are mixed from raw materials or they can be proprietary, commercial solutions. The temperature of these chemical-etching treatments is generally above 120–140°C to ensure fast processing; however, effective treatments can also be carried out at room temperature. These acids chemically alter the polymer surface as well as producing micro-roughened or even porouslike structures on the surfaces. The nature of the surface modification is dependent on the polymer and the etchant used. Chromic acid, for example, will oxidize polyolefin surfaces, whereas sodium naphthalene etching will remove the surface fluorine atoms from a fluorocarbon surface.

Extensive etching of the surface can lead to a cohesively weakened surface structure. As a result, surface-treating processes must be followed explicitly. Complete removal of the etching chemicals by a rinse step is essential. Highly reactive etchants can continue reacting with the surface after application of the adhesive and thereby degrade the chemical and physical stability of the surface.

In decorating, decorative effects on plastic can be produced by a process similar to that of etching metals and glass. Instead of acid, however, solvents are used on the plastic. A material resistant to the solvent is used as the design-bearing stencil and is either cemented or clamped to the piece. Polystyrene can be etched with benzene; the cellulosics, with acetone, ketones, or esters; and other plastics with their respective solvents. The drawback of this process is that a plastic worked over with solvents remains soft for several days. Moreover, a sharp borderline that is comparable with etching on metal cannot be achieved.

ether Ethers are organic oxides derived from two molecules of alcohol by the elimination of water. When two molecules of the same alcohol are used, simple ethers result. Mixed or complex ethers are formed when the alcohol radicals are different. *Glycol ethers* are an important class of solvent.

ethyl alcohol Ethyl alcohol, also called *ethanol* when made synthetically, is the common beverage alcohol. When denatured for nonbeverage purposes it is called *industrial alcohol.* Ethyl alcohol is a colorless liquid with a pleasant odor but a burning taste. The composition is CH_3CH_2OH, specific gravity 0.79, boiling point 78°C, and freezing point -117°C. It is one of the best solvents and dissolves many organic materials such as gums, resins, and essential oils.

The major suppliers of denatured ethyl alcohol include Shell Chemical Corp. and Union Carbide.

ethyl cellulose
See cellulosic plastic.

ethylene acrylic acid copolymer (EAA) Ethylene acrylic acid (EAA) copolymers are polyethylene copolymers that are used in adhesive formulations. They are characterized by outstanding adhesion to metallic and nonmetallic substrates. The presence of the carboxyl and hydroxyl functionalities promotes hydrogen bonding, and these strong intermolecular interactions are taken advantage of to bond aluminum foil to polyethylene in multilayer extrusion-laminated toothpaste tubes and as tough coatings for aluminum foil pouches.

ethylene ethyl acrylate copolymer (EEA) Ethylene ethyl acrylate (EEA) copolymers typically contain 15–30% by weight of ethyl acrylate and are flexible polymers of relatively high molecular weight suitable for extrusion, injection molding, and blow molding. Products made of EEA have high environmental stress cracking resistance, excellent resistance to flexural fatigue, and retention of low-temperature properties down to as low as −65°C.

EEA competes with low-density polyethylene (LDPE) and plasticized polyvinyl chloride (PVC). At room temperature EEA has about the same flexibility as plasticized PVC and four times the flexibility of LDPE. However, the tensile strength of EEA is lower than polyethylene or PVC. The copolymer maintains its rubbery character without the use of plasticizers down to temperatures as low as −100°C. Also, its heat stability makes it easier to injection and blow mold than PVC.

Typical formulations include polymer modifications where EEA is blended with olefin polymers to yield a blend with a specific modulus, yet with the advantages of EEA's polarity. The EEA presence promotes toughness, flexibility, and greater adhesive properties. EEA blending can also provide a cost-effective way to improve the impact resistance of polyamides and polyesters.

The resin is adaptable to extrusion, coating, vacuum forming, and calendering techniques. Applications include molded rubberlike parts, flexible film for disposable gloves and hospital sheeting, extruded hoses, and bumpers. Applications also include fishing boat anchors, injection-molded mop buckets, electrical terminal covers, agricultural tubing, squeeze spray bottles, flexible toys, and refrigerator gaskets.

ethylene methyl acrylate copolymer (EMA) Ethylene methyl acrylate copolymer (EMA) is often blown into film with very rubbery mechanical properties and outstanding dart drop impact strength. The latex rubber-like properties of EMA film lend to its use in disposable gloves and medical devices without the associated hazards to people with allergies to latex rubber.

Because of their adhesive properties, EMA copolymers are used in extrusion coating, coextrusions, and laminating applications as heat-seal layers. EMA is one of the most thermally stable of this group, and as such it is commonly used to form hot and dielectric seals, as well in multiextrusion tie layer applications.

This copolymer is also widely used as a blending compound with olefin homopolymers as well as with polyamides, polyesters, and polycarbonate to improve impact strength and toughness and either to increase heat seal response or to promote adhesion. EMA is also used in soft blow-molded articles such as squeeze toys, tubing, disposable medical gloves, and foamed sheet. EMA copolymers and ethylene ethyl acrylate (EEA) copolymer containing up to 8% ethyl acrylate are approved by the FDA for food packaging.

ethylene *n*-butyl acrylate copolymer (EBA) Ethylene *n*-butyl acrylate copolymers (EBA) are widely blended with olefin homopolymer to improve impact strength toughness and heat sealability and to promote adhesion. The repeat unit of EBA copolymers is shown in Fig. E.3.

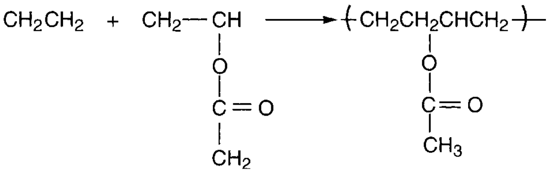


Figure E.3 Polymerization and structure of ethylene n-butyl acrylate (EBA).

ethylene plastic Ethylene plastics are those whose base polymers are homopolymers of ethylene or copolymers in which ethylene is the major monomeric component.

ethylene propylene copolymer (EPM) and ethylene propylene diene terpolymer (EPDM) Ethylene propylene copolymer (EPM) and ethylene propylene diene terpolymer (EPDM) are *thermoplastic elastomers* that can be polymerized with metallocene catalyst. Both can be produced by solution polymerization, and suspension and slurry polymerization are viable options.

Both EPM and EPDM, which were commercialized in the early 1960s, have seen tremendous growth in market share because of their inherent oxygen and heat resistance and a good balance of other properties. They also have the ability to accept high loadings of reinforcing agents, fillers, and plasticizers. EPM and EPDM compounds, in general, have excellent chemical resistance to water, ozone, radiation, weather, brake fluid, and glycol.

EPM is preferred for dynamic applications because its age resistance retains initial product design properties over time and environmental exposure. EPDM is preferred for its high resilience. EPM is resistant to acids, bases, and hot detergent solution. EPM and EMDM are resistant to salt solutions, oxygenated solvents, and synthetic hydraulic fluids. Properties are determined by the composition of the base compound.

EPDM formulations are increasingly popular for medium-voltage, up to 105°C continuous-use temperature, wire and cable covering. EPDMs are good vulcanizates, providing improved wet electrical properties. When diene vinyl norbornene is incorporated on the EPDM backbone by a gel-free process, a significantly improved EPDM terpolymer is obtained for wire and cable applications.

Other applications are automotive body seals, mounts, weather-stripping, roofing, hose, tubing, ducts, and tires. Molded EPDM rubber is used for bumpers and fillers to dampen vibrations around the vehicle. EPDM can be bonded to steels, aluminum, and brass, with modified polyacrylic acid and polyvinylamine water-soluble coupling agents.

ethylene propylene liquid polymer *Trilene* from Uniroyal Chemical Co., Inc. is a family of ethylene propylene copolymers and ethylene propylene nonconjugated diene terpolymers. The terpolymers have pendant unsaturation. These materials are randomly polymerized to produce liquid elastomers with stable, saturated hydrocarbon backbones. Viscosity is 100,000 cP at 95°C. The trilenes can be cured at room temperature with *p*-quinone dioxime systems or two-component peroxide systems. They can also be cured at elevated temperature with sulfur.

Ethlylene propylene liquid polymers are frequently used as electrical encapsulation compounds. The dielectric constant of the cured materials is 2.1–2.2, and the volume resistivity is 10^{16} ohm-cm. They have low moisture permeability and low strength and are UV resistant. Applications include automobile and construction sealants, waterproofing membranes, and electrical encapsulants. From a safety standpoint, these materials have an extremely low level of dermal, oral, and inhalation toxicity and low eye irritation.

ethylene tetrafluoroethylene copolymer (ETFE) Ethylene tetrafluoroethylene copolymer is a copolymer of ethylene and tetrafluoroethylene.

See fluoropolymers.

ethylene vinyl acetate copolymer (EVA) Ethylene vinyl acetate (EVA) copolymers are characterized by the structure shown in Fig. E.4. They find commercial importance in the coating, laminating, and film industries. EVA copolymers typically contain between 10 and 15% vinyl acetate. However, grades are available where the vinyl acetate content can be as low as 3%. The low-vinyl acetate content copolymers possess properties closely related to those of low-density polyethylene. The higher-vinyl acetate copolymers look more like gum rubber.

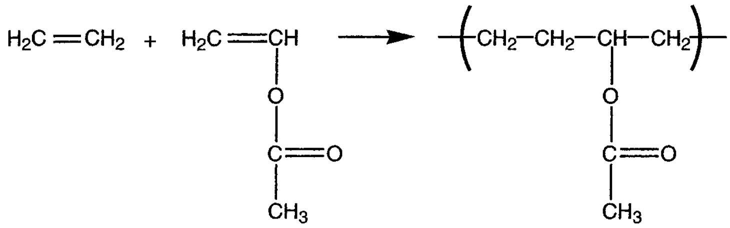


Figure E.4 Polymerization and structure of ethylene vinyl acetate (EVA).

EVA copolymers have low crystallinity because the acetate branches interfere with crystallization. These resins are characterized by increased flexibility and resilience over a wide temperature range and by improved clarity. EVA copolymers are widely used as a nonplasticizer alternative for polyvinyl chloride (PVC) applications. These copolymers also have higher moduli than standard elastomers and are preferable in that they are more easily processed without the need to vulcanize.

Accelerated tests have shown that EVA copolymers resist degradation by weathering better than conventional polyethylene. However, chemical resistance and barrier properties of EVA copolymers are inferior. EVA polymers accept high degrees of filler loading without serious degradation of their physical properties.

EVA copolymers are used in areas where flexibility, resilience, clarity, dielectric sealability, toughness, compatibility, and excellent low-temperature properties are required. They find application as disposable syringes, squeeze pumps, enema tips, and droppers for medical applications. Film and sheeting produced from EVA copolymers find use in some types of construction film, shower curtains, disposable gloves, inflatable toys, inflatable splints, and pool liners. Injection-molded items include shoe soles, pool table bumpers, small appliance bumpers, canister gaskets, disposable brushes, and automobile mud flaps.

EVA copolymers used for wax blending and adhesives are of higher density and lower molecular weight than the copolymers designated for use in extrusion and molding. Films are soft and tacky and therefore appropriate for cling wrap applications as well as interlayers in coextruded and laminated films.

ethylene vinyl alcohol (EVOH) Ethylene vinyl alcohol (EVOH) is a copolymer of ethylene and vinyl alcohol. In commercial EVOH materials the vinyl alcohol content typically ranges between about 52 and 73 mole percent. The melting temperature increases with decreasing ethylene content.

EVOH has very good barrier properties against gases, many solvents, and aromas. In general these effects increase with increasing vinyl alcohol content. However, as the hygroscopicity, associated with the hydroxyl groups, also increases, there is a reduction in the barrier properties against water vapor. To minimize moisture absorption, the EVOH layer can be flanked by protective layers of other polymers. This preserves a main application of EVOH as a barrier layer in multilayer coextruded packaging films and sheeting.

exotherm The exotherm is (1) the temperature curve of a chemical reaction giving off heat (generally used for analytical or quality control purposes) or (2) the amount of heat given off in a chemical reaction. The term has not been standardized with respect to sample size, ambient temperature, degree of mixing, etc., all of which have a part in determining the degree of exotherm.

Many thermoset mixes give off heat during cure. Some room-temperature polyesters and epoxies will exotherm severely if processed incorrectly. For example, when too much methyl ethyl ketone peroxide (MEKP) catalyst is added to a polyester that contains cobalt napthenate promoter, the mix can get hot enough to smoke and even catch fire. Only a few thermosets (e.g., silicones and certain urethanes) can be cast in large volumes without exotherming. Wet polyester layups can be processed at room temperature, using only exothermic heat to achieve cure. Thus exotherm can be a help or a hindrance, depending on the application.

Exothermic reactions in certain applications such as casting resins can have several implications. Exotherm can result in a serious safety consideration in that large batches cannot be mixed safely. The size of the batch will contribute to the degree of exotherm because heat cannot escape. Major fires in resin factories have occurred because of uncontrolled exotherm. Exotherm also limits the amount of charge that can be mixed at one time. This may have serious implications in production of large parts.

expanded plastic

See cellular plastic; foamed plastic.

expanding monomer Epolin, Inc. is developing a line of materials that form polymers that expand on curing. The line consists of *spiro-orthocarbonates* such as bismethylene spiro-orthocarbonate or those containing norborane with melting points above 250°C. They can be disbursed in epoxies and other materials to produce two-phase polymerizing systems. The monomer expands as it goes into solution, and the final product expands as well. This results from ring opening that increases the size of the polymer, counteracting the usual cure shrinkage.

An interesting possibility is the formulation of a material with zero coefficient of thermal expansion by adding just enough expanding monomer to counteract the normal shrinkage of the resin.

extender Extenders are low-cost fillers, resins and other substances, that are used as diluents for higher-cost resins without impairing their properties too seriously. Thus asphalts are used for extending rubber. Extenders may also have positive value in modifying the physical properties of the formulation of the final product.

The term is sometimes used to include all the ingredients of a plastic compound except those there to perform a specific function. Common extenders are flours, soluble lignin, and pulverized partly cured synthetic resins.

extensometer An extensometer is an instrument for measuring changes in linear dimensions as with a caliper. It is used for measuring strain and is often called a *strain gauge.* An extensometer may be either a mechanical or an optical measuring device.

extruder screw Extruder screws fit into the barrel and are supported by the thrust bearing. The screw's shank length fits into the thrust bearing, while the flighted length contacts the plastic. Extruder screws are specified by their outside diameter, and the L/D ratio, which is generally the flight length divided by the screw diameter. Screw features are shown in Fig. E.5.

Pitch is the axial distance from the center of one flight to the center of the next flight, whereas *lead* is the axial distance the screw moves in one full rotation.

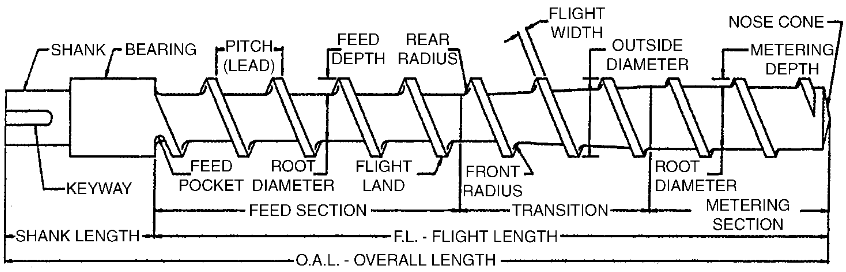


Figure E.5 Nomenclature for sections of an extruder screw. (Ref: Barry, C.M.F. and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, McGraw-Hill, New York, 2000)

Because most extruders use square pitched metering screws, both the pitch and lead equal the diameter, and the helix angle is 17.7°.

See also extrusion.

extrusion In the extrusion process, polymer is propelled continuously along a screw through regions of high temperature and pressure, where it is melted and compacted, and finally forced through a die shaped to give the final object. A diagram of a simple plastic extruder is shown in Fig. E.6.

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Figure E.6 Diagram of a plastic extruder. (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 495).

A wide variety of shapes can be made by extrusion including rods, channels, and other structural shapes; tubing and hose; sheeting up to several feet wide and 1/4 in. or more thick; and film of similar width down to a few thousands of an inch in thickness.

The *screw* of an extruder is divided into several sections, each with a specific purpose. The feed section picks up the finely divided polymer from a hopper and propels it into the main part of the extruder. In the compression section, the loosely packed feed is compacted, melted, and formed into a continuous stream of molten plastic. Some external heat must be applied, but much is generated by friction. The metering section contributes to uniform flow rate, required to produce uniform dimensions in the finished product, and builds up sufficient pressure in the polymer melt to force the plastic through the rest of the extruder and out of the die.

Because viscous polymer melts can be mixed only by the application of shearing forces (their viscosity is too high to allow turbulence or diffusion to contribute appreciably to mixing), an additional working section may be needed before the die. There are some extruders containing two or more screws, and some extruders have been made that have no screws. The great majority of extruders in use today, however, are of the type known as a *single-screw extruder*.

The extrusion process is used whenever extended lengths of a product are required, or when a large number of short pieces are required that can be cut from such extended lengths. The product or material delivered by an extruder, such as film, pipe, and coating on wire, is known as the *extrudate*.

An extruder can also be used to compound materials by mixing two or more components together. It can also blend virgin with regrind stock and, in fact, is the machine used to form long filaments that, when chopped up, are the pellets used to injection mold or extrude special shapes.

In addition to the basic extruding operation, the process may include a number of postextruding operations such as forming round to oval shapes, cutting section to length, blowing the part to a larger or different shape, machining the extrusion, and punching. When combined with the various postextrusion operations, the extrusion process is a most useful and versatile technique. The extrusion process can also result in the highest rate of output per hour of any plastic process. Some large extruders have a throughput of as high as 2000 lb/hr of pipe or similar part.

The single-screw extruder consists essentially of the following seven machine elements:

a. A *feed throat* into which the pellets are placed
b. The *barrel*, which contains the screw and is equipped, on its exterior, with elements for heating and cooling
c. The *screw*, which acts to plasticate the pellets, heat them to a liquid state, and convey them to the die
d. A *motor and gear reduction system* used to turn the screw
e. *Screen packs* and *breaker plates* used to “filter” the melt and create backpressure
f. The *die*, which determines the shape of the extrusion.
g. Thermocouples, pressure gauge valves, and other instrumentation used to indicate and control the machine variables of temperature, pressure, and screw rotation speed.

Multiple-screw machines use two to four screws. In general they are used for materials that are heat sensitive, such as PVC. Other special uses for these models are in compounding, where the mixing action is said to be more thorough than single-screw machines and with materials that require steady, positive pumping action. Types include intermeshing counter-rotating screws, intermeshing corotating screws, and non-intermeshing counter-rotating screws.

The *vertical extruder* has the advantages of occupying much less floor space, better feeding, no cantilever distortion of the barrel, and the screw can be cooled easily at the metering end for better temperature control of the melt. Currently, vertical extruders are used mainly for wire coating, pipe and tubing, blow molding, and general compounding.

There are also several forms of *screwless extruders* that are less used. One form depends on friction between a rotating and a stationary plate to develop the shear action. A second form uses a ram feeding a manifold to result in continuous extrusion.

One of the main uses for extrusion is the manufacture of pipe and tubing. Common materials for pipe include polyethylene, rigid polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), and cellulose acetate (CA). Tubing is commonly made from polyethylene, flexible PVC, ABS, and nylon. Production of film is another very large application for extruders. Two methods of making film are in use. One method is known as the *blown film extrusion* technique, and the other produces what is called *cast film extrusion* (the extruded film is "cast" onto a chilled roller).

Blown film production is considerably greater than cast film production. The blown film process consists of extruding the molten plastic through a circular die to form a thin-walled tube. The tube is almost always extruded vertically, and, as it leaves the die, internal air pressure introduced through the die mandrel expands the tube anywhere from 1.5 to 2.5 times the diameter. Blown tubing is also known as *lay flat tubing* because, after being blown, it is flattened by the collapsing frame and the nip rolls at the top of the apparatus.

Lay flat tubing is commonly made in widths of 12–40 in., but tubing has been made as wide as 120 in., which can be split to give film 24 in. wide. The blowing of the film not only increases the width of the product but also orients the film slightly in the transverse direction, thus increasing its strength. At the same time, the film is being drawn down by the pull rolls imparting some degree of orientation in the machine direction. The resulting film, because of the small biaxial orientation, is a stronger, tougher film than that made by the casting process.

Cast film is made by extruding the melt (usually polyethylene) through a large die equal in size to the width of the film being cast. The material is extruded as a thin sheet onto a mirrored surface chill roll, and it is then drawn down further by other rolls. In addition to the die, which deposits the hot melt directly onto the chill roll, an air blast is often used at the chill roll to help eliminate air entrapment and force the melt onto the chill roll.

Both blown and cast film extrusion operations use special resin formulations, which include a number of additives to impart various characteristics to the film. Among the most important additives are materials to control slip and decrease blocking tendencies. *Slip* is defined as the tendency of the film to slide on itself and is related to the material's coefficient of friction. *Blocking* is the tendency of a tightly wound roll of film to stick to itself and form a solid block of plastic that cannot be easily unwound.

Coating paper, metal foil, fabric, or other materials is another large application of the extrusion process called *extrusion coating*. Commercial packaging is one of the many product lines in which it is applied. Polyethylene-coated paper to make milk cartons represents the largest consumption of coated materials. The process for extrusion coating is similar to the cast extrusion process except that only one extruder is used and the substrate is heated. Another difference is that the extruded melt and the substrate are forced together by means of a rubber roll that exerts pressures as high as 100 lb/linear in.

Extrusion covering is the term used for a process that fully surrounds a continuous substrate with a cover of extruded polymeric material. It is most commonly used for the formation of an electrical insulating layer or a protective jacket on power or communications electrical wires and cables.

Other common extrusion processes are pipe, profile, wire coating, extrusion, and fiber spinning. Coextrusion permits multiple-layer extrusion of film, sheet, pipes, tubing, profiles, and extrusion coating. It is used mostly in packaging applications where one of the extrudates is a barrier film.

See also coextrusion; single-screw extrusion; twin-screw extrusion.

extrusion barrel The barrel is a metal cylinder that surrounds the screw. One end fastens to the feed throat, and the opposite end connects directly to the die adapter. Extruder barrels must withstand pressures up to 10,000 psi. Extruder barrels typically have length-to-diameter ratios of 24:1 to 36:1, but they can be larger. Because melting occurs over a longer transition zone, longer barrels provide increased output. However, the longer screw requires larger drive systems and produces greater screw deflection.

See also extrusion.

extrusion blow molding Extrusion blow molding is the most common blow molding process. In extrusion blow molding a parison is extruded from a plastic melt and is then entrapped between the halves of a mold. The parison is expanded, under air pressure, against the mold cavity to form the hollow part. It is then cooled, removed from the mold, and trimmed.

See also blow molding.

extruder breaker plate The extruder breaker plate acts as a seal between the extruder barrel and the die adapter, thus preventing leakage of the melt. The breaker plate also supports the screen pack, develops head pressure (restricts flow), and converts the rotational motion of the melt to axial motion.

A *rupture disk* is located in the extruder barrel just before the breaker plate. When the extruder pressure exceeds the disk's rate value, the rupture disk opens, thereby reducing the pressure. These are required for operator safety.

See also extrusion.

extrusion die The extrusion die is a streamlined orifice that effectively reduces the heat-softened plastic mass being delivered through it to a predetermined exit shape. Such dies can produce a virtually unlimited variety of shapes. The extrusion process is designed to continue the flow of material at a uniform and uninterrupted rate to the land, or forming section of the die, and to avoid flow shadows. Obstructions to flow, such as enclosed flow pockets or wide variances in the approach angle, should be avoided as far as possible. In general, if the approach angle is too abrupt, material will be entrapped and surging will result. If, however, the approach angle is too gradual, die restriction will result in low-production output.

The angle of approach (or entrance angle) is the maximum angle at which the molten material enters the land area of the die, measured from the centerline of the mandrel. The angle of approach for any extruded material is an inverse function of its viscosity as it passes through the die. If the land is too short, it is difficult to maintain the shape being extruded. If the land is too long, it creates an excessive backpressure, which restricts production. Because section thickness is a direct function of die restriction with the cross-sectional limits of any given extrusion machine, the ratio of the land length to the part thickness is a valuable consideration in determining the optimum land length for any given material.

See also die.

extrusion drive motor Extrusion drive motors must turn the extrusion screw, minimize the variation in screw speed, permit variable speed control (typically 50–150 r/min), and maintain constant torque. In selecting drive motors, the three major factors are (1) base speed variation, (2) the presence or absence of brushes, and (3) cost. The speed variation of a drive motor is based on the maximum speed available for the motor. Because this variation does not change when the speed is reduced, screw speed, which is generally 5–10 percent of motor speed, varies more than the motor speed.

The three basic types of drives are alternating current (AC), direct current (DC), and hydraulic. Although a number of drives have been used in extruders, the most common are DC silicon control rectified (SCR) and AC adjustable frequency drives.

The high-speed drive motor is coupled to the low-speed screw with a reducer or gearbox. Typical reduction rations are 15:1 or 20:1. Although helical gears are most common, worm gears are used on older or very small machines.

See also extrusion.

extrusion feed hopper The extrusion feed hopper feeds material to the extruder. Single-screw extruders are usually fed gravimetrically through standard conical or rectangular hoppers. A spiral hopper improves dry flow, whereas vibrating pads or hammers are sometimes attached to hoppers to break up the feedstock. Vacuum feed hoppers reduce the trapped air that hinders proper feeding. In crammer feeders, an auger forces material into a barrel, whereas metered feeding uses an auger to feed a set amount of material in the barrel.

See also extrusion.

extrusion feed throat and feed port The extrusion feed throat fits around the first few flights of the extrusion screw and is usually separate from the barrel of the extruder. It is insulated from the barrel and cooled with water to prevent bridging and premature melting of the resin particles.

The feed port is the opening in the feed throat. Standard feed ports are round or square, and these parts are suitable for plastics pellets and some granules. An undercut feed port, which exposes the bottom of the screw, is used for rolls and strips of film or fiber, for film scrap, and for polymer melts. A sloped feed port is better suited to irregularly shaped particles, whereas a tangential feed port can be used for powders and regrinds.

See also extrusion.

extrusion plastometer (rheometer) An extrusion plastometer is a type of viscometer used for determining the melt index of a polymer. It consists of a vertical cylinder with two longitudinally bored holes (one for measuring temperature and one for containing the specimen, the latter having an orifice of stipulated diameter at the bottom and a plunger entering form the top). External bands heat the cylinder, and weight is placed on the plunger to force the polymer specimen through the orifice. The result is reported in grams per 10 min. The functionality of the extrusion plastometer is similar to that of the *capillary rheometer.*

See also capillary rheometer

extrusion screen pack The extruder screen pack filters melt for contamination and gel particles, generates head pressure, and minimizes surging. Five or more screens are used in typical screen pack designs. The screens are rated by the number of holes per millimeter or inch. The screens become finer as they approach the *breaker plate*. Selection of screen sizes depends on the material and extrusion process. Increasing the number of screens or the mesh size increases the pressure developed during extrusion.

See also extrusion.

F

fabric A fabric is generally a planer structure produced by interlacing yarns, fibers, or filaments. Woven fabrics and knit fabrics are composed of *webs* of fiber *yarns*. The yarns may be of either filament (continuous) or staple (short) fibers. In knit fabrics, the yarns are fastened to each other by interlocking loops to form the web. In woven fabrics, the yarns are interlaced at right angles to each other to produce the web. The lengthwise yarns are called the *warp*, and the crosswise ones are the *fill* (or *woof*) yarns.

The many variations of woven fabric can be grouped into four basic weaves. In *plain weave* fabrics, each filling yarn alternates up and under successive warp yarns. With a plain weave, the most yarn interlacings per square inch can be obtained for maximum density, "cover," and impermeability. The tightness or openness of the weave can be varied to a desired degree. In *twill weave* fabrics, a sharp diagonal line is produced by the warp yarn crossing over two or more filling yarns. *Satin weave* fabrics are characterized by regularly spaced interlacings at wide intervals. This weave produces a porous fabric with a smooth surface. Satins woven of cotton are called *sateen*. In the *leno weave* fabrics, the warp yarns are twisted and the filling yarns are threaded through the twist openings. This weave is used for meshed fabrics and nets. Modifications by having yarns cross two or more adjacent yarns or staggering the crossing along the warp result in other weaves called *basket*, *eight-harness satin*, and *mock leno*, all of which are used by the reinforced plastic industry. (*See also* weave.)

Fabric specifications generally include the type of weave; the thread count, in both warp and fill; whether the yarn is filament or staple; the crimp, in percentage; the twist per inch; and the yarn number for warp and fill.

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Woven roving is a mat fabric made by weaving multiple strands collected in a roving into a coarse fabric. The physical properties of woven roving are intermediate between mats and fabrics. These constructions are used in low-pressure laminations and in pultrusion. Various thicknesses are made in widths up to 10 ft.

In reinforced plastics the fabrics most commonly used are *glass*, *cotton*, *nylon*, *polyethylene*, and *aramid*. Glass fabrics are used in electrical-grade laminates, mechanical laminates, and marine-grade laminates. *Scrim glass* fabrics are used as facing layers for smooth, cosmetic applications.

Fabrics of *cotton* or *linen* are used as reinforcement in several grades of laminates—usually impregnated with a phenolic resin. Laminates with these fabrics have better water resistance than paper-based laminates. They machine well and have good physical properties, especially impact strength and abrasion resistance. Their electrical properties are poor. They are used for gears and pulleys.

Nylon fabrics are used with phenolic resins to produce tough laminates with good electrical properties. They are listed as Grade N-1 in NEMA Standard LI-1. Creep or cold flow limits their application.

Polyethylene can be made into a high-strength, high-modulus fiber (tradenamed *Spectra* by Allied Signal, Inc.) and then into a fabric. The polyethylene is an ultrahigh-molecular-weight polymer. The density of Spectra is the lowest of all fibers, which makes its use in aerospace laminates especially attractive. However, laminates must not be exposed to temperatures over 250°F. Spectra has very attractive electrical properties with low dielectric constant and loss factor. These properties are useful in radomes. Spectra is also used in ballistic applications like helmets and aircraft panels.

Aramid fiber (*Kevlar* from Du Pont) is an aromatic polyamide (nylon) that is woven into fabrics for reinforced plastics and laminates. Thin (2 mil, 1 oz per sq yd) to thick (30 mil, 16 oz per sq yd) fabrics are made. Aramid fabrics are used in a wide variety of aircraft and aerospace components where the low density and high strength of aramid are critical. Sports applications include laminated canoes and kayaks, downhill skis, tennis rackets, and golf shafts. The use of aramid fabrics in printed circuit boards is increasing.

See also weave; fiber; and fiber by type.

fabrication In the plastics industry the term *fabrication* refers to the production of finished articles by the machining and forming of thermoplastic and thermosetting sheets, rods, and tubes. Fabrication is especially suitable for large parts, which cannot technically or economically be produced by other methods, as well as small parts, which can be rapidly cut from stock forms. Tolerances on fabricated parts can be held, in most cases, to those of molded and extruded parts and sometimes will exceed them.

The fabrication of plastic materials requires specialized processes because of the unique nature of the materials being fabricated. Forming, drawing, sawing, turning, blanking, and milling are the major procedures for shaping a part. Auxiliary procedures include drilling, centerless grinding, piercing, routing, trimming, and filing. Assembly is achieved by cementing or mechanical means. Finishing procedures make use of tumbling, ashing, sanding, buffing, and polishing.

fadometer The fadometer is an apparatus for determining the resistance of resins and other materials to fading from exposure to natural light. This apparatus accelerates the fading by subjecting the article to high-intensity ultraviolet rays of approximately the same wavelength as those found in sunlight.

false neck A false neck is a neck construction that is additional to the neck finish of a container and is only intended to facilitate the blow molding operation. Afterwards the false neck part is removed from the container.

family mold A family mold is a multicavity mold in which each of the cavities forms one of the component parts of the assembled finished object. The schematic in Fig. F.1 illustrates a layout for a family mold. The term is often applied to a mold in which parts from different customers are grouped together for economical reasons. The family mold is also sometimes called a *combination mold*.

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Figure F.1 Family mold. (Ref: Bellofsky, H., *Plastics Product Design and Process Engineering*, Hanser Publishing, New York, 1995)

fan gate The fan gate is a gate that flares out from the runner. The fan gate permits inflow of material through a wide but shallow gate. Because it spreads out the plastic before it enters the cavity, it minimizes flow lines and improves the flow of the melt. Fan gates are useful in molding thin, flat pieces of large area.

See also Gate.

fatigue Fatigue is the change in a given property of a material when it is subjected to repeated cycles of stress, especially progressive fracture caused by a spreading crack.

When subjected to cyclic mechanical stresses, most materials fail at a stress level that is considerably lower than that required to cause rupture in a single stress cycle. This phenomenon is called *fatigue*. Various modes of fatigue testing in common use include alternating tensile and compressive stress and cyclic flexural stress. Results are reported as plots of stress vs. number of cycles to fail. Many materials show a *fatigue endurance limit*, or a maximum stress below which fatigue failure never takes place.

Fatigue failure may arise from the absorption of energy in a material that is not perfectly elastic. The energy is manifested as heat, leading to a temperature rise, a lower modulus, and rapid failure. Energy absorption is accompanied and measured by a difference in phase between stress and strain in the cyclic test.

fatigue endurance The fatigue endurance of a material is its ability to resist deterioration due to cyclic stress. This is measured by tests described in ASTM D671. The test measures the effect of repeated flexural stress of the same magnitude with a fixed cantilever apparatus designed to produce constant amplitude of force on the plastic test specimen.

The results are suitable for application in design only when all of the application parameters are directly comparable to those of the test. Consequently, this test is primarily used only for comparison purposes.

The *fatigue limit* is the stress below which a material can be stressed cyclically for an infinite number of times without failure. The *fatigue strength* is the cyclic stress a material can withstand for a given number of cycles before failure. The *S-N diagram* is the plot of stress (S) against the number of cycles (N) required to cause failure of similar specimens in a fatigue test of exactly the same conditions.

feather edge A feather edge is a thin, pointed section of a mold resulting from an effort to produce a rounded corner or beveled edge. Because such a feather edge is easily broken, it should be avoided and a flat area designed in its place. For the same reason, molded threads should be stopped short to avoid a feather edge.

feed In compression, injection, and extrusion machines, the plastic material is fed continuously into a hopper, from which it advances to the compression mold or heating cylinder. This supply of raw material is called the feed.

feldspar Feldspar belongs to a class of igneous rock. It is an anhydrous alkali-aluminum silicate normally of relatively large particle size (20–50 μm).

These fillers are easily wet and dispersed; enable transparency and translucence in most polymers; and exhibit chemical, weather, and abrasion resistance. They are suitable for food contact. Feldspar's transparency and matched index of refraction allow its use with transparent plastics to produce reasonably transparent compounds.

Feldspar is not considered a general-purpose filler, but it does have large-volume sales as well as special uses in many products. Major applications and advantages of its use are shown in Table F.1.

The combination of acid resistance and abrasion resistance of feldspar makes it a preferred filler in applications such as pipe that is intended to transport abrasive and acidic slurries.

Table F.1 Major Applications and Advantages of Feldspar Filler

Resin Matrix	Characteristic	Application
PVC plastisol films	Show-through clarity Heat stability Lower plasticizer concentration can be used	Shower curtains Vinyl floor covering
Rigid PVC blown film	Improved printing gloss reduction	Decorative sheet for paneling
Flexible PVC sheet	Show-through clarity UV absorber concentration can be lowered	Roll roofing
Gelcoats	Reduced shrinkage on curing	Various
Reinforced plastics	Prevent fiber bloom Improved stress crack resistance	Outdoor laminates Filament wound pipe
Thermoplastics	Increased modulus and heat deflection temperature Improved wear resistance Improved acid resistance Reduce abrasion on extrusion dies	Various

Nepheline syenite is also a filler derived from igneous rock. It is used in many of the same polymers and for the same reasons that feldspar is used. Nepheline syenite is generally available in finer grades that are more suitable to thermoplastics and extrusion processing. The filler provides abrasion resistance in the finished product as well as reduced abrasive wear on extrusion dies and equipment.

Major suppliers of feldspar include Franklin Limestone Co.; KMG Minerals Inc.; Spartan Minerals Corp.; and Unimin Specialty Minerals Inc. Major suppliers of nepheline syenite include Unimin Specialty Minerals Inc.

felt Felt is a fibrous material made up of loosely interlocking fibers. Felt products can be made by mechanical or chemical means, moisture, or heat. Felts are made from fibers such as glass and cotton.

fiber Fiber is a general term used to refer to filamentary materials. Often fiber is used synonymously with *filament*. It is a general term for a filament with a finite length that is at least 100 times its diameter, which is typically 0.10–0.13 mm (0.004–0.005 in.). In most cases it is prepared by drawing from a molten bath, spinning, or depositing on a substrate. Fibers can be continuous or specific short lengths (discontinuous), normally no less than 3.2 mm (1/8 in.).

Many fibers are used in laminates and reinforced plastics. The type of fiber used will depend on the cost, the properties required, and the nature of the polymeric system. Although glass fiber is the most common reinforcement, many others are used. Fiber reinforcements can also come in many forms such as discontinuous fibers, continuous fibers, mat and fabric. Fiber content is the amount of fiber present in reinforced plastics and composites, usually expressed as a percentage volume fraction or weight fraction.

The wide range of materials classified as fibers includes natural and synthetic, organic and inorganic products. Some polymers used as fibers, such as nylon and cellulose acetates, serve equally well as plastics. The classification of a fiber depends more on its shape than on any other property. One common definition of a fiber requires that its length be at least 100 times its diameter. Artificial fibers can usually be made in any desired ratio of length to diameter. Among the natural fibers, cotton, wool, and flax are often found with lengths 1000–3000 times their diamter; coarser fibers such as jute, ramie, and hemp have lengths 100–1000 times their diameter. Appendix M offers properties and comparative information on the various types and grades of fibers that are used in the plastics industry.

To be useful as a textile material, a synthetic polymer must have suitable characteristics with respect to several physical properties. These include a high softening point to allow ironing, adequate tensile strength over a fairly wide temperature range, solubility or meltability for spinning, a high modulus or stiffness, and good textile qualities.

Most artificial fibers may be obtained either as a very long *continuous filament*, or as a *staple*, made by cutting continuous filament into relatively short lengths. Natural fibers, with the exception of silk, are obtained only in the staple form.

The *denier* of a fiber, a measure of its size, is defined as the weight in grams of 9000 m of the fiber. It is thus proportional to the density of the fiber and to its cross-sectional area. At least 10 other measures of the size of fibers are in use, but the denier is the most widely accepted.

The tensile strength of a fiber is usually expressed in terms of *tenacity*. Tenacity is defined as the strength per unit size number, such as the denier, where the size number is expressed as a weight per unit length. Tenacity is thus a function of the density of the fiber as well as its tensile strength. Two fibers having the same denier and the same breaking strength have the same tenacity. If they have the same density, they have the same tensile strength as well. *Creep* in a fiber is defined as in a plastic material—viscoelastic deformation under load.

Moisture content of a fiber is the amount of moisture present at equilibrium under standard conditions (such as 65% relative humidity and 21°C). It is expressed as a percentage of the total weight of the moist fiber. If it is expressed as a percentage of the oven dry weight of the fiber, it is known as *moisture regain*.

Crimp is the waviness of a fiber, a measure of the difference between the length of the unstraightened and the straightened fiber. Some naturally occurring fibers have a natural crimp. Crimp can be artificially produced in fibers by suitable heat treatment or by rolling them between heated, fluted rolls. The esthetic qualities of fabrics are defined in terms such as appearance, *hand* (or *handle*), and *drape*. Although the qualitative meanings of these terms are obvious, their quantitative definitions and interpretations in terms of fiber properties are quite difficult. Hand and drape are largely determined by the tensile and elastic behavior of the fiber.

For the most part, the synthetic fibers are produced by converting the components to a fluid and extruding that fluid though a nozzle or *spinneret*. Some are extruded into a chemical or coagulating bath that effects the change from fluid to solid; some are air dried; and some, such as glass fibers, are merely cooled. Extrusion through a spinneret containing a number of very fine holes produces multifilament yarn. A spinneret with only one hole will yield monofilament yarn. Monofilaments are also made in multihole spinnerets, but they are not twisted into a single yarn before winding up as the multifills are.

See also specific fiber (e.g., graphite fiber; polymer fiber; glass fiber); spinning.

fiberglass Fiberglass is a term generally used for plastic composites consisting of thermosetting resins reinforced with glass fibers (i.e., *fiber-reinforced plastic* or *FRP*). However, in a strict sense, it refers to glass fiber that can be used as a filler and/or reinforcement in reinforced plastics, molding compounds, and other plastic compounds.

See also fiber-reinforced plastic; composite; glass fiber.

fiber-reinforced plastic (FRP) The term *fiber-reinforced plastic* (FRP) is often restricted to those plastic-fiber composites in which the plastic component is a thermosetting resin. Glass fibers are most widely used as the fibrous reinforcement in FRP, but other fibers are also used, particularly where the composite has to meet special strength and/or modulus requirements. Glass fiber-reinforced plastics are also known as *glass-reinforced plastic* or *GRP*.

See also composite; laminate.

fiber show Fiber show is a term that refers to strands or bundles of fibers that are not covered by resin and that are at or above the surface of a reinforced plastic or composite.

fiber washout Fiber washout is the movement of fiber during cure because of large hydrostatic forces generated in low-viscosity resin systems. The fibers are carried along with flowing resin during processing and cure. Often fiber washout will alter the direction of fibers from the predetermined general direction of reinforcement.

filament winding Filament winding is a process by which continuous reinforcements in the form of *rovings* or *tows* (gathered strands of fibers) are wound over a rotating mandrel. The mandrel can be cylindrical, round, or other shapes as long as it does not have reentrant curvature. Special machines traverse a mandrel length at a speed synchronized with the mandrel rotation. The machine also controls the winding angle of the reinforcement and the fiber lay down rate.

The reinforcement may be wrapped in adjacent bands or in repeating bands that are stepped the width of the band, which eventually cover the mandrel surface. Local reinforcement can be added to the structure during circumferential winding, local helical bands, or by the use of woven or unidirectional cloth. The wrap angle can be varied from low-angle helical to high-angle circumferential or “hoop,” which allows winding from about 4° to 90° relative to the mandrel axis. Newer filament winding machines can place fiber at 0°.

There are advantages and disadvantages to filament winding compared with other methods. The most obvious advantages are cost savings, both capital and recurring labor, and the ability to build a structure that is larger than autoclave capacity. The disadvantages of filament winding generally involve stripping of the mandrel. Fabricators of large rocket motors have used plaster mandrels that can be stripped. Reverse curvature can be formed into a positive curvature by the addition of oriented fiber or mats. If the curvature is necessary to the design, such as an air foil, it can be accomplished by removing the uncured structure from the mandrel and using alternate means of compaction to form the composite.

Newer filament winding machines have the capacity to change the winding angle at any point over the part's surface. This provides the option of actually winding the fiber into a reversed curvature by selecting the winding angle that will follow a hyperboloidal path into a smooth recess without bridging or slipping.

The poor external surface can be smoothed somewhat by the proper selection of resin and fiber, the use of a surfacing mat, the use of filled smoothing compounds at some weight penalty, or by compaction and cure in a female die mold using vacuum bag or autoclave pressure.

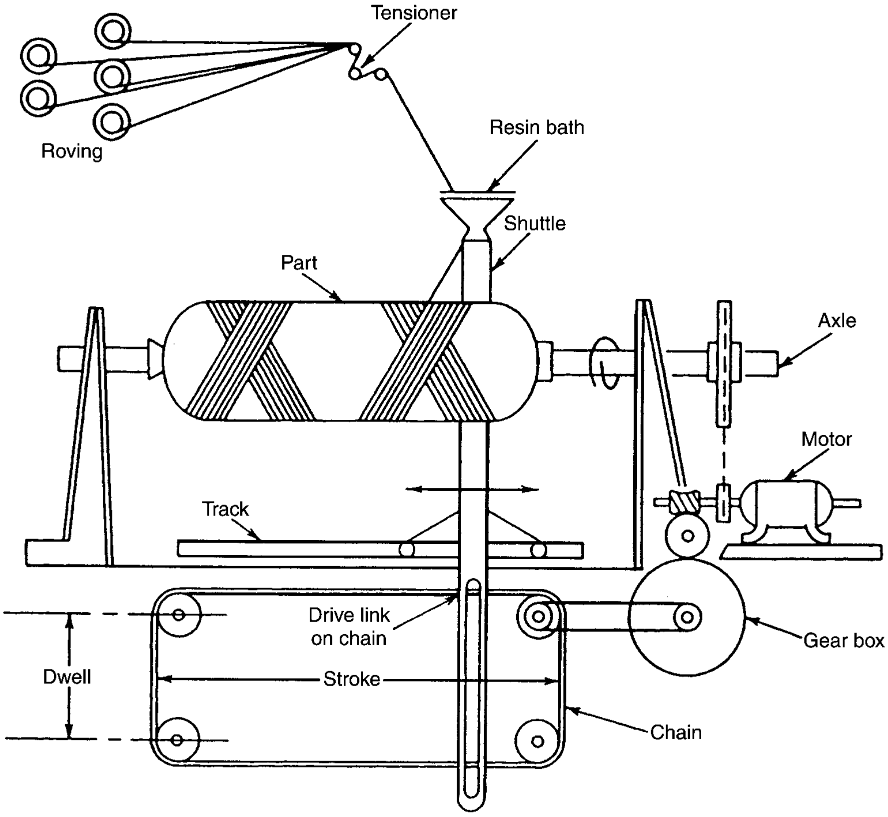

Figure F.2 Filament winding process using a liquid thermosetting resin system. (Ref: Hull, J.L., "Processing of Thermosets", *Modern Plastics Handbook*, McGraw-Hill, New York, 2000)

The filament winding process, like *pultrusion*, can employ wet resin systems to result in potentially lower-cost composite structures. Guidelines for a wet resin system that are unique to wet filament winding are that viscosity should be low, pot life should be as long as possible, and toxicity should be low. Thermoset resins have generally been used as the binders for the reinforcements in filament-wound products. These resins can be applied to the dry roving at the time of winding (wet winding) or may be applied previously and gelled to a *B-stage* as *prepreg*. The fiber can be impregnated and rerolled without B-staging and used promptly or refrigerated. Prepreg and wet rerolled materials are useful because of the opportunity they afford to perform quality control checks early on in the process.

The cure of the filament-wound composite is generally conducted at elevated temperatures without the addition of any process for composite compaction. However, sometimes shrink wrap film is applied to the wet filament-wound layup to prevent resin from dripping off the winding during cure. The main advantage of filament winding is its flexibility in "designing" a construction that meets the load requirements. Table F.2 offers typical properties of filament-wound products.

Table F.2 General Properties of Filament Wound Products (Ref: Harper, C.A., "Laminates and Reinforced Plastic Materials and Processes", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Property	Value
Specific gravity	2.0
Density, lb/in.^{3}	0.072
Thermal conductivity, Btu/(hr)(ft^2)(°F/in.)	2.2
Thermal expansion, per °F $\times 10^{-6}$	7.0
Specific heat, Btu/(lb)(°F)	0.227
Maximum use temperature, °F	<400
Hoop tension, psi $\times 10^{-3}$:	
Unidirectional windings	230
Helical windings	135
Compressive strength, psi $\times 10^{-3}$	70
Flexural strength, psi $\times 10^{-3}$	100
Bearing strength, psi $\times 10^{-3}$	35
Shear strength, psi $\times 10^{-3}$:	
Interlaminar	6
Cross	18
Modulus of elasticity, tension, psi $\times 10^{-6}$	6.0
Modulus of rigidity, torsion, psi $\times 10^{-6}$	2
Dielectric strength, step-by-step, volts/mil	400

filing, grinding, and sanding Thermosetting plastics are relatively hard and brittle and as such are relatively easy to file, grind, and sand. These processes are generally used as finishing steps in manufacturing a plastic product.

Filing is required in plastics fabrication principally in removing *burrs* and giving radius to a finished piece. Care must be taken to protect the surface of the material, because deep scratches must to be removed in an extra operation. Filing plays an important part in finishing molded parts.

Filing removes materials in the form of light powder. Aluminum type A shear tooth or other files that have coarse, single-cut teeth with an angle of 45° are preferred. The deep-angle file teeth enable the file to clear itself of plastic chips. On the other hand, thermoplastics are tough and flexible materials. These have a tendency to clog files. Curve tooth files, like those used in auto body shops, are good because they clear themselves of plastic chips. Specially designed files for plastics should be kept clean and not used to file metals.

Grinding is generally not done on plastic parts unless open grit wheels with a coolant are used. Plastics are generally ground more slowly than metals, and the grinding is kept to a minimum to avoid unnecessary polishing later. Thermosets can be ground at cutting speeds of 4–8 ft/s after a rough belt grinding. Thermoplastics are preferably ground wet, because of better cooling, at cutting speeds of 3–5 ft/s while using a thicker application of grinding media.

Thermoplastics can be ground or sanded to a finished edge, to fabrication fit-up, or to close dimensional tolerance. The work is generally done on a machine (belt, disk, or band) by wet sanding using water cooling for removing the heat built up. High tool speed and light feed or pressure is recommended. This will prevent softening of the plastic and subsequent buildup of viscous material on the grinding wheel. Wet grinding is used to square edges and to touch up angles, arcs, or curves for fit-up. Beveling can be done on a tilt bed wet sander.

For sanding, a number-80 grit silicon-carbide abrasive is recommended for rough sanding. Progressively finer abrasives are then used in finishing. In any machine sanding, light pressure is used to prevent overheating. Disk sanders should be operated at speeds of 1750 rpm and belt sanders at a surface speed of 3600 ft/min. After sanding, further finishing operations can be completed.

See also grinding.

fill In fabric construction, the fill is the transverse threads or fibers, oriented at right angles to the *warp* (the fibers running lengthwise), in a woven fabric. The fill is also called *filling*, *yarn*, *woof*, or *weft*.

See also warp; glass fabric.

fill and wipe Fill and wipe is a process used for coating or painting depressions that are purposely molded into a part. Here the paint is applied to the depressions and surrounding surfaces. The excess paint on the surrounding surfaces is then removed by wiping or by using a solvent-dampened pad, leaving only paint in the depressed areas. Fill and wipe is a useful method for painting numbers or letters that are molded into the surface of the part. The fill and wipe process is also often used for decorative coating.

filler The term *filler* refers to solid additives, which are incorporated into the plastic matrix generally to enhance properties or reduce cost. A filler can be any material that is added to plastics or elastomer formulations. Fillers that are added primarily to reduce the cost are called *extenders*. Reinforcing fillers are added to a plastic resin to modify physical properties, particularly hardness, stiffness, and impact strength.

Inert fillers, as well as reducing cost, may increase the density of the compound, lower the shrinkage, increase the hardness, and increase the heat deflection temperature. Reinforcing fillers typically will increase the tensile, compressive, and shear strength; increase the heat deflection temperature; lower shrinkage; increase the modulus; and improve the creep behavior.

Reinforcing fillers improve the properties via several mechanisms. In some cases a chemical bond is formed between the filler and the polymer, whereas in other cases the volume occupied by the filler affects the properties of the plastic. As a result, the surface properties and interaction between the filler and the thermoplastic are of interest.

Certain properties of the filler are of great importance. These include the particle shape, the particle size and distribution, and the surface chemistry of the particle. In general, the smaller the particle, the higher the effect will be on the mechanical property of interest.

Many plastics are virtually useless alone but are converted into highly serviceable products by combination with particulate or fibrous solids. Phenolic and amino resins are almost always compounded, or filled, with substances like wood flour, pure short-fiber cellulose, and powdered mica. These materials greatly enhance dimensional stability, impact resistance, tensile and compressive strength, abrasion resistance, and thermal stability. The use of glass fiber as a reinforcing filler for polyester resins is another important example. Soft thermoplastics like hydrocarbon resins are usually blended with very large amounts (over 80% by weight) of mineral solids such as crushed quartz, limestone, or clay. In compounds of this type, the resin functions as an interparticle adhesive; these products often have poor tensile properties but excellent compressive strength, abrasion resistance, and dimensional stability.

The principal fillers used for molding compounds and other thermoset and thermoplastic compounds can be classified as (1) agricultural and plant products, (2) conductive fillers, (3) fibrous fillers, (4) mineral fillers, and (5) reclaimed material.

Agricultural and plant products include cellulose, corn cob, nutshells, and derivatives, rice hull, starch, and wheat straw. The major fillers in the category are:

1. Wood flour, made by grinding soft wood to about 100 mesh. This is the least expensive and a widely used filler for phenolic resins.
2. Cotton flock, obtained from cotton linters or clippings. This filler improves impact resistance somewhat.
3. α-Cellulose, obtained from wood pulp or high-quality paper. This filler has the advantage of being white, but it provides little improvement in properties. It is used with amino resins to produce light-colored objects.

Conductive fillers include carbon black; carbon or metal fabric, mat, or fiber; metal-coated microspheres or organic fiber; and powders of aluminum, stainless steel, gold, silver, etc. These are generally used to give the plastic product greater electrical and/or thermal conductivity. These materials have been used for parts that must bleed off static charges and in wire and cable shielding. They also have been incorporated in sufficiently high concentrations to provide plastics with high enough levels of electrical conductivity to provide shielding against electromagnetic interference. Thus they have found their way into electrical and electronic cabinets, housings, etc.

Fibrous fillers include glass, carbon/graphite, ceramic, and more conventional synthetic and natural fibers, such as nylon and cotton. In their short form fiber reinforcement leads to improved impact strength and somewhat enhanced physical, electrical, and thermal properties. Longer fibers or continuous fibers have a significant effect on physical property of the composite in the direction of the fiber. Synthetic fibers, in the form of flock, chopped fiber, or dipped fabric, are used with allylic resins, rather than the low-cost phenolics. High-strength fibers such as glass, carbon/graphite, aramid, boron, and ceramic are used as chopped fiber or continuous filament to manufacture structural plastic parts.

Mineral fillers include aluminum trihydrate, calcium carbonate, calcium sulfate, feldspar, Kaolin, mica, silica, talc, titanium dioxide, and wollastonite. These improve properties such as flame resistance, impact strength, and color. Table F.3 shows the major resin markets for selected mineral fillers/reinforcements.

Table F.3 Selected Minerals Used in Plastics Compounding (Ref: *Plastics Compounding*, 1991/1992 Redbook, Edgell Communications, p. 80)

Mineral	Major Resin	Function
Alumina trihydrate	Polyester	Flame retardance
Calcium carbonate, ground	PVC	Cost reduction
Calcium carbonate, precipitated	PVC	Impact strength
Kaolin, air floated	Polyester	Thixotropy
Kaolin, calcined	PVC	Electrical resistance
Kaolin, surface treated	Nylon	Dimensional stability
Mica	Polypropylene	Flexural strength
Silica, ground	Epoxy	Dimensional stability
Talc	Polypropylene	Stiffness
Wollastonite	Nylon	Reinforcement

Calcium carbonate is an important filler with a particle size of about 1 μm. It is a natural product from sedimentary rocks and is separated into chalk, limestone, and marble. In some cases the calcium carbonate may be treated to improve the bonding with the thermoplastic. *Glass spheres* are also used as thermoplastic fillers. They may be either solid or hollow, depending on the particular application. *Talc* is an important filler with a lamellar particle shape. It is a natural hydrated magnesium silicate with good slip properties. Kaolin and mica are also natural materials with lamellar structure. *Carbon black* is used as a filler primarily in the rubber industry, but it also finds application in thermoplastics for conductivity and UV protection and as a pigment.

Reclaimed fillers include macerated fabric and cord. These fillers lead to compounds with 10 or more times the impact strength of corresponding wood flour-filled compositions. Reclaimed rubber, such as nitrile rubber, improves flexibility as well as impact strength in phenolic resins. *Thermoplastic fillers* are also used in thermoset resins for the purpose of increasing toughness and impact strength.

Appendix M indicates just how versatile these materials have become. It shows where each of the filler and reinforcements is being used and for what purpose. Four resins [polyvinyl chloride (PVC), polyester, polypropylene, and nylon] account for far greater volume for fillers than all the other resins put together.

An extremely important example of the beneficial effects of fillers is the reinforcement of elastomers. The properties of elastomers can be enhanced by the addition of certain fillers to the rubber compound before vulcanization or cross-linking. Fillers for rubber can be divided into two classes; *inert fillers*, such as clay, whiting, and barites, which may make the rubber mixture easier to handle before vulcanization but have little effect on its physical properties; and *reinforcing fillers*, which do improve the physical properties.

Carbon black is the outstanding reinforcing filler for both natural and synthetic rubbers. Although the nature of reinforcement is not completely understood, it appears to add a network of many relatively weak “fix points” to the more diffuse network of strong primary bond cross-links introduced by vulcanization. Vulcanization restrains the long-range movements of the polymer molecules but leaves their local segmental mobility high; reinforcement stiffens the mass and improves its toughness by restricting this local freedom of movement.

See also specific filler name (e.g., carbon black).

fillet A fillet is a rounded filling of the internal angle between two surfaces of a plastic molding. In adhesive bonding, it is the adhesive or sealant material that fills the corner or angle where two adherends are joined. For example, in honeycomb construction, having a fillet at the corner of the honeycomb core walls and the surfacing sheets is a good practice to provide for optimum strength.

film The term *film* usually refers to plastic sheet of less than 0.010-in. thickness. Flat stock greater than 0.010 in. is referred to as *sheet*. The term *foil* is sometimes applied to very thin gauges of plastic film; however, this term should be confined entirely to fine-gauge metals.

All films are produced for specific markets, falling into three main categories: industrial applications, consumer soft goods, and packaging. Industrial applications, in which the particular plastic used is constantly changing, are purely functional, such as insulating tape and other insulation, gasketing, photography film, and adhesive backing. Consumer soft goods include such articles as raincoats, shower curtains, draperies, umbrellas, and covers. Packaging is a complex separate field in itself. The packaging of food items is one of the largest uses of films in the packaging field.

Although general-purpose films are available, they can be varied in composition to meet specific requirements. Such special formations may be superior to standard films in flame resistance, heat sealing characteristics, water absorption, cold resistance, water vapor transmission, light or solvent resistance, etc.

Films are made from any of the commonly used plastics materials; however, the majority of films are thermoplastics and can thus be easily produced by common processes of solvent casting, extruding, and/or calendering. There is considerable variation in the physical properties of the same type of film depending on the method by which it is made.

In general, casting gives a film greater uniformity of thickness and greater clarity than either extruding or calendering. Films made by this technique have fine gloss and freedom from defects such as die lines, which can never be eliminated from extruded film. Casting also permits more flexibility of formulation and yields a film with somewhat better physical properties for a given gauge. The easiest method of obtaining thin films is to cast a solution of the polymer onto a belt, which is sent through a heating tunnel. By precise adjustment of the temperature in the tunnel and the belt speed, the solvent is removed and a finished film is recovered at the end of the tunnel. Cellulosics, such as cellulose acetate, have been made extensively by this process.

The advantage of calendering and extrusion methods is that they generally do not use any solvents — a factor making more economical production possible. The most common method for producing film (and sheet) is by extrusion from a melt. Virtually any thermoplastic can be extruded into film and sheet with an extruder, air knife, chill roll, and turret take-up winding. When used with an appropriate film die, materials up to 6 ft wide can be extruded at thickness as low as 0.001 in. The material can then be stretched to produce thickness as low as 0.00025 in.

One of the major problems in the production of film by extrusion is the maintenance of uniform thickness throughout the width of the film. To allow for variance in the die opening, the die lips are equipped with adjustment bolts along the width of the die. Although the measurements and adjustments can be made manually, the latest technique is to use a β-ray nuclear gauge scanner across the width of the film to monitor the film thickness and instantly indicate the need for adjustments in the die lips. Automatic controllers can also be tied in with the scanners to allow the fastest response. Other types of scanners use X-ray and infrared sensors to accomplish the same purpose.

An extrusion system used extensively for thin films of polyethylene and polypropylene is the *blown film* process. In this process the polymer is extruded as a relatively thick tubular extrusion and is then blown up by internal air pressure to form a thin-walled tube. The tube is then slit to form a sheet of film up to 10 ft in width or is left as a flattened tube known commercially as *lay-flat tubing*. To improve gauge uniformity in this process, the circular extrusion die, the air cooling ring, or both are frequently rotated. Although low-density polyethylene and polypropylene are the materials most used for this process, polyvinyl chloride, polyamides (nylon), and some polystyrenes have all been used. (*See also* blown film; lay-flat tubing.)

A process used almost exclusively for polyvinyl chloride resins is *calendering*. A formulation of resin, plasticizer, colorants, stabilizers, etc. is heated and passed through polished and heated rollers, which are successively placed closer and closer together. This same process is also used in production of rubber sheeting or fabric-reinforced plastic.

Skiving is a method of continuously cutting thin sheets or films from a cylinder of raw material. This process is used to produce film from polymers that are not normally amenable to extruding or solution casting. In practice, it has been used almost exclusively for production of films of Teflon TFE (polytetrafluoroethylene). Figure F.3 illustrates the skiving process.

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Figure F.3 Skiving process for films. (Ref: Swartz, S.S., and Goodman, S.H., *Plastics Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 508)

Three processes are used to enhance certain properties of films: (1) *orientation*, (2) *coating*, and (3) *lamination*. These special processes are usually incorporated into the main manufacturing processes of casting, extruding, and calendering.

Orientation consists of a controlled stretching of the polymer chains of the film in such a way as to orient the chains in a direction parallel to the plane of the film. In general, all thermoplastics may be oriented; the benefits are somewhat greater for some materials than others depending on the material and/or the particular characteristic that is to be improved. Orientation generally improves toughness, tensile strength, flexibility, and shrinkability. It may also be used to improve the clarity of transparent films and to decrease the gas and moisture permeability of some films.

A variety of coatings are used to impart special characteristics or improve some property of a film. In general coatings are thin (less than 0.001 in.) and are applied as lacquers, solvent dispersion, aqueous dispersion, etc. Coatings can be used to act as heat-sealing adhesives, to improve the barrier properties to passage of gases and moisture, and to change the handling characteristics of the film.

Many polymers are used in film form. Table F.4 provides general characteristics of some of the more common polymer films. Regenerated cellulose or cellophane has long been used, often coated with a thermoplastic for heat sealing. Cellulose nitrite and cellulose acetate were among the earliest of polymeric films. Low-density and high-density polyethylene are by far the most common film materials.

Table F.4 Properties of Common Polymer Films. (Ref: Harper, C.A., "Laminates and Reinforced Plastic Materials and Processes", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Film	Cost	Thermal Stability	Dielectric Constant	Dissipation Factor	Strength	Electric Strength	Water Absorption	Folding Endurance
Cellulose.	Low	Low	Medium	Medium	High	Medium	High	Low
FEP fluorocarbon. . .	High	High	Low	Low	Low	High	Very low	Medium
Polyamide.	Medium	Medium	Medium	Medium	High	Low	High	Very high
PTFE polytetrafluoroethylene.	High	High	Low	Low	Low	Low	Very low	Medium
Acrylic.	Medium	Low	Medium	Medium	Medium	Low	Medium	Medium
Polyethylene.	Low	Low	Low	Low	Low	Low	Low	High
Polypropylene.	Low	Medium	Low	Low	Low	Medium	Low	High
Polyvinyl fluoride. . .	High	High	High	High	High	Medium	Low	High
Polyester.	Medium	Medium	Medium	Low	High	High	Low	Very high
Polytrifluorochloroethylene	High	High	Low	Low	Medium	Medium	Very low	Medium
Polycarbonate.	Medium	Medium	Medium	Medium	Medium	Low	Medium	Low
Polyimide.	Very high	High	Medium	Low	High	High	High	Medium

Polypropylene is generally used as oriented polypropylene. Polyvinyl chloride film is commonly used in plasticized form. Polyvinylidene chloride is often known as Saran and is generally used in copolymer form with acrylonitrile. Polyethylene terephthalate is a thermoplastic polyester. Polystyrene is sometimes used in biaxially oriented form. Polycarbonates, polysulfones, polyether sulfones, polyimides, polyetherimides, and several fluoropolymers are also used for specialty applications.

Laminations are combinations of two or more forms of a film and another material (e.g., metal foil, paper). The purpose for the laminate is to produce a composite with properties that are superior to those that might be obtained in the same thickness of a single layer of only one of the materials. The polymer part of the laminate is often used as a hot melt adhesive to the nonpolymer part. Primers and adhesion promoters are also often used to improve adhesion between the plies.

Multilayer lamination of film to film is not normally done because of the difficulty in controlling the process, air entrapment, and so on. However, multilayer films are very commonly made by a process known as coextrusion, in which two or more polymers are simultaneously extruded through one die. Typically, for food packaging applications, different layers will provide the following major properties: mechanical strength, sealing, vapor or moisture barrier.

film adhesive The term film adhesive can refer to (1) a thin layer of dried adhesive and, more generally, (2) a class of adhesive provided in dry film form with or without reinforcing fabric that is cured by heat and pressure. Film adhesives can be thermoplastic films that are applied as a hot melt or as thermoset B-staged systems. The thermoset film adhesives are used primarily as *structural adhesives*. The thermoplastic adhesive films are generally used for low-strength, temporary, or high-volume applications.

Tape and *film* adhesives are terms used loosely and interchangeably for adhesives in sheet form. More correctly, tapes are supported on a web of paper or nonwoven fabric or on an open-weave scrim of cotton or nylon. Supporting fibers are useful in that they provide a positive stop under bonding pressure. This can be used to control bond line thickness and often to help distribute stresses. Films on the other hand, are free of reinforcing fibers and consist only of the adhesive in thin, sheet form.

Tape and film adhesives are poor gap fillers, especially if the gap between parts varies in depth across the bonding surface. However, they offer a uniformly thick bond line and easy dispensing. Being a single-compound system, there is no need for metering. Tape and film adhesives can be used for bonding large areas such as in the aerospace industry. For example, the joining of aluminum *honeycomb* structure to flat sheets is best accomplished with thermosetting film adhesives.

film stacked composite A film stacked composite represents advanced technology that has been used only in specialty applications (e.g., aerospace). It consists of a structurally designed composite with a thermoplastic matrix. The film stacked composite is produced from fiber prepregs that are interspaced with thermoplastic films.

fin The fin is the molded compound that forms in the narrow gap between the movable parts in the mold. *Flash* refers to the material that is forced out of the mold, whereas a fin is the compound that forms between mold section areas or around mold pins. Generally, both fins and flash must be removed from the part after it is molded.

finish There are several definitions of finish in the plastics industry. Finish is the ultimate surface structure of an article. It is also a term that refers to synthetic resins used for paints and coatings (e.g., phenolics, modified phenolics, alkyd resins, epoxy resins). (*See also* coating resin; enamels.)

A finish could also be an after treatment for fiber or fabrics. Here, finishes are applied to reduce the damage during processing, promote adhesion to matrix resins, and improve the end properties such as hand (softness), water repellency, and wash-wear characteristic of textile products.

To affect the feel or hand of fabrics, finishes increase or decrease the natural friction between the fibers. Thus *lubricants* make the fabrics feel softer or have increased pliability. On the other hand, antislip finishes such as rosin, carbomethyl cellulose, and hydroxyethyl cellulose impart a harsh feel to the fabric.

Ethylene and propylene glycols and their low polymers with the ability to absorb and retain moisture act as softening, plasticizing, and antistatic agents for hydrophilic textile fibers. Treatment with waxes such as paraffin emulsions impart *water repellency* to cellulose fabrics, but the effect is not permanent. Silicones impart water repellency to all fabrics.

One of the major advances in textile technology in recent years has been the introduction of resin finishes that impart the wrinkle- and crease-resistant properties associated with “wash and wear” fabrics. Ordinarily used with cotton and viscose rayon, resin finishes are currently applied to the majority of shirts, blouses, etc. The resin finishes consist of aqueous solutions of urea formaldehyde or melamine formaldehyde precondensates or of cyclic ureas such as dimethylol ethylene urea. It is thought that wrinkle resistance is imparted through the cross-linking of adjacent cellulose chains in the fiber, rather than from resin formation in or between fibers.

Several finishes have been developed as surface treatments to improve the wetting and adhesion characteristics of glass fiber. Common to all these treatments are properties that allow one part of the chemical compound to adhere to the fiber surface while another part of the same molecule reacts with the resin matrix. This causes a chemical/mechanical bridge between the glass fiber and the resin matrix in high-strength composites. *Silane* coupling agents are commonly used for glass finishes.

Finishes on reinforcing fibers notably improve the inherent dry strength of the composite, but often they are used to retain physical properties after exposure to a wet environment. Finishes generally can be formulated to work with both thermoplastic and thermosetting resins and various types of glass fiber reinforcements.

finish insert The finish insert is the removable part of a blow mold that is used to form a specific neck finish on a plastic bottle. The finish insert is sometimes called a *neck insert*.

fish eye A fish eye is a fault in transparent or translucent plastics materials, such as film or sheet. It appears as a small, globular mass and is caused by incomplete blending of the mass with surrounding material. Often the incomplete blending is due to the fact that the localized material is of higher molecular weight, partially oxidized, partially cross-linked, or not completely solvated in the case of solvent systems. Fish eyes can occur in both thermoplastic and thermosetting materials.

fish paper Fish paper is an electrical insulation grade of paper made from vulcanized fiber in thin cross section. It was used with appropriate resins such as phenolics in constructing early electrical grade laminates. Fish paper laminates are not used much today.

flame polishing Many thermoplastic materials may be flame polished by a procedure similar to that used for glass. The product is rotated or passed over a flame, which softens the surface sufficiently so that rough spots are smoothed out as it cools and hardens. Under the melting action of the flame, the surface tension of the materials will usually cause a uniform glossy surface to form.

A technique similar to flame polishing can be used to treat certain plastic surfaces before coating or adhesives bonding. *See* flame treatment; surface treatment.

flame retardant Flame retardants are materials added to plastics to improve their flame resistance. Flammability of plastics is under regulation in various states, with major concerns being combustion toxicity and smoke generation. A number of additives are available that enable plastics to pass specific required tests.

However, flame retardants are in a unique position among plastics additives in that their market is sustained by regulations and yet threatened by other regulations. Environmental and toxicity concerns now have regulators looking at the important halogenated and antimony-based synergist flame retardants that have been developed over the years. Any regulation that limits the use of such products will again change the industry and force producers to develop a new generation of products.

The major factors in reducing the flammability of materials are (1) elimination of volatile fuel, as by cooling; (2) production of a thermal barrier, as by charring, thus eliminating fuel by reducing heat transfer; and (3) quenching the chain reactions in the flame, as by adding suitable radical scavengers. The additives used to meet these criteria are described below:

char formers Usually phosphorus compounds, which remove the carbon fuel source and provide an insulation layer against the fire's heat.

heat absorbers Usually metal hydrates such as aluminum trihydrate (ATH) or magnesium hydroxide, which remove heat by using it to evaporate water in their structure.

flame quenchers Usually bromine- or chlorine-based halogen systems, which interfere with the reactions in a flame.

synergists Usually antimony compounds, which enhance performance of the flame quencher.

The materials chosen to perform these functions must not interfere with the final product's properties, the usefulness of the product, safety, or other environmental and toxicity requirements. It is common to formulate plastics with multiple flame retardants, typically a primary flame retardant plus a synergist such as antimony oxide, to enhance overall flame retardant efficiency at the lowest cost. Several hundred different flame retardant systems are used by the plastics industry because of these formulation practices.

Popular flame retardants for acrylonitrile butadiene styrene (ABS) are aromatic bromines. Typical ratios for achieving a V-0 rating (self-extinguishing as determined by UL testing) are from 8 to 20 percent loading of the aromatic bromines plus 2–6 percent of antimony oxide. For high-impact polystyrene, a typical formulation might include decabromodiphenyl oxide at levels of 11–13 percent plus 3–4 percent of antimony oxide. Polypropylene could use up to 30 percent of a cycloaliphatic chlorine compound plus up to 13 percent of antimony oxide to get a V-0 or V-1 rating.

Epoxy molding compounds are made flame retardant with tetrabromo-bisphenol A as the reactive intermediate in manufacturing the epoxy compound. Rigid polyvinyl chloride (PVC) usually does not require flame retardants because of its high chlorine content. However, flexible PVC will use retardants such as antimony oxide, zinc borate, and chlorinated paraffins and phosphate esters. ATH can also be used in compounds that tolerate fillers and is typically combined with antimony oxide and phosphate esters.

Flame retardants for plastics can generally be classified as *reactive* (the flame-retarding agent reacts chemically with the plastic to become an integral part of it) or *additive* (nonreactive agents that are simply blended or mixed into the compound). Flame retardants can also be classified by their major chemical group as shown in Table F.5.

Alloying different plastics with different flame retardant characteristics can also improve flame retardancy. A typical compound would be ABS-PVC alloys. Recently, PVC with antimony oxide has also been investigated for alloying with thermoplastic polyurethane.

For specific flame-retardant additives, *see* specific chemical type (e.g., alumina trihydrate).

flame retardant resin A flame retardant resin is a resin that is compounded with certain chemicals to reduce or eliminate its tendency to burn. For polyethylene and similar resins, chemicals such as antimony trioxide and chlorinated paraffins are useful.

A flame-retardant resin could also be a resin that inherently has a high degree of flame retardancy. Examples are rigid polyvinyl chloride (PVC) and neoprene. The high degree of flame retardancy is generally achieved by a high concentration of chlorine atoms along the molecular chain.

Table F.5 Major Types of Flame Retardants, Typical Products, Applications, and Suppliers

Type	Typical Products	Typical Applications	Typical Suppliers
Alumina Trihydrate	Available in various particle size grades and in surface treated grades	Polyesters, phenolics, and epoxies. Also polypropylene and ethylene / rubber compounds	Alcan Chemicals: Alcoa Industrial Chemicals, Div.; Harwick Chemical Corp.; Whittaker, Clark & Daniels
Magnesium	Magnesium Hydroxide Magnesium Carbonate	Synergists with ATH for smoke reduction	
Chlorines	Chlorinated Paraffins Tris (dichloropropyl) phosphate, methyl pentachlorostearate, other chlorinated phosphates Cycloaliphatic chlorine Chlorendic Anhydride	LDPE film and flexible PVC Urethane foam and topical fabric Polypropylene and nylon Reactive intermediate in making polyester and epoxy flame retardant resins	Dover Chemical Corp.; Ferro Crop.; Witco Corp.
Bromines	Aromatic Bromines (e.g., Decarbromopheny oxide ether Tetrabromo-bisphenol A Pentabromodiphenyl oxide) Aliphatic Bromines Ionic Bromines Benzene-ethenyltribromo derivatives Polypentabromobenzyl acrylate	Polyolefins, ABS, polyesters Thermosets and thermoplastics Urethane foams and polyesters Plastic foams and polyester fibers Thermoplastics usually as a synergist Engineering thermoplastics Glass reinforced nylon and PBT	Akzo Chemicals Inc.; Ferro Corp.; Great Lakes Chemical Corp.
Phosphorous	Phosphate Esters and others (halogenated and nonhalogenated)	Polyurethane foams, polyesters, and themoplastics such as flexible PVC, modified PPO, and cellulosics. Also polyethylene, polypropylene, polystyrene, and ethylene / propylene copolymers	Akzo Chemicals Inc.; CSA Chemical; Great Lakes Chemical Corp.; C.P. Hall Co.

(*Continued*)

Table F.5 (*Continued*)

Type	Typical Products	Typical Applications	Typical Suppliers
Antimony oxide	Dusting and Nondusting grades are available of various particle sizes	Works synergistically with reactive or additive halogenated compounds ABS, polyethylene, polypropylene, polystyrene, thermoplastic polyester, unsaturated polyesters	Asarco Inc.; Harwick Chemical Corp.; US Antimony Sales Corp.
Borates	Zinc Borate, Barium Metaborates, Ammonium Fluoroborate, Boric Acid	Flexible PVC, polyolefins, unsaturated polyesters, thermoplastic polyesters, epoxies, nylons, urethanes, and phenolics	CSA Chemical; Harwick Chemical Corp.; US Borax & Chemical Corp.
Molybdenum compounds		Used in combination with other retardants for flexible PVC and reinforced polyesters. Behave as synergists with halogen containing compounds	Climax Performance Materials; CSA Chemical; Sherwin Williams Chemicals

flame spraying Flame spraying is the method of applying a plastic coating in which finely powdered fragments of the plastic, together with suitable fluxes, are projected through a cone of flame onto the surface of a substrate.

flame treatment Flame treatment burns off contaminants and oxidizes the surface of the polymer similar to corona treatment. Flame treatment is used as a surface treatment for low-energy polymeric parts before bonding, printing, or painting.

Flame treatment is believed to provide a polar surface that is conducive to adhesion. A brief exposure to the flame oxidizes the surface through a free radical mechanism, introducing higher-surface-energy groups (hydroxyl, carbonyl, carboxyl, and amide groups) to the part's surface. Molecular chain scission and cross-linking also occur depending on the polymer and on the nature of the flame treatment. It is widely used to prepare polyolefin surfaces for painting, printing, or adhesive bonding. Flame treatment can be used for both film and shaped products and can be used for both continuous and bulk processing.

Flame treatment consists of exposing a surface to a flame for a time of less than several seconds. The gas burners are fed from the mains (chief component methane) or bottled gas (propane or butane). Of importance in the operation of a flame treater is the gas to air mix ratio. A slight excess of oxygen over that required for complete combustion is recommended. Depending on the level of gas in the mix, the flame can have substantially different characteristics. A surface is typically exposed to the flame region just above the blue cone until it becomes glossy.

This treating method increases the resulting adhesive strength of joints made with polyolefins and other low-energy plastics. It also provides a surface that is better prepared to accept printing ink, paint, and coatings. The flame oxidizes the surface, resulting in an increase in critical surface energy. The time that the flame is applied and its nearness to the surface are important quality control factors. It is important not to overexpose the plastic because warping or other damage of the part may result.

Automated processing equipment is possible, similar to the corona treaters. Hand-held equipment such as a torch or Bunsen burner can also be used, although uniform treatment is more difficult. The effect of additives on treatment efficiency is not as great as with corona treatment.

See also surface treatment.

flammability (in-plant safety) Liquids are classified according to ignitability, and *flash point* tests can be used to measure this property. The test consists of a liquid of sample in a heated cup with an ignition source above the cup. The sample is heated until the vapors ignite, and the flash point is reported as the ignition temperature.

The limits of flammability are defined as the minimum concentration and maximum concentration in air that can be ignited. For example, methyl ethyl ketone will not ignite below 1.8 percent or above 11.5 percent when mixed with air. For some industrial operations, solvent vapors are held below 25 percent of the lower limit. Nitrogen purge can be used to prevent fire hazards in some situations, such as in closed processing systems.

flammability of plastics Most plastics will burn. The degree of a plastic's ability to burn or its flammability is determined by the resin's molecular structure and whatever additives, modifiers, etc. may be present. How rapidly fabricated pieces will burn depends on their thickness and whether they are packed closely or loosely with or without air spaces between them. Flammability also depends on the fire conditions (e.g., oxygen content).

Plastics classified as burning readily are acrylic, cellulosics, polyethylene, and polystyrene. Among the slower-burning plastics are phenol formaldehyde, urea formaldehyde, nylon, vinyl chloride (rigid), vinylidene chloride, melamine formaldehyde, and phenolic laminates. Most of these are self-extinguishing, that is, they stop burning when the source of the heat is removed. A few plastics, such as polytetrafluoroethylene, do not burn at all.

Because flammability depends as much on the fire conditions as on the material, there are many standard tests to measure flammability. In the United States alone over 100 tests are used to evaluate the reaction of plastics to fire. ASTM D3814 lists standard combustion test methods.

The reaction of plastic materials to fire can be described by seven factors:

- Ease of ignition—how readily a material ignites
- Flame spread—how rapidly fire spreads across a polymer surface
- Fire endurance—how rapidly fire penetrates a wall or barrier
- Rate of heat release
- Ease of extinction
- Smoke evolution
- Toxic gas generation

Strong feelings have been expressed that small-scale laboratory tests do not accurately predict results for large-scale fire tests. Likewise, some investigators feel that many descriptive terms for flammability rating, such as self-extinguishing (SE), tend to give the user an unjustified sense of security.

When used together the tests can predict material performance. Depending on the material's use, one or more of these tests are generally specified. Descriptions of the more standard test methods are provided in Table F.6.

Several tests are under development. The cone calorimeter is a heat-release calorimeter using oxygen depletion as a measurement technique. The LIFTS (lateral ignition and flame spread test) apparatus is similar to the radiant panel, but turned on its side. The NIBS toxicity test is under development by the National Institute of Building Sciences. Several tests are aimed specifically at plastics in aircraft passenger compartments. These are described in ASTM E906.

flash Flash is the excess material that overflows along the parting line of the mold. This clings to the molded piece on ejection and must be removed by finishing operation. Flash is most common in compression molds, in which a small amount is actually essential to obtain parts of full density. Flash may also occur in

Table F.6 Major Test Methods Used to Determine the Flammability of Plastic Material

Property Measured	Test Method
Ignitability	ASTM D1929 measures the temperature necessary to cause sufficient decomposition to generate volatile fuel that can be ignited. ASTM D635 involves repeated application of Bunsen burner flames to small samples for short fixed periods of time. UL 94 involves a standard series of tests similar to ASTM D635 but uses an actual manufactured part. Specimens can be classified as V-0, V-1, or V-2, depending on its burning behavior.
Flame spread	ASTM E162 places a polymer sample against a radiant heat panel at 670°C. A small pilot flame is produced and the rate of burning down the sample is measured. The Steiner tunnel test is often used to evaluate construction materials. This test monitors how fast the flame front travels as well as smoke development and fuel contribution.
Toxicity	Standard chemical analysis is used to identifying the individual products of combustion. The combined biological effects of the toxic compounds are then predicted using criteria such as animal exposure tests.
Smoke	ASTM E662 uses a NBS smoke chamber; ASTM D2843 uses a XP-2 smoke chamber; and ASTM E84 uses a tunnel test. Generally optical density is measured.

transfer and injection molds when the mold is opened slightly by excess pressure or impact.

The *flash line* is the raised line appearing on the surface of a molding and formed at the junction of mold surfaces. A *flash groove* is a groove that is machined in a force or land area to permit flash to escape. A *flash mold* is a mold designed to permit excess molding materials to escape during closing. In a flash mold the flowing resin material has no restriction to its flow. Nearly all the molds used in injection and transfer processes are flash molds.

It is usually necessary to remove the flash for cosmetic or functional reasons. No single method is universally applicable for the removal of flash and gate material. Each part's geometry and materials will have its specific requirements and individual problems. Generally rigid, brittle materials are relatively easy to deflash, whereas tough, flexible materials are more difficult. Sometimes cryogenic temperatures are used to make the plastic rigid and brittle for the purpose of deflashing.

The techniques generally used are hand deflashing (filing, sanding, and machining) and tumbling. For removal of flash, tumbling is generally preferred. However, the shape, size, or contour of the article may require filing to remove heavy flash, gate sections, or burrs that may be left by machining operations. Other methods of deflashing parts that are less common are chemical deflashing and water honing. (*See* deflashing.)

flash mold A flash mold is defined as a mold type in which the parting line is at right angles to the direction of the force that has been applied to close the mold and keep it closed during the cure or setting time. In this mold configuration, the greater the clamping pressure, the tighter the mold seam. Injection molds, transfer molds, and compression molds make use of the flash type of parting line.

flash point The flash point is the lowest temperature at which a combustible liquid will give off a flammable vapor that will burn momentarily when ignited. In plastics, the flash point or *flash ignition temperature* denotes the lowest temperature of air passing around a test specimen in a furnace at which a sufficient amount of combustible gaseous material is evolved to be ignited by a small external pilot flame.

flatting agent (matting agent) A flatting or matting agent is an additive incorporated in a plastic material to reduce surface gloss and/or produce a matte "silk" finish. Most flatting agents have also some antiblocking action. Examples of flatting agents are silicas and certain acrylic resins.

See also antiblocking agents.

flex cracking Flex cracking is the formation of small cracks on the surface of a material when it is repeatedly flexed or bent. The number of times a material can be bent before it cracks is called its *flex life*. The property is important in all flexible plastics, such as coated fabrics, film, and tubing.

Flex fatigue is a term that is commonly used in the testing of elastomers. Flex fatigue is the result of a rubber fracturing after being subjected to fluctuating stresses.

flexibilizer A flexibilizer is an additive that makes a resin or rubber more flexible or resilient. It can be either inert or a reactive part of the chemical reaction. A flexibilzer can also be a plasticizer.

See also plasticizer.

flexible circuit Although most printed circuit boards are based on the use of rigid plastic laminates as substrates, the use of flexible circuit boards (usually called simply flexible circuits or *flex circuits*) is rapidly increasing. The reason is the increasing need to have circuit interconnections in nonflat bendable configurations, as in automotive electrical assemblies, telephones, and instrument panels. Although many flexible plastic films can be used as substrates, polyester and polyimide films are most common. Generally, these high-temperature films are bonded to conductive copper foil with an adhesive.

See also printed circuit boards; electronic plastic.

flexible mold Flexible molds can be formed out of elastomeric materials and used as an inexpensive mold for a low volume number of parts. Flexible molds are generally used on polymers that can be cast and cured at room temperature such as epoxies, polyester, plaster, and waxes.

Flexible molds have a limited life that is more appropriate for items that are cast in small numbers. Their life is determined by the number of molding cycles, the amount of flexing required to remove the finished parts from the mold, the mold's resistance to chemical attack by the polymer, adhesion of the mold to the part, and resulting tearing.

Materials that can be used for producing flexible molds include urethane, polysulfide, and heat-fused vinyl chloride plastisol. Urethane and polysulfide molds, the most common types of flexible mold, are usually made by pouring the resin over a model of the part to be manufactured, which is placed in a container. After the mold has cured the container is removed and the mold is slit down one side and removed from the model. It is then placed in a jig support and is ready for casting.

flexural properties The flexural properties of a material are properties that define the flexibility of a material or resistance of the material to bending forces. The test is performed by suspending a specimen between supports and applying a downward load at the midpoint between them.

The *flexural strength* of a material is its strength in bending. It is measured as the resistance of a material to rupture under a bending stress applied at the center of a rectangular test specimen supported at both ends. ASTM D790 and D650 use a molded or machined test specimen with a span (between the supports) of at least 16 times the thickness. The specimen is generally 0.50 in. × 5.00 in. and its thickness can vary from 0.06 to 0.25 in. The load is applied at rates defined by the specimen size until fracture occurs or until the strain in the outer fibers reaches 5 percent. Most thermoplastics do not break in this test, so that the flexural strength is the flexural stress at 5 percent strain. With plastic materials the flexural strength value is usually higher than the straight tensile strength value.

The *flexural modulus* is the ratio, within the elastic limit, of stress to the corresponding strain. The flexural modulus is the primary means of measuring the stiffness of a material. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deformation curve and calculating the following equation:

$$E_B = L^3 m / 4bd^3$$

Where E_B is the modulus, b is the width of the beam tested, d is the depth of the beam, m is the slope of the tangent, and L is the span in inches.

flow coating In a flow coater, the coating material is pumped through hoses and nozzles onto the surfaces of the product, from which the excess drains into a reservoir to be recycled. Flow coaters can be either automatic or manual. Film thickness is controlled by the viscosity and solvent balance of the coating material. A continuous coater is an advanced flow coater using airless spray nozzles mounted on a rotating arm in an enclosure.

Advantages of flow coating are high transfer efficiency and low volume of paint in the system. Products will not float off hangers, and extremely large products can be painted. As with dip coating, the disadvantages of flow coating are coating thickness control and solvent refluxing.

flow drilling Flow drilling is a method of producing a drilled hole in a thermoplastic sheet that is reinforced by materials built up around the periphery. This thickening of the sheet around the hole results from outward flow of material under the action of a special drill used in appropriately controlled drilling conditions. Flow-drilled holes provide additional support for inserts and are particularly advantageous in thin sheets and where subsequent threading and insertion of threaded bolts or screws is required.

flow molding Flow molding is the process of producing leatherlike materials by placing a die-cut plastic blank (generally solid or expanded vinyl or vinyl-coated substrate) into a mold cavity and applying power via a high-frequency generator to melt the plastic such that it flows into the mold to the desired shape and with the desired texture. Often silicone rubber molds are used in this low-pressure process.

flow tests An important characteristic of a thermosetting molding compound is its ability to flow under pressure within the confines of a heated mold. This property value is of utmost importance of the molder and will vary according to the molding method, mold design, molding equipment, and certainly the configuration of the molded part.

As a result, flow testing procedures are important. Flow testing procedures have one main purpose—to provide specific and detailed information based on the compound's intended use. Compounds that are designated for use in compression molds will have decidedly different flow requirements than if the intended use is in either a transfer or an injection molding process.

In most flow tests (with the exception of the Brabender test) three elements are always kept constant during the testing procedure: amount of compound or charge; mold temperature (usually 150°C); and molding pressure (usually 1000 psi).

In the *cup-closing flow test* a room-temperature charge of compound is placed in the lower half of a 150°C preheated cup-shaped mold and the mold is closed with 1000-psi pressure. The time required for the mold to completely close is recorded in seconds. The longer the time, the stiffer the compound. Usually stiff-flow compounds will require 15 s or more, whereas the medium-flow compounds will be in the 8- to 14-s range and the soft flow compounds in the less than 8-s range.

In the *disk flow test*, a measured amount of room-temperature compound is placed on the lower half of the mold and the mold is closed and then reopened as soon as the compound is cured. The molded disk is then measured for diameter and thickness. Either the thickness of the disk or the diameter of the disk can be used as a gauge. The thinner the disk or the larger the diameter, the softer the flow. The thicker the disk or the smaller the diameter, the stiffer the flow.

The *orifice flow test* involves the use of a mold with a lower plate containing a cavity into which a measured quantity of room-temperature compound is placed. The upper plate has a plunger with two small orifices cut into the outer circumference. The test generally uses a charge of 12–15 g and a mold temperature of 150°C. Various pressures can be applied, depending on the molding process to be used. With the mold charged, the heated platens of the press close, and the compound is forced out of the two orifices. The mold is kept closed until the compound has stopped flowing and is cured. On completion of the molding cycle, the cured compound remaining in the mold is extracted and weighed to determine the percentage of flow.

In another type of orifice flow test, a mold is designed as a pot in the lower half and a plunger affixed to the top half. The pot block is designed with a sprue hole in the bottom of the cavity, which feeds the molding compound into a runner that comes out one side of the mold. The pot is charged with 90 g of compound and the mold is closed under 1000 psi with a mold temperature of 150°C. The compound exiting from the runner can be weighed once the flow has ceased. The time of flow is measured from start to finish. The rate of flow can be calculated in g/s. This is a very useful tool for application in transfer or injection molding of thermosets.

There are two types of *spiral flow tests* and molds: one for the very soft flow encapsulation compounds generally associated with the encapsulation grades of the epoxy family of compounds (the Emmi mold) and a spiral flow mold (the Mesa flow mold) that is used when testing the high-pressure thermoset compounds. (*See also* spiral flow test).

The *Brabender Plasticorder* was introduced as a more sophisticated means for measuring the rheology of thermosetting compounds applied to an extruder screw. There is a need to know the duration of a compound's flow life when exposed to both the initial barrel temperatures as the compound is prepared for its movement into the mold and when the compound enters the much hotter mold. (*See also* Brabender Plasticorder.)

The Brabender Plasticorder will provide meaningful data for a specific compound's flow life or duration when exposed to the thermal condition previously described. It measures the viscosity and gel time, and results can be correlated to the performance of a compound during molding operations. The instrument supplier is Brabender Instrument, Inc.

fluidized bed powder coating Fluidized bed powder coating is simply a dipping process that uses dry, finely divided plastic materials. A fluidized bed is a tank with a porous bottom plate, as illustrated in Fig. F.4.

The plenum below the porous plate supplies low-pressure air uniformly across the plate. The rising air surrounds and suspends the finely divided plastic powder particles, so the powder-air mixture resembles a boiling liquid. Products that are preheated above the melt temperature of the material are dipped in the fluidized bed, where the powder melts and fuses into a continuous coating. Thermosetting powders often require additional heat to cure the film on the product.

The high transfer efficiency of this coating process results from little dragout and consequently no dripping. This method is used to apply heavy coats, 3–10 mil, in one dip, uniformly to complex-shaped products. The film thickness is dependent on the powder chemistry, preheat temperature, and dwell time. It is possible to build a film thickness of 100 mil by using higher preheat temperatures and multiple dips.

In an electrostatic fluidized bed small products such as electrical components can be coated uniformly and quickly. The advantages of fluidized bed powder are uniform and reproducible film thickness on all complex-shaped product surfaces.

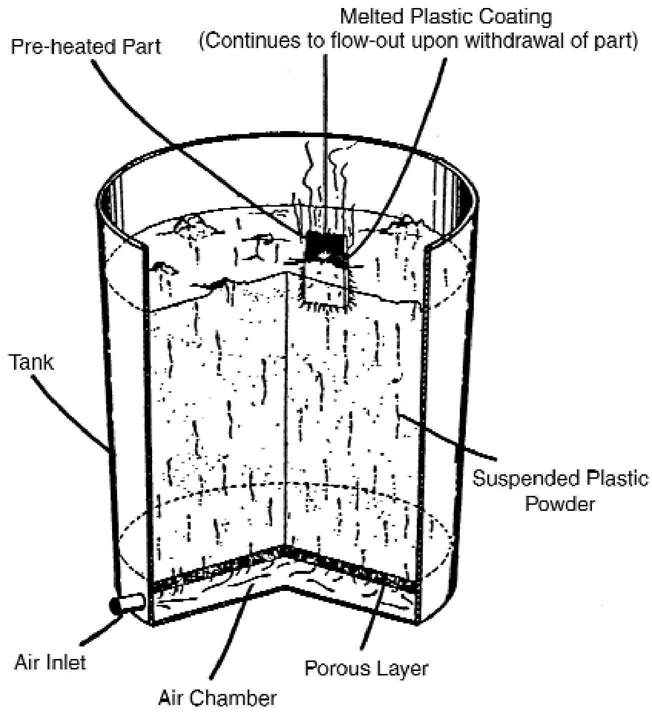


Figure F.4 Illustration of fluidized bed process principle. (Ref: Izzo, C.P., "Protective and Decorative Coatings", *Handbook of Plastics, Elastomers and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Another advantage is the heavy coating in one dip. A disadvantage of this method is the 3-mil minimum thickness required to form a continuous film. Another disadvantage is that inside corners have low film thickness owing to the well-known Faraday cage effect.

An electrostatic fluidized bed powder coating process is essentially a fluidized bed with a high-voltage DC grid installed above the porous plate to charge the finely divided particles. Once charged, the particles are repelled by the grid and repel each other, forming a cloud of powder above the grid. These electrostatically charged particles are attracted to and coat products that are at ground potential. Film thicknesses of 1.5–5 mil are possible on cold parts, and 20–25 mil is possible on heated parts.

See also electrostatic powder coating, powder coating.

fluorocarbon/fluoropolymer/fluoroplastic A fluorocarbon is an organic compound having fluorine atoms in its chemical structure. The term *fluoropolymer* (or *fluoroplastic*) is usually used when the organic compound is a polymer. This structure usually lends chemical and thermal stability to plastics. They are also characterized by low-energy surfaces that are difficult to bond, low coefficient of friction, low dissipation factor, and a low dielectric constant. Their mechanical properties are not high unless reinforcing fillers, such as glass fibers, are added.

For practical purposes there are eight types of fluoropolymers, as summarized in Table F.7. Included in this family of plastics are polytetrafluoroethylene (PTFE), polychlorotrifluoroethylene (PCTFE), polyvinyl fluoride (PVF), fluorinated ethylene propylene (FEP), and others. Depending on which of the fluoropolymers are used, they can be produced as molding materials, extrusion materials, dispersion, film, or tape. Processing of fluoropolymers requires adequate ventilation for the toxic gases (HF) that may be produced.

polytetrafluoroethylene (PTFE) Polytetrafluoroethylene (PTFE) is polymerized from tetrafluoroethylene by free radical methods. Commercially, there are two major processes for the polymerization of PTFE, one yielding a finer-particle-size dispersion polymer with lower molecular weight than the second method, which yields a granular polymer. PTFE is a linear crystalline polymer with a melting point of 327°C,

PTFE has excellent chemical resistance, but may go into solution near its crystalline melting point. PTFE is resistant to most chemicals. Only alkali metals (molten) attack the polymer. The polymer does not absorb significant quantities of water and has low permeability to gases and moisture vapor. PTFE is a tough polymer with good insulating properties. It is also known for its low coefficient of friction, with values in the range of 0.02 to 0.10. PTFE, like the other fluoropolymers, has excellent heat resistance and can withstand temperatures up to 260°C. Because of its high thermal stability, the electrical properties of PTFE remain stable for long periods at temperatures up to 250°C. However, PTFE can be degraded by high-energy radiation.

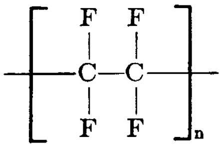
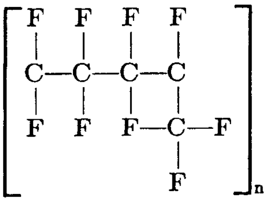
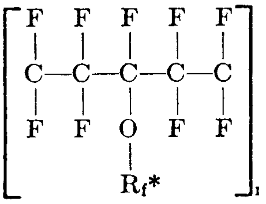
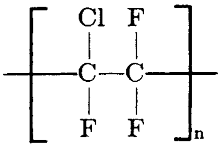
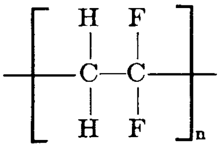
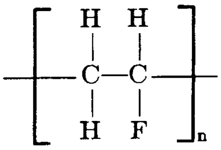
PTFE is extremely difficult to process by either molding or extrusion. PTFE has a very high viscosity, prohibiting the use of many conventional polymeric processing techniques. For this reason, techniques developed for the processing of ceramics are often used. PTFE is normally processed in powder form by either sintering or compression molding. It is also available as a dispersion for coating or impregnating porous materials.

Additives for PTFE must be able to withstand the high processing temperatures required, which limits the range of additives available. Glass fiber is usually added to improve certain mechanical properties. Graphite or molybdenum disulfide may be added to retain the low coefficient of friction while improving dimensional stability.

Because of its excellent electrical properties, PTFE is used in a variety of electrical applications, such as wire and cable insulation and insulation for motors, capacitors, coils, and transformers. PTFE is also used for chemical equipment, such as valve parts and gaskets. The flow friction characteristics make PTFE suitable for use in bearings, mold release devices, and antistick cookware. Low-molecular-weight polymers may be used in aerosols for dry lubrication.

fluorinated ethylenepropylene (FEP) Fluorinated ethylenepropylene is a copolymer of tetrafluoroethylene and hexafluoropropylene. It has properties

Table F.7 Structures, Tradenames, and Suppliers of Fluorocarbons

Fluorocarbon	Structure	Typical Trade Names and Suppliers
TFE (tetrafluoroethylene)	 $\left[-CF_2-CF_2-\right]_n$	Teflon TFE (E. I. du Pont) Halon TFE (Allied Chemical)
FEP (fluorinated ethylenepropylene)	 $\left[CF_2-CF_2-CF_2-CF(CF_3)\right]_n$	Teflon FEP (E.I. du Pont)
ETFE (ethylene-tetra fluoroethylene copolymer)	Copolymer of ethylene and TFE	Tefzel (E. I. du Pont)
PFA (perfluoroalkoxy)	 $\left[CF_2-CF_2-CF(OR_f^*)-CF_2-CF_2\right]_1$	Teflon PFA (E. I. du Pont)
CTFE (chlorotrifluoro-ethylene)	 $\left[-CClF-CF_2-\right]_n$	Kel-F (3M)
E-CTFE (ethylene-chlorotri fluoroethylene copolymer)	Copolymer of ethylene and CTFE	Halar E-CTFE (Allied Chemical)
PVF_2 (vinylidene fluoride)	 $\left[-CH_2-CF_2-\right]_n$	Kynar (Pennsalt Chemicals)
PVF (polyvinyl fluoride)	 $\left[-CH_2-CHF-\right]_n$	Tedlar (E. I. du Pont)

$^*R_f = C_nF_{2n-1}$.

similar to PTFE, but with a melt viscosity suitable for molding with conventional thermoplastic processing techniques. The improved processability is obtained by replacing one of the fluorine groups on PTFE with a trifluoromethyl group.

FEP is a crystalline polymer with a melting point of 290°C. The polymer can be used for long periods at 200°C with good retention of all properties. FEP has good chemical resistance, a low dielectric constant, low friction properties, and low gas permeability. Its impact strength is better than PTFE, but other mechanical properties are similar to those of PTFE. However, its useful temperature is limited to about 200°C.

FEP may be processed by injection, compression, or blow molding. FEP may be extruded into sheets, films, rods, or other shapes. Typical processing temperatures are in the range of 300–380°C. Extrusion should be done at low shear rates.

Applications for FEP include chemical process pipe linings, wire and cable, and solar collector glazing. A material similar to FEP, *Hostaflaon TFB* (Hoechst) is a terpolymer of tetrafluoroethylene, hexafluoropropylene, and vinylidene fluoride.

ethylene-chlorotrifluoroethylene copolymer (ECTFE) ECTFE is an alternating copolymer of chlorotrifluoroethylene and ethylene. It has better wear properties than PTFE along with good flame resistance. Applications include wire and cable jackets, tank linings, chemical process valve and pump components, and corrosion-resistant coatings.

ethylene-tetrafluoroethylene copolymer (ETFE) ETFE is a copolymer of ethylene and tetrafluoroethylene similar to ECTFE, but with a higher use temperature. ETFE has a continuous temperature rating of 150°C. It can be used intermittently up to 200°C depending on exposure time, load, and environment. Glass fiber-reinforced ETFE appears capable of useful service at 200°C. It does not have the flame resistance of chlorotrifluoroethylene (CTFE), however, and will decompose and melt when exposed to a flame. The polymer has good abrasion resistance for a fluorine-containing polymer, along with good impact strengths.

ETFE exhibits good melt flow, allowing the filling of thin sections (10 mil for small parts). It is the first fluoropolymer that can be reinforced (not merely filled) with glass fiber. ETFE, reinforced with glass, can be molded by conventional methods with rapid molding cycles. The polymer is used for wire and cable insulation where its high-temperature properties are important. ETFE finds application in electrical systems for computers, aircraft, and heating systems.

chlorotrifluoroethylene (CTFE) CTFE is made by the polymerization of chlorotrifluoroethylene, which is prepared by the dechlorination of trichlorotrifluorethane. The polymerization is initiated with redox initiators. The replacement of one fluorine atom with a chlorine atom breaks up the symmetry of the

PTFE molecule, resulting in a lower melting point and allowing CTFE to be processed more easily than PTFE. The crystalline melting point of CTFE is 218°C. Clear sheets of CTFE with no crystallinity have been prepared.

CTFE is resistant to temperatures up to 200°C and has excellent solvent resistance with the exception of halogenated solvents or oxygen-containing materials, which may swell the polymer. The electrical properties of CTFE are inferior to those of PTFE, but CTFE is harder and has higher tensile strength. The melt viscosity of CTFE is low enough that it may be processed by most thermoplastic processing techniques. Typical processing temperatures are in the range of 230–290°C. CTFE is higher in cost than PTFE, which somewhat limits its use. Applications include gaskets, tubing, and wire and cable insulation. Very low-vapor-transmission films and sheets may also be prepared.

polyvinylidene fluoride (PVDF) PVDF is crystalline with a melting point near 170°C. PVDF has good chemical and weather resistance, along with good resistance to distortion and creep at both low and high temperatures. The useful temperature range is from −80 to 300°F. Although the chemical resistance is good, the polymer can be affected by very polar solvents, primary amines, and concentrated acids. PVDF has a limited use as an insulator because the dielectric properties are frequency dependent. The polymer is important because of its relatively low cost compared to other fluoropolymers. PVDF is unique in that the material has piezoelectric properties, meaning that it will generate electric current when compressed. This effect is advantageously used in manufacturing PVDF pressure sensors.

PVDF can be melt processed by most conventional processing techniques. The polymer has a wide range between the decomposition temperature and the melting point. Melt temperatures are usually 240–260°C. Processing equipment should be extremely clean because any contaminant may affect thermal stability. PVDF is used for applications in gaskets, coatings, wire and cable jackets, and chemical process piping seals.

polyvinyl fluoride (PVF) PVF is a crystalline polymer available in film form and used as a lamination on plywood and other panels. The film is impermeable to many gases. PVF is structurally similar to polyvinyl chloride (PVC) except for the replacement of a chlorine atom with a fluorine atom. PVF exhibits low moisture absorption, good weatherability, and good thermal stability. Similar to PVC, PVF may give off hydrogen halides in the form of HF at elevated temperatures. However, PVF has a greater tendency to crystallize and better heat resistance than PVC.

perfluoroalkoxy resins (PFA) PFA resins, of all of the melt-processable fluoropolymers, combine the ease and economics of thermoplastic processing with high temperature performance in the range of TFE fluorocarbon resins. PFA resins resemble FEP fluorocarbon resins in having a branched polymer chain that provides good mechanical properties at melt viscosities much lower than those of TFE. However, the unique branch in PFA is longer and more flexible, leading to improvement in the high-temperature properties, higher melting point, and greater thermal stability.

PFA resins have the desirable properties typical of fluorocarbons, including resistance to virtually all chemicals, antistick, low coefficient of friction, excellent electrical characteristics, low smoke, excellent flammability resistance, ability to perform in temperature extremes, and excellent weatherability. The strength and stiffness at high operating temperatures are at least equivalent to those of TFE, and the creep resistance appears to be better over a wide temperature range. PFA parts perform well in the 250°C range. Film and sheet find use as electrical insulation in flat cable and circuitry and in laminates used in electrical and mechanical applications.

fluoroelastomer (FKM) Fluoroelastomers (FKMs) can be copolymerized with copolymers and terpolymers of tetrafluoroethylene, hexafluoroethylene, and vinylidene fluoride. The fluorine content largely determines chemical resistance and T_g, which increases with increasing fluorine content. Low-temperature flexibility decreases with increasing fluorine content. The fluorine content for fluoroelastomers is typically 57 percent by weight.

The fluorinated rubbers are exceptionally good for high-temperature service, but they are below silicones in this respect. They resist most of the lubricants, fuels, and hydraulic fluids encountered in aircraft; a wide variety of chemicals, especially the corrosive variety; and also most chlorinated solvents. They have good physical properties, somewhere near those of styrene butadiene rubber (SBR) at the higher hardness levels. FKM is valuable in automotive use for its extreme heat and oil resistance and is on a much higher level in this respect than the acrylic elastomers. It has weathering properties superior to those of neoprene. However, fluoroelastomers are relatively expensive.

FKMs are coextruded with lower-cost copolymers such as ethylene acrylic copolymer. They can be modified by blending and vulcanizing with other synthetic rubbers such as silicones, ethylene propylene rubber (EPR) and ethylene propylene diene monomer (EPDM) rubbers, epichlorohydrin, and nitriles. Fluoroelastomers are blended with modified nitrile butadiene rubber (NBR) to obtain an intermediate performance-cost balance. These blends are useful for underhood applications in environments outside the engine temperature zone such as timing chain tensioner seals. Fluoroelastomers can also be blended with fluorosilicones and other high-temperature polymers to meet engine compartment environments and cost-performance balance.

Typical products in this class include *Aflas* (Ashai Glass Co.), *Dyneon* (Dyneon LLC), *Viton* (Du Pont Dow Elastomers LLC), and *Kalrez* (Du Pont Dow Elastomers LLC).

flux Flux is an additive to a plastic composition during processing to improve its flow. For example, coumarone-indene resins are used as a flux during the milling of vinyl polymers.

foamed plastic Foamed plastics are resins with a spongelike, cellular structure. Foamed plastics may be flexible or rigid, the cells closed or interconnected, and the density anything from that of the solid parent resin down to, in some cases, 2 lb/ft^3. Compressive strength of rigid foams is fair, making them useful as core materials for sandwich structures, especially where weight reduction is necessary. Both rigid and flexible types have good thermal and acoustical insulation properties. Other names for foamed plastics are *cellular*, *expanded*, and *sponged plastics*.

There are several types of foamed plastics including syntactic foam, closed-cell foam, and open-cell foam. *Syntactic foam* is a special type of plastic foam in which the cellular structure is formed by the use of small, hollow spheres made of resin, glass, or other hollow particles. The spheres are dispersed throughout a matrix of resin, usually thermosetting, which when cured resembles a conventional foam plastic. Once mixed, syntactic foam may be cast or formed in place by a pouring or trowling action.

Closed-cell, or unicellular, foams are those in which the greatest proportion of cells are not connected together by open passageways. Such a material only absorbs water or other liquid on the outermost surface cells. Closed-cell foams do not make effective sound-absorbing materials. Therefore, closed-cell foams are used for flotation devices and similar items. *Open-cell*, or interconnecting-cell, foam is a foam in which the greatest proportion of cells are connected by open passageways to other cells. Such a foam will absorb water when placed under water.

The production of all plastic foams is accomplished by generating a gas in a fluid polymer, usually at an elevated temperature. The particular material that causes any given plastic to foam is called a *blowing agent*. Two types of blowing agents are common: (1) gas, which is introduced into the molten liquid or liquid plastic materials, and (2) chemicals, which are incorporated into the plastic and which, at a given temperature, decompose to liberate gas. In either case, the gas, if evenly dispersed, expands to form the cells of the foam. There are a number of different ways to bring about the cell formation, depending on the gas being used, the type of blowing agent, the type of plastic resin being used, and the type of processing method.

Plastic foams are principally made by one of seven different processes:

1. A foam may be made by incorporating a chemical blowing agent into the polymer to form a gas by decomposition at a given elevated temperature. Usually the blowing agents are in the form of fine powders, which can be either evenly dispersed in a liquid resin or mixed with molding pellets. The usual gas is nitrogen liberated from organic materials known as *azo compounds*. A typical blowing agent is azobisformamide (ABFA), also called azodicarbonamide. Blowing agents are available that decompose at temperatures from 110°C to as high as 280°C.
2. Another method of producing foamed plastic is to inject a gas, usually nitrogen, into a molten or partially cured resin. The gas may be injected into the resin either in the barrel of an extruder or injection press or into a large mass in an autoclave.
3. Some polyurethane foams are made by combining a bifunctional material such as a diisocyanate with a polyester or other liquid polymer. During the

polymerization process the isocyanate reacts to liberate a gas, which forms the cells.

4. Foams may also be produced by the volatilization of a low-boiling liquid either by the heat liberated by an exothermic reaction or by externally applied heat. Commonly used in these foams are liquid fluorocarbons (e.g., *Freon* from Du Pont). This is the usual technique in production of polyurethane foams.
5. A nonchemical, gas-liberating agent, such as finely divided carbon with gas adsorbed onto its surface, may also be used in a resin matrix. On heating the gas is released to produce the foamed cells.
6. Foam may be made by whipping air into a colloidal resin suspension and then gelling the porous mass. Foamed latex rubber is made in this way.
7. Finally, foam may be produced by the expansion of small beads of a thermoplastic resin by heating an internally contained blowing agent. This technique is employed for expansion of polystyrene beads used to make cups, packaging, display boards, etc.

Flexible plastic foams may be found in the form of very soft cushioning materials used in upholstery, clothing interlayers, automobile seats, vibration absorbers, etc. The most common flexible foam resins are polyurethanes, foamed vinyls, cellular polyethylene, cross-linked polyethylene, and silicone foam. Semirigid foams are used for floatation devices, marine bumpers, special electrical insulation on television cables, packaging, and a host of other applications. Rigid foams are used in the production of airplane parts, boats, electronic encapsulation, and many furniture applications where wood was formerly used.

An important application for foams is direct substitution for a solid part made either of plastic or in some cases metal. The part may be made lighter, stiffer, or both, when a foam is used in place of a solid plastic part. The resulting part may be improved and/or made more cheaply, simply because of the savings in material quantity and weight.

Foams are versatile both in their applications and in the way in which the materials are made. These include the production of various shapes by casting, extruding, injection molding, thermoforming, and reaction injection molding. Foam versatility also includes the fact that any plastic material, thermoplastic or thermoset, may be produced in cellular form.

Polyurethane foams can be formulated to be flexible, semirigid, or very hard, rigid materials. The densities of these materials can range from as low as 1 $\mathrm{lb/ft^3}$ or lower to as high as 60 $\mathrm{lb/ft^3}$. Polyurethane foams, in general, are produced by the reaction of a diisocyanate and a polyol or a mixture of polyols that are hydroxy terminated. Such materials are polyesters or polyethers, or even castor oil. The reaction between the isocyanate and the polyol produces the urethane resin. A further reaction between a slight excess of isocyanate and water, added to the polyol, can then produce carbon dioxide gas to form the cellular structure of the foam. This reaction, however, is now considered obsolete. In its place a low-boiling, inert liquid fluorocarbon is mixed in with the polyol. When the polymerization reaction takes place, the exotherm is sufficient to cause the fluorocarbon to volatilize and act as a blowing agent. It should also be noted that a typical urethane formulation, in addition to the isocyanate, polyol, and blowing agent, will also have incorporated, usually in the polyol, a catalyst and a surface-active agent. The catalyst, in most cases an organotin compound, is used to accelerate the reaction so gelation will take place before the gas is dispersed. The surface-active agent, called a surfactant, is usually a silicone liquid and is used to obtain a finely dispersed foam. Depending on the particular formulation, urethane foams may be compounded to gel or "cream" in very short time periods or take several minutes to react.

Open-cell vinyl foams are usually made from plastisols by one of two methods: (1) a chemical blowing agent technique or (2) frothing, in which a gas is also used as part of the blowing mechanism. In the first method a paste made of powdered blowing agent dispersed in a plasticizer is added to the plastisol. Soft, very flexible vinyl foams used for garment insulation, upholstery, and similar applications are made with this process. The second process is used to produce large amounts of vinyl foams such as flooring underlay and wall coverings. In this method, the plastisol is mixed with a given amount of air in a high-shear, temperature-controlled mixing head. The resulting product is cast onto a belt or fabric and knifed to a definite thickness. Passage through an oven then causes fusion of the plastisol.

Closed-cell vinyl foam is made in a manner similar to the technique used to produce open-cell foam with chemical blowing agents. However, much higher pressures are used, and the process is accomplished in two steps. First the vinyl plastisol, containing the blowing agent, is placed in a mold. The mold is then heated, causing decomposition of the blowing agent and, at the same time, fusion of the foam. This step raises the internal pressure in the mold to very high levels. At these high pressures, the gas is dissolved in the resin in the form of microscopically small bubbles. The part is then allowed to cool and harden in the mold before removal. The second step in this process consists of reheating the molded part at approximately 93–120°C. At this time the resin softens, and the gas expands to form a closed-cell foam.

Cellular polyethylene is usually produced by extrusion. In this process, a blowing agent is mixed in with the polyethylene pellets. During mixing and shearing in the barrel, the pellets melt, and the blowing agent decomposes. The liberated gas dissolves in the molten resin. On extrusion, the gas expands and forms the cellular material. Densities commonly produced are in the range of 2 to 10 lb/ft^3. Major applications are packaging, marine bumpers, sporting goods padding, etc.

Another type of polyethylene foam is *crosslinked foam*, made by either using a chemical cross-linking agent or using radiation. In the chemical process the polyethylene pellets are first blended with a crosslinking agent, usually a peroxide. They are then blended with a chemical blowing agent. After blending, the material is placed in a mold and heated to a temperature first high enough to cause cross-linking and then at a higher temperature, to cause decomposition of the blowing agent. Radiation-crosslinked foam is made by similarly blending the component materials and then extruding the mixture as a sheet. The sheet is then subjected to electron beam radiation, after which it is heated to cause foaming of the sheet. The thickness of the sheet is limited by the inability of the radiation to penetrate too deeply.

Flexible silicone foams can be made to expand and cure at room temperature. They are supplied as two-part mixtures, a resin and a curing agent. After thorough mixing the foam starts to expand and cure within minutes. The foam is usually elastomeric with a typical density of 12–16.5 lb/cu ft. Like all silicones, the foam has very good resistance to both high and low temperatures.

The most common rigid foam materials are polyurethanes, polystyrene, cellulose acetate, and thermosetting resin foam (e.g., epoxy, phenolic, urea-formaldehyde), and syntactic foam. Rigid foams are essentially nonreturnable to their original dimensions when compressed. Rigid foams are usually made in the lighter densities of from 2 to 6 lb/cu ft. They are also usually closed-cell material, good for heat insulation but not very satisfactory for sound absorbers or insulators.

Polyurethane rigid foams are made by using basically the same process described for making flexible or semirigid foams. Polyester polyols are frequently used for the rigid foams. Possibly one of the fastest growing processes for the production of parts of rigid or semirigid urethane foam is the *reaction injection molding* process, also called *RIM*. In this process, the two ingredients, polyol (containing the catalyst and blowing agent) and isocyanate, are metered and injected at a high pressure into a mold. This process can be used to very rapidly produce diverse parts with an integral skin. Applications are automobile bumpers, dashboards, business machine housings, furniture, and similar parts.

Styrofoam (Dow Chemical Co.) is the tradename for *expanded polystyrene foam*. It is made by a process similar to the one described for foamed polyethylene. The materials have a closed-cell structure with very low thermal conductivity and low moisture absorption. One of the serious limitations of polystyrene foam is its rather low maximum operating temperature of approximately 80°C. It is used mainly as thermal insulation in buildings, flotation apparatus, decorations, and packaging.

Expandable polystyrene is the usual name for the beads used to make molded polystyrene foam parts. Parts made with these beads are usually made in a two-step process. The first step consists of pre-expansion of the beads by heat. After this step, the beads are stored for 6–12 h to allow them to reach equilibrium. The beads are then conveyed to the mold, where they expand to the final dimensions. Steam is the preferred mode of heating, either by introducing live steam through perforations in the mold or by the means of steam probes, which are withdrawn as the beads are expanding. Expandable polystyrene foam can be distinguished from expanded polystyrene foam by the round bead outlines on the surface of the part. The expanded foam has a smooth surface.

Cellular cellulose acetate is made in a manner somewhat similar to the one used in the production of expanded polystyrene. It is relatively the same density of expanded polystyrene; however, the useful temperature range is extended up to 175°C. It also has somewhat better chemical resistance than polystyrene foam. Thus it is seen in many of the same applications as polystyrene foam where these additional properties are necessary (e.g., aircraft structure cores, flotation devices). Cellulose acetate foam is trademarked *Strux* (Aircraft Specialties Corp.).

Foams made from thermosetting resins are similar to rigid thermoplastic foams in appearance and general physical properties. Heat resistance is usually better than most thermoplastic foams, but the materials are somewhat brittle. *Thermoset foams* are made by using the same general process as those for thermoplastics. Heat is used to activate a blowing agent while the resin is a liquid. The major difference is that the heat may be generated from the heat of reaction or exotherm.

Epoxy foams are made in two types. One type is a powder foamant that contains powdered epoxy resins, hardener, and blowing agent. The mixture is heated and liquefied, and the blowing agent causes foaming, after which the curing agent causes hardening. The other method is as a liquid system in which the curing agent, blowing agents, and surfactants are added to liquid resins.

Phenolic foams are typically made by catalysis of a liquid phenolic resin to which has been added a small amount of blowing agent and a silicone surfactant. The condensation reaction of the phenolic during polymerization liberates a small amount of water, which along with the blowing agent is volatilized by the exothermic reaction. Low-density phenolic foam is extremely brittle but has a very low thermal conductivity. Phenolic foam also has a high degree of cell interconnections. The great moisture absorption ability makes phenolic foams ideal for mounting floral displays.

Urea formaldehyde foam also cures by a condensation reaction. However, the foam is made by mixing the resin with air, an aqueous detergent, and an acid catalyst. The finished foam has a density of about 0.7 lb/ft^3 with very low compressive strength. When used in thick sections it is a good sound insulator. It is also relatively noncombustible. It is mainly used as home thermal and sound insulation, where it is installed in situ, and in fines as a fire stop material.

Syntactic foams are made by using a resin matrix to which has been added hollow spheres. The spheres can be made from many different materials including glass, plastic, ceramic, and naturally occurring substances. The most common matrix resins are epoxy and polyester. The foam is made by simply mixing the microspheres into the catalyzed resin, casting a product, and finally allowing it to cure either at room temperature or at an elevated temperature.

foaming agent Foaming agents are chemicals added to plastics and elastomers that generate inert gases on heating, causing the resin to assume a cellular structure.

See also blowing agent; foamed plastic.

foam molding Foam molding is a molding process whereby a heat-softened plastic containing a foaming agent is injection molded into a cavity where it hardens, producing a product having a solid continuous skin with a foam core.

In situ foaming is a process of depositing a foamable plastic (before foaming) into the place where it is intended that foaming shall take place. An example is the placing of a foamable plastic into a cavity to provide a gasket. After being positioned, the material foams to fill the cavity.

See also foamed plastic; structural foam molding; sandwich molding.

fogging Fogging is the accumulation of deposits on surfaces of parts that are meant to be clear or transparent (i.e., windshields in automobiles, display covers on instruments, glass facing on electric meter casings). Fogging can be attributed to the volatilization and transfer of low-molecular-weight constituents within the plastic formulation. Plasticizers and/or other low-molecular-weight impurities can cause fogging.

Tests to measure fogging are specified in ASTM D5293. It measures the effect on the average gloss value of a glass plate that is fogged in the test.

foil decorating Foil decorating is a form of decorating plastic parts by molding paper, textile, or plastic foils that are printed with compatible inks directly into a plastic part. In this way the foil is visible below the surface of the part as an integral decoration.

See also hot stamping; decorating.

folding endurance Folding endurance is a measure of the material's resistance to flexure or creasing. It is generally used in testing and specifying polymeric films, especially those used in packaging. Folding endurance is greatly influenced by the polymer's glass transition temperature and the presence of plasticizers. ASTM D2176 describes the procedure to determine the number of folds necessary to break the sample film.

force plate The force plate is the plate that carries the plunger or force plug of a mold and the guide pins or bushings. Because it is usually drilled for steam or water lines, the force plate is also called the *steam plate*.

force plug The force plug is the portion of a male half of the mold that enters the cavity block and exerts pressure on the molding compound, causing it to flow. It may be designated as the top force or bottom force by position in the assembly. The force plug is also called the *plunger*, *ram*, or *piston.*

forging Forging is the fabrication of thermoplastics in the solid form by metal working techniques such as impact or hydraulic pressure. The process begins with a solid plastic blank that is heated and fabricated by bulk deformation of the material in constraining dies by the application of force. This process is also called *solid-phase forming* or *solid-state stamping*.

formaldehyde Formaldehyde is a colorless gas usually used as a solution in water. It possesses a suffocating, pungent odor. Formaldehyde is derived from the oxidation of methanol or low-boiling petroleum gases such as methane, ethane, propane, and butane. It is widely used in the production of phenol formaldehyde (phenolic), urea formaldehyde (urea), and melamine formaldehyde (melamine) resins.

four-harness satin

See weave.

fracture Fracture is the separation of a body. It can be defined both as a rupture of the surface without complete separation of the material or, more commonly, as a complete separation of a body because of external or internal forces.

The *fracture strength* of a material is the normal stress at the beginning of fracture. It is calculated from the load at the beginning of fracture during a tension test and the original cross-sectional area of the specimen. *Fracture stress* is the true, normal stress on the minimum cross-sectional area at the beginning of fracture.

The *fracture toughness* is the measure of the damage tolerance of a matrix containing initial flaws or cracks. G_{1c} and G_{2c} are the critical strain energy release rates in the 1 and 2 directions respectively. Fracture toughness is expressed as the *critical stress intensity factor* as measured in ASTM E399.

free radical

See radical.

free radical polymerization Free radical polymerization is a type of polymerization in which the propagating species is a long-chain free radical initiated by the introduction of free radicals from thermal or photochemical decomposition of an initiator molecule. The curing of unsaturated polyester resins is an example of free radical polymerization.

There are three steps to a free radical polymerization reaction: initiation, propagation, and termination. During the *initiation* phase, free radicals are generated (generally by decomposition of an initiator and reaction with the monomer). During *propagation*, the chain radical formed in the initiation step is capable of adding successive monomers to propagate the chain. Propagation would continue until the supply of monomer was exhausted were it not for the strong tendency of radicals to react in pairs to form a paired-electron covalent bond with loss of radical activity. This step is known as *termination*.

See also addition polymerization.

free volume Free volume is that part of the total volume of a solid or liquid substance, at a given temperature, that is not occupied by the molecules making up the substance. The free volume concept is helpful in understanding such phenomena as plasticization, glass transition, and diffusion of penetrants.

friction Many plastics, especially dry rubbers, are generally accepted as having a high coefficient of friction. Many plastics have coefficients of friction around 0.2, compared with 0.1 for graphite and 0.05 for diamond.

Measurement of coefficient of friction (COF) can be done in many ways. ASTM D1894 is one method. For instance, static COF, the force needed to start movement across a polymeric surface, can be quite high. Dynamic COF, the force required to maintain movement, is always lower.

Furthermore, many factors affect the frictional force measured. These include sample hardness, the load and speed used in the test, and the particular material and surface morphology of the surface against which the sample is pressed. Compounding differences of polymer type and especially additives (which can bloom to the surface) have major effects. Lubrication of surfaces by light oils or soapy water can render them very slippery.

friction calendering Friction calendering is a process whereby an elastomeric compound is forced into the interstices of woven or cord fabrics while passing through the rolls of a calender.

See also calender.

friction welding Friction welding is a form of *indirect heat welding* used for assembly of plastic pieces. In friction welding, the interface alone is heated because of mechanical friction caused by one substrate contacting and sliding over another substrate surface. The frictional heat generated is sufficient to create a melt zone at the interface. Once a melt zone is created, the relative movement is stopped and the parts are held together under slight pressure until the melt zone cools and sets. This method is therefore mainly applicable to thermoplastic materials. Common friction welding processes include spin welding, ultrasonic welding, and vibration welding.

See also heat welding (indirect); spin welding; ultrasonic welding; vibration welding.

frost line The frost line is an apparent crystalline pattern on the surface of a plastic. In the extrusion of polyethylene lay-flat film, the frost line is a ring-shaped zone located at the point where the film reaches its final diameter. This zone is characterized by a frosty appearance to the film caused by the film temperature falling below the softening range of the resin.

frothing Frothing is a technique for applying urethane foam in which blowing agents or tiny air bubbles are introduced under pressure into the liquid mixture of foam ingredients.

See also foamed plastic; polyurethane.

fuller's earth Fuller's earth is a soft, opaque clay that is a hydrated compound of silica and alumina. The usual color is greenish white to greenish brown. It is generally used as a filter medium in clarifying resins and oils but can also be used as a plastic filler. It is also used as a pigment extender and a substitute for talcum powder.

fullerine Fullerines were introduced in the mid-1980s as large carbon molecules having 60 or more carbon atoms arranged in cagelike pseudospheres similar in shape to Buckminster Fuller's geodesic dome and thus called *bucky balls*. *Carbon 60* or *C60* molecules are a new form of carbon fullerine with potential for use in steel, catalysts, lubricants, superconductors, diamond synthesis, and monocrystalline film and as building blocks for high-strength polymers.

functionality Functionality is the ability of a compound to form covalent bonds. It represents the number of functional groups participating in a reaction. For example, compounds may be monofunctional, difunctional, trifunctional, and polyfunctional.

fungicide/fungistat

See biocide.

fungus resistance Synthetic resins in themselves neither support nor hinder fungus growth, but fillers, plasticizers, and other ingredients are susceptible to attack in varying degree. Cloth and paper in molded and laminated products are strongly attacked, whereas glass and other mineral fillers are resistant. Plastics, which do not serve as nutrients for fungi, may nevertheless have external contaminants that do encourage fungus growth. Some unfilled thermoplastics such as nylon, polyethylene, and acrylic are not known to be affected; other thermoplastics may be made more resistant by incorporating *fungicides* into the molding formulation.

furane resin Furane resins are based on furfuraldehyde, which is derived from waste vegetable matter. It is used in thermosetting resins in combination with phenol, converted to furfural alcohol, which itself can be thermoset by acids, or reacted with aldehydes or ketones to give polymerizable products. The resins are dark in color, but they are strong, have good chemical resistance especially to acids and alkalis, and penetrate porous surfaces well. Furane resins are available primarily as liquids ranging from low-viscosity polymers to thick, heavy syrups.

Furane resins are generally used in the manufacture of molding materials, adhesives, and impregnating varnishes. As an acid- and alkali-proof cement, they are extensively used as bonding media for chemical stoneware in the processing industries. Protective coatings have been developed for imparting chemical resistance to surfaces subject to attack.

The furane polymers, as casting resins and as impregnating compounds, are found in applications requiring excellent chemical resistance. In particular, their unique penetrating qualities have opened up new applications in the treatment of porous substrates (e.g., plaster of Paris castings).

furfural Furfural, also known as phenol-furfural, is a thermosetting resin by virtue of its aldehyde group and reactive furane ring. It can be used to replace part of the formaldehyde in phenolic resins. The resulting compounds have a long flow time before setting up at lower temperatures, coupled with a rapid curing at higher temperatures. Properties include high resistance to acids and alkalies. Furfural resins that are used in the manufacture of molding materials, adhesives, and impregnating varnishes are dark colored. Their major applications are in molding large pieces, such as television cabinets.

fuse The term fuse, generally used in plastisol molding, refers to heating the plastisol to the temperature at which it becomes a single homogenous phase. In this sense, *cure* has the same meaning as fuse.

Fusion point is the temperature at which, in a specified set of conditions, particles of polyvinyl chloride (PVC) resin are first made transparent, gelled, or dissolved by a plasticizer. The other relevant terms are “clear point,” “solid gel transition temperature”, and “apparent wetting temperature.” The fusion point provides a numerical indication of the compatibility of the plasticizer with the PVC resin.

G

gang mold The gang mold is a variation of the *flash mold* used in compression molding in which the cavities are located at the bottom of a common *loading well*. The material for all the cavities is loaded into this well. As the mold closes, the material is forced into the cavities and a thin flash is left connecting the molded parts. The principal advantage of this type of mold lies in the restriction it imposes on the escaping material. Material can be confined to develop greater back pressures and thus secure greater density in the molded part than a flash mold would produce.

The *subcavity gang mold* is most useful in the production of large quantities of small-size thermosetting parts. Gangs may consist of 50 or 100 cavities, and a mold may contain several gangs. A single preform may be used in each gang, and molded parts are discharged as a unit. Mold and part costs are generally lower than for any other class of compression mold.

See also flash mold.

Gardner color scale The Gardner color scale is a scale based on glass standards numbered 1 through 18, each standard representing a particular combination of chromaticity coordinates, luminous transmittance, and transmittance tolerance. The scale serves as a means of description and determination of the colors of transparent liquid resins and resin solutions, drying oils, varnishes and the like. The Gardner color scale is specified in ASTM D1544.

gasket material Gasket materials are used for sealing joints between parts to prevent leakage of gas or liquid. Many different plastics are used for gaskets,

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depending on whether heat, oil, or chemical resistance or some other property is primarily required. They include nylon, polyvinyl alcohol, polyvinyl chloride, polyethylene, phenolic laminates, and fluoropolymers. Synthetic rubber or elastomers, foamed synthetic rubbers of thermoplastics, glass and aramid fibers, carbon and graphite fibers are also used as gasketing materials. Gaskets may be any sheet material but may also be in the form of cordage or molded shapes.

Some of the specialty plastics, selected for heat resistance or chemical resistance, are used alone or with fillers or as binders for fibrous materials. *Haveg 106075* (Haveg Industries, Inc.) is a gasketing sheet based on *Viton* (Du Pont), a copolymer of vinylidene fluoride and hexafluoropropylene. It can withstand hot oils and superoctane gasolines and has temperature resistance to 200°C with intermittent temperature to 316°C. It has a tensile strength of 2000 psi and 400 percent elongation. Another gasket from Haveg is based on *Hypalon CSM-60*, a chlorosulfonated polyethylene. It has a tensile strength of 2250 psi and elongation of 30 percent. A square rope type of packing called *Graphlon C* has a core of braided asbestos fibers impregnated with Teflon, over which is a braided jacket of Teflon fiber with an outer jacket of graphite fiber. It is self-lubricating, has high chemical resistance, and withstands temperatures to 357°C. Since the decline in use of asbestos as gasket material, several high-temperature alternatives have been developed including aramid (*Kevlar* from Du Pont) and carbon fibers.

Gasketing materials are generally preformed elastomers that are available as o-rings, rope, and other convenient shapes. Gaskets may also be cut from stock material such as thin sheet. However, *sealants* can be used to make *formed-in-place gaskets*. A ribbon of uncured sealant is applied to the flange area of the components to be sealed. On assembly of the components, the sealant is compressed to conform exactly to the mating surfaces.

The formed-in-place gasket functions differently from a cut gasket. The cut gasket maintains a seal through its compression that is maintained in service by mechanical fasteners. The cut gasket must remain under compression to function. Any loss of load due to relaxation of the gasket material or loosening of the fasteners could cause the gasket to leak. Formed-in-place gaskets, on the other hand, do not require compression. Instead, they rely on adhesion for maintaining the seal.

In a formed-in-place gasket joint design, there is metal-to-metal contact between flanges so that the gasket cures to a predetermined constant thickness after assembly. If tension is lost in the mechanical fasteners, the gasket will still function by virtue of the adhesion of the sealant to the metal surfaces. It is very important that the flange systems be specifically designed for formed-in-place gaskets. Joint thickness especially will depend on the physical properties expected of the cured gasket material. However, because of the joint filling capacity, greater irregularities in either mating surface can be tolerated with formed-in-place gaskets than with conventional gaskets. Components whose sealing surfaces are scratched or nicked and would be impossible to seal with preformed gaskets are sealed directly with formed-in-place gasketing, which fills the voids.

Two types of sealants are conventionally used for formed-in-place applications. These are room-temperature curing silicones and anaerobic sealants. *Anaerobic* *sealants* will cure to a rigid system. As a result, they require rigid flanges and a joint arrangement with a small gap that is designed to prevent any joint movement. *RTV (room temperature vulcanizing) silicones* are generally used for formed-in-place gaskets where longer cure times are possible. These sealants are generally formulated from medium-modulus silicone elastomers. They are used in joints where movement is required. With this material, it is important that the flange design allow a sufficient gap to provide for the movement capability. With RTV silicone sealants, it is also necessary to provide a gap to permit atmospheric moisture to cure the silicone material.

Another type of formed-in-place gasket can be made by applying a multicomponent or a UV-cured sealant directly to one flange, allowing the sealant to cure and then mating the surfaces together. A low-durometer, single-component silicone sealant has been developed that can be applied robotically and cures in place within 30 s after passing beneath a UV lamp. Only very soft types of sealants will work well with this method. Formed-in-place gaskets can also use foamed material.

Formed-in-place gasketing alleviates many of the problems associated with conventional cut gaskets. In addition, formed-in-place gasketing lowers manufacturing costs. Because each gasket is dispensed to the desired shape, there is no waste and only one formulation is needed to meet many different gasketing needs. Formed-in-place gaskets also allow the gasket profile to be changed as needed to ensure a proper seal for the surfaces being mated. The challenge created by formed-in-place gaskets is that the sealant must be applied uniformly with no knit line at the start-stop point. However, development of dispensing valves and robotics application techniques has minimized these concerns.

General difficulties in working with formed-in-place gaskets include nonflat or bowed flanges, excessive joint gap thickness variation, and gaps that exceed specification. It is also very important that the applied formed-in-place gasket be a continuous material filling the entire joint cavity. Gaps in the joint could be caused by erratic application technique or air bubbles entrapped in the sealant. Such gaps could easily lead to leaking gaskets.

gas trap The interior of a closed mold is not empty before it is filled with plastic. The space is occupied by air. The plastic displaces the gas, chasing the gas before it as it fills the mold. Certain design configurations create a trap with nowhere for the gas to escape. Such a design detail is referred to as a gas trap and the compression of the gas into it causes the gas to burn.

The mold maker can place very small vents (on the order of 0.0005 in. deep × 0.25–0.50 in. wide) at the parting line for the gas to escape the mold. These vents are often added after the first molding trials, which reveal the gas traps.

See also vent.

gate The gate is the orifice through which liquid resin enters the mold in plastic molding operations. It is also that portion of the molded piece which lies in the orifice through which plastic material enters the cavity of a transfer or injection mold. Sometimes the gate has the same cross section as the runner leading to it; often it is severely restricted.

The gate provides the means for controlling the rate of flow into the cavity and also governs the degree of packing, or compression flow, into the cavity after it is volumetrically filled. The size and shape of the molded article determines the type, location, and size of the gate. The successful operation of a mold may depend upon the correct location of the gate.

To minimize the distance the plastic must travel in filling the cavity, the gate should always be located as near to the center of the part as design factors will permit. Where part design or appearance considerations prohibit a central gate location, a larger gate or several gates per cavity should be provided to permit more rapid fill.

Because the gate always leaves a surface imperfection on the molded part, it should be located on a nonappearance surface, if possible. Gate-cutting fixtures are used to sever the gates uniformly from all cavities in a single operation. On transfer-molded parts, the gates are merely broken off at the press.

There are several commonly used gate designs in addition to the large, round gate and similar half-round and square gates that were used in early mold designs. See Fig. G.1. The *fan gate* is simply a flattened version of the large, round gate and is used for parts having large areas and relatively thin wall sections. The *flash gate* is well suited to large, flat areas. Here a secondary runner is cut parallel to the cavity wall, fed at the midpoint by the main runner. The thin flash gate enables the cavity to fill rapidly, yet it chills quickly, permitting fast cycles. *Pinpoint* or *restricted gates* should be used whenever the design or size of the part permits. A pinpoint gate should not be used with highly viscous polymers or those that are heat sensitive.

Several varieties of gates are used in the injection molding industry:

- A *tab gate* is an extension of the part that connects with the runner, thereby locating shear stresses outside the part. For this reason, tab gates are used with flat, thin parts and for materials such as polycarbonate, acrylics, SAN, and ABS, which develop high levels of shear stress during molding.
- *Edge gates* connect to the edge of a part, whereas *overlap gates* overlap the part walls or surfaces. Overlap gates often replace edge gates to prevent the melt front from jetting.
- A *fan gate* spreads out from the runner to fill a wider edge of the part; the gate thickness decreases gradually and is shallowest at the entrance to the part. Fan gates provide uniform flow into parts where warpage and dimensional stability are important.
- In *disk gates* the melt flows from the runner into a thin disk before entering the mold. This produces uniform filling of cylindrical or round parts and prevents weld lines.
- *Spoke (or spider) gates* are easier to remove than disk gates; they produce weld lines and do not permit perfect concentricity.
- *Ring gates* can also be used for cylindrical or round parts and, because they allow easy venting, are most effective when the part has a hole in the center. In ring gates, the melt fills a thick ring and then passes through a thinner inner ring to reach the part.

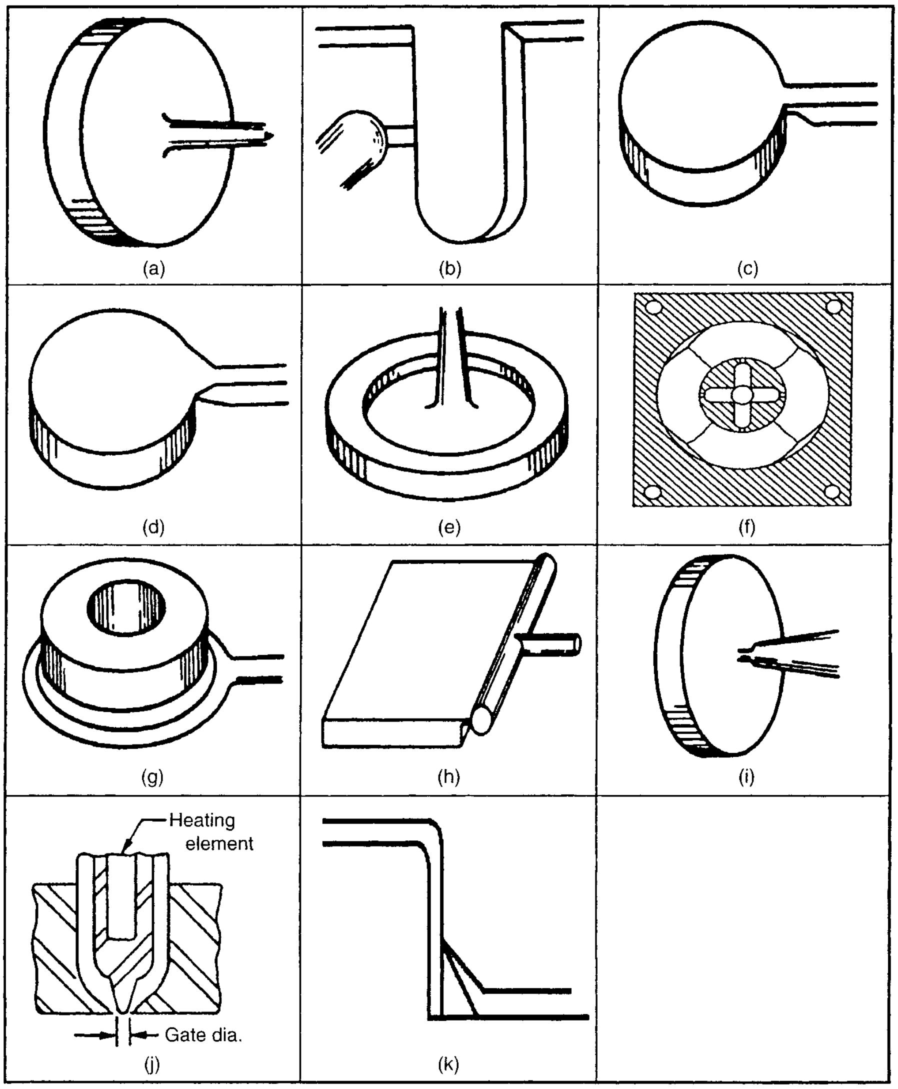

Figure G.1 Gates: (a) sprue, (b) tab, (c) edge, (d) fan, (e) disk, (f) spoke, (g) ring, (h) film, (i) pin, (j) hot, and (k) submarine. (Ref: Barry, C.M.F. and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, McGraw-Hill, New York, 2000)

- A *film (or flash) gate* permits uniform filling of flat parts. The melt fills a runner and then crosses a wide, but thin, "land" to enter the cavity. *Pin gates* are very fine-diameter (typically 0.25–1.6 mm) entrances to the cavity. They are used in three-plate molds or hot runner molds to facilitate degating.
- A *hot probe (or hot runner) gate* delivers material through heated runners directly into the cavity.

- *Submarine (or tunnel or chisel) gates* are fine-diameter (0.25–2.0 mm) gates that are angled from the parting line. Used in two-plate molds, they permit automatic degating of the part from the runner systems.

gel The gel is the soft, rubbery, semisolid mass that is formed as a thermosetting resin goes from a fluid to an infusible solid. This is an intermediate state in a curing reaction and a stage in which the resin is mechanically very weak. In general, gels have very low strength and do not flow like a liquid. They are soft and flexible and may rupture under their own weight unless supported externally.

Gelation refers to the formation of infinitely large polymer networks in the reaction mixture. It is the point in the resin cure at which the viscosity has increased to a point where the resin barely moves when probed with a sharp point. (*See also* gel point.)

In polyethylene, the gel is a small, amorphous resin particle that differs from its surroundings by being of higher molecular weight and/or cross-linked. The processing characteristics of the gel differ from those of the surrounding resin to such a degree that it is not easily dispersed in the surrounding resin. A gel is readily discernible in thin films.

With respect to vinyl plastisols, a gel is a state between liquid and solid that occurs in the initial stages of heating or after prolonged storage.

gel coat The gel coat is a thin outer layer of resin applied to a reinforced plastics molding for cosmetic or protective purposes (e.g., increased gloss, barrier to moisture permeation or weathering, coloration). It becomes an integral part of the finished product.

The gel coat is often made of the same primary resin as the molded part on which it is applied. A gel coat sometimes contains a pigment. The gel coat does not have the concentration of fillers or reinforcement that the molding compound has. Thus the gel coat provides an attractive resin-rich surface layer. The gel coat can be either applied to the surface of the mold and gelled before layup or applied as a coating after the part is fully processed.

Most room-temperature cured polyester layups include a gel coat that is applied to the bare mold surface before addition of the fiberglass. After the gel coat reaches a near-cured or leathery state, it is coated with fresh catalyzed resin and covered with a specified number of fiberglass plies to complete the layup.

gel content The gel content is a measurement of the polymer cross-link density of a plastic or elastomer. It is that part of the polymer (gel) which is insoluble in a solvent under the conditions of the test. The soluble part is sometimes referred to as the *sol fraction*. In gel content determinations on cross-linked polyvinyl chloride (PVC) the solvent is usually tetrahydrofuran, and on cross-linked polyethylene the solvent is xylene. Gel content measurements are specified in ASTM D2765.

See also gel.

gel permeation chromatography (GPC) Gel permeation chromatography (GPC) is a column chromatography technique using a series of columns containing closely packed rigid gel particles. The polymer to be analyzed is introduced at the top of the column and then is eluted with a solvent. The polymer molecules diffuse through the gel at rates that depend on their molecular size. As they emerge from the columns, they are detected by a differential refractometer coupled to a chart recorder, on which a molecular weight distribution curve can be plotted.

See also chromatography.

gel point (gel time) The gel point is the stage during the thermoset curing reaction at which gelation begins. This is when the polymer begins to exhibit pseudoelastic properties. It is also the point when the polymer first attains a finite value of its average molecular weight. This stage may be conveniently observed from the inflection point on a viscosity-time plot.

Gel time is the time required for a liquid material to form a gel under specified conditions of temperature as measured by a specific test. The gelation is generally caused by cross-linking of the polymer. Thus gel time is a measure of the reactivity of polymer systems. It is often used as a quality control test to determine consistency from resin to resin and from catalyzed batch to catalyzed batch.

Generally, the gel time is measured on a small amount of catalyzed resin. The sample is heated at a controlled temperature and probed until the resin does not exhibit any flow. The time between the point the temperature was applied (or the catalyst and resin mixed, if a room-temperature setting system) and the gel state is recorded as the gel time.

Several standard tests are available for determining the gel time of thermosetting resins. These include ASTM D2471, which offers a method for determining gel time and exothermic temperature, and ASTM D4473 for measurement of cure progress by dynamic mechanical methods.

See also gel.

glass-bonded mica Glass-bonded mica, also known as *ceramoplastic*, is a thermoplastic inorganic molding material in which powdered mica is bonded by glass. Lead borate is most commonly used as the glass binder. The material is hard, dense, and stonelike, with excellent dimensional stability. It has low electrical losses, high dielectric strength, good arc resistance, good mechanical strength and heat resistance, and very low water absorption.

The material is generally molded into plates, bars, and rods for fabrication into the final shape by conventional machining operations. It is also molded in compression and transfer molds into more intricate shapes. The general molding practice is to preheat the previously preformed glass-mica mixture according to a temperature-time cycle, until the glass attains a very plastic state. The hot compound is then shaped in a heated mold by the application of pressure. When the hot part is removed from the mold, it is cooled down slowly in an annealing oven.

Glass-bonded mica has been used for sleeves for aircraft ignition harness, lamp bases, switch blocks, and insulators. The materials can be used satisfactorily for parts whose service temperatures are in the range of 350–400°C.

glass fabric Many different fabrics are made for reinforcing plastics, with E-glass fabric being the most common. Laminates using glass of other types are also common with the filaments combined into strands and the strands plied into yarns. These yarns can be woven into fabrics on looms.

The machine direction of the loom is called the *warp*, and the cross-direction is the *fill* (also called *woof* or *weft*). The number of yarns can be varied in both warp and fill to control the weight, thickness, appearance, and strength of the fabric. When each fill yarn is laced alternately over and then under the warp, the type of fabric (called the weave) is known as *plain weave*.

Modifying this one-on-one arrangement by having yarns cross two or more adjacent yarns or staggering the crossing along the warp results in other weaves called *basket*, *satin*, *eight-harness satin*, *leno*, and *mock leno*, all of which are used by the reinforced plastics industry. Many varied combinations of glass fiber strands in both warp and fill are made into fabrics. All yarn for weaving is usually plied for balance, and cloth weights vary from 2.5 to 40 oz/yd^2.

Appendix M lists the fabrics used in electrical-grade laminates, mechanical laminates, and laminates used in marine applications. Also included in this appendix are descriptions of scrim fabrics used as facing layers for smooth cosmetic applications.

See also fabric; fiber.

glass fiber Glass fiber (or *fiberglass*) refers to individual filaments made by attenuating molten glass in special fiber-forming furnaces. A *continuous filament* is a glass fiber of great or indefinite length; a *staple fiber* is a glass fiber of relatively short length.

Six glass fiber formulations are made. The most common is *E-glass*. This glass resists moisture and results in products with excellent electrical properties. *C-glass* is designed for use where optimum chemical resistance is required. *D-glass* (a high-boron-content glass) has very good electrical properties, particularly the dielectric constant, and is used in electronic applications. *S-glass* is used for high strength and stiffness, whereas *R-glass* is a lower-cost fiber than S-glass. Table G.1 shows the physical and electrical properties of these fibers.

Glass filaments are made in a variety of diameters. The filaments are formed into a strand with 200, 400, 800, 1000, 2000, 3000, or 4000 filaments to a strand. A sizing agent is applied to the filaments to bond them into the strand and to give them environmental and abrasive protection. Subsequently, coupling agents are added to the finished products to enhance adhesion of the resin matrix to the glass fiber. Silanes, chrome complexes, and polymers are used as coupling agents.

The strands are then used to manufacture the various types of glass reinforcements. *Glass fabrics*, *glass mats*, and *chopped strands* are the most common reinforcements in reinforced plastics, but there are also many others. Appendix M provides descriptions of these various forms of glass fiber reinforcement.

In the form of short (1/4 – 1/2 in.) fibers, glass leads to good impact strength, electrical properties, and temperature resistance in many thermosetting compositions. This use is not to be confused with its function as long fibers or woven fabric to reinforce resin matrix composites.

See also fiber.

Table G.1 Properties of Glass Fibers (Ref: Sampson, R.N., "Laminates and Reinforced Plastics Materials and Processes," *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

	Glass Type					
	A	C	D	E	R	S and S2
			Physical properties			
Specific gravity	2.50	2.49	2.16	2.52–2.61	2.55	2.49
tensile strength, lb/in^2	350,000	400,000	350,000	500,000	640,000	665,000
Tensile elastic modulus	9,800,000	10,000,000	7,500,000	10,500,000	12,475,000	12,600,000
Elongation at 72°F, %	—	—	—	3–4	—	5.4
Poisson's ratio	—	—	—	0.22	—	—
			Thermal properties			
Softening point, °F	1300	1380	1420	1540–1555	1481	1778
Coefficient of thermal expansion—in/in/°F × 10^{-7}	90	40	17	28–33	74	13–17
Thermal conductivity (k) BTU in/hr/ft^2/°F at 72°F	—	—	—	7.2	6.9	—
Specific heat at 72°F BTU/lb/°F	—	—	—	0.197	—	—
			Optical properties			
Index of refraction	1.512	1.541	1.47	1.56	—	1.523
			Electrical properties			
Dielectric constant, 72°F, 10^6 Hz	6.90	6.24	3.56	6.1–6.7	6.2	5.34
Loss tangent, 72°F, 10^6 Hz	0.0085	0.0052	0.0005	0.001	0.0015	0.002

(*Continued*)

Table G.1 (*Continued*)

	Glass type					
	A	C	D	E	R	S and S2
Features						
	Soda-lime glass with limited water resistance	Chemical glass	Lowest dielectric constant	Electrical grade	High strength plus modulus	Highest physical properties
Uses						
	Surface mat	Chopped roving surface mat yarns	Yarn	Roving fabrics yarn	Yarn	Roving yarn

glass finish The glass finish is a material applied to the surface of a glass reinforcement to improve the bond between the glass and the plastic resin matrix.

See also finish.

glass mat Glass mats are made from glass strands that are cut and dropped onto a moving belt, where a polymer binder is applied to hold the mat together. Mats vary in weight from 0.75 to 3 oz/ft^2 and have widths up to 10 ft.

Continuous-strand mat is made when the strands are not cut but deposited continuously in a swirling pattern onto a moving belt where a binder has been applied. The physical properties of continuous-strand mats are better than those of cut mats, but the material is less homogeneous. Continuous-strand mats vary in weight from 0.75 to 4.5 oz/ft^2 and have widths of up to 6 ft.

Woven roving is a mat fabric made by weaving multiple strands collected into a roving and then into a coarse fabric. The physical properties of woven roving are intermediate between mats and fabrics. These constructions are used in low-pressure laminations and in pultrusion. Various thicknesses are made in widths of up to 10 ft.

glass sphere Solid glass spheres or beads, also referred to as *microspheres*, are available in a wide range of diameters (5–1000 μm). Their smooth shapes reduce abrasive and viscosity effects, but their manufacturing process tends to make them more expensive than many other sphere-like fillers. Excellent surface treatments are available for enhanced adhesion to polymers.

Hollow glass spheres (*microballoons*) have densities as low as 9 lb/ft^3. For a given external diameter (normally 10–500 μm), the density is a function of the wall thickness, which, in turn, affects the mechanical strength of the hollow spheres.

Low-density hollow glass spheres are primarily used in polymers whose processing does not involve high viscosities and high pressures. Polymers filled with hollow glass spheres contain entrapped gas, which makes them comparable to foams. In fact, they are called *syntactic foams*. Besides density gains, stiffness as well as thermal and acoustical insulation can be significantly improved.

See also microspheres; syntactic foam.

glass transition The glass transition is the reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle condition. This transition occurs at a temperature called the *glass transition temperature* or T_g.

Polymers exhibit a number of thermal transitions, which are not primary transitions, such as those that take place at the melting point, boiling point, etc. Despite their high molecular weight, polymer chain motion can take place at temperatures far below their melting point. If one takes a polymer down to 0°K (−273°C) and warms it up, one finds that the polymer goes through several transitions until its decomposition temperature is reached. These transitions are usually given Greek letters, with the higher letters representing transition at lower and lower temperatures.

In addition to the melt temperature, the transition of most concern to polymer scientists is the α-transition or the *glass transition temperature,* T_g. The glass transition temperature is the temperature at which a polymer's physical properties change from those of a glasslike material to those of a tough or rubbery material. It is usually associated with the onset of long-range motion in the polymer backbone due to temperature effects. Both mechanical and electrical properties degrade significantly as the temperature increases above the T_g. T_g is usually a narrow temperature range, rather than a sharp point, as in freezing or boiling.

As shown in Fig. G.2, the temperature at which the polymer behavior changes from glassy to leathery is known as the T_g. The rubbery plateau has a relatively stable modulus until, as the temperature is further increased, a rubbery flow begins. Motion at this point does not involve entire molecules, but in this region deformations begin to become nonrecoverable as permanent set takes place. As temperature is further increased, eventually the onset of liquid flow takes place. There is little elastic recovery in this region, and the flow involves entire molecules slipping past each other.

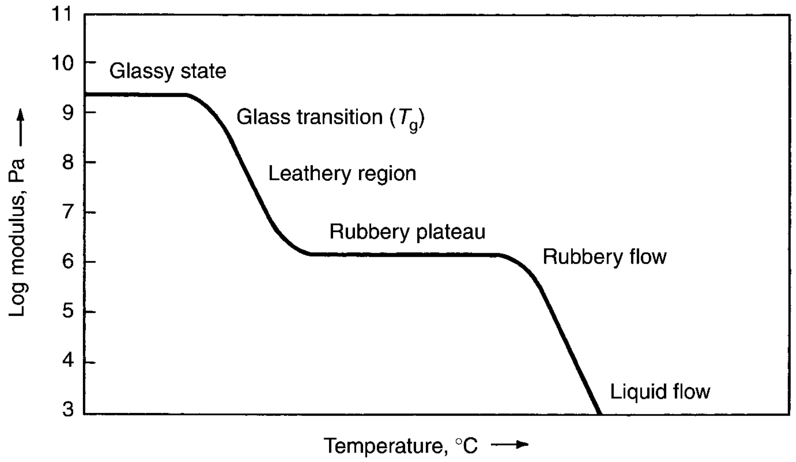

Figure G.2 Relationship between elastic modulus and temperature showing the glass transition region. (Ref: Baker, A.M.M., and Mead, J., "Thermoplastics", *Modern Plastics Handbook*, McGraw-Hill, New York, 2000)

glass transition temperature, T_g The glass transition temperature (T_g) is the approximate midpoint of the temperature range over which the primary glass transition takes place.

The glass transition temperature can be detected in a variety of experiments, which can be roughly classified into those dealing with bulk properties of the polymer and those measuring the nature and extent of molecular motion. The most common way of estimating T_g is by means of the volume expansion coefficient. At the T_g point, there is a change in slope of the curve of volume vs. temperature.

Other bulk properties whose temperature coefficients undergo marked changes at T_g include heat content, refractive index, stiffness, and hardness. Experiments that are sensitive to the onset of molecular motion in polymer chains may also be used to detect the T_g. Such methods include the measurement of internal friction, dielectric loss in polar polymers, and NMR spectroscopy.

Apart from measuring volume expansion, the methods commonly used to determine T_g are differential thermal analysis (DTA), differential scanning calorimetry (DSC), and dynamic mechanical analysis (DMA). ASTM D3418 specifies T_g determination by DTA and DSC.

The glass transition temperature is actually a range of temperatures because the value is different for each test procedure and for the conditions of the test protocol. Usually a single value is provided; therefore, it should be treated as an approximation. The measured value of T_g depends considerably on the rate of temperature change in any experiment and on the frequency or rate of deformation in a mechanical test. Test methods involving slow rates of testing generally give lower T_g values than faster-rate methods.

glazing material Acrylic and glass reinforced plastics are used for windows, skylights, etc. in public and industrial buildings to reduce breakage and maintenance costs. This reduction offsets their higher initial cost than that of glass. They are easily handled and cut and can be curved. Acrylic has also been approved by some states for certain automotive applications, other than windshields, along with flexible vinyl plastics.

gloss Gloss is the *shine* or *luster* of the surface of a material. It is the geometrically selective reflectance of a surface responsible for its shiny or lustrous appearance. Surface reflectance is commonly at a maximum in or near the specular direction (i.e., the direction at which a mirror would reflect light).

Photoelectric instruments are available for measuring gloss at a variety of angles of incidence and reflection. The apparatus used in such measurements is known as a *glossmeter.* A bright light is reflected off a specimen at an angle, and the *luminance* or brightness of the reflected beam is measured. Plastic gloss measurements are strongly dependent on the method of molding. Gloss testing is specified in ASTM D523.

Haze and gloss test methods measure how well a material reflects and transmits light. They quantify characteristics such as clear and shiny. Although haze is appropriate for transparent or translucent materials, gloss can be measured for any material. Both gloss and haze tests are precise, but they are often used to measure appearance, which is more subjective. The correlation between haze and gloss values and how people rate the clarity or shininess of a plastic is uncertain.

See also haze.

glue

See adhesive; casein; dextrin.

glue line The glue line (or *bond line*) is the layer of adhesive that attaches two adherends. The *glue line thickness* is the thickness of the fully cured adhesive layer between two adherends.

glycol Glycol (ethylene glycol, ethylene alcohol, and glycol alcohol) is an alcohol containing two hydroxyl (—OH) groups. It is prepared by reacting ethylene with chlorine, forming ethylene chloride, and dehydrolyzing with alkali to replace the chlorine atoms with hydroxyl groups.

Glycol is used in preparation of polyester resins. The lower *glycol esters* are softening agents or plasticizers of cellophane, polyvinyl alcohol, and acetate sheeting. *Glycol ethers* are used as solvents for several classes of plastics. *Cellosolve* is the monoethyl ether of glycol; *methyl cellosolve* is the monomethyl ether. These compounds are only typical; there are many glycol ethers.

By removing a molecule of water from a pair of glycol molecules, diethylene glycol is made; further water removal yields triethylene glycol, etc. These compounds are called *polyglycols*. The most useful derivatives are those of *triethylene glycol*. This is widely used as a plasticizer for polyvinyl butryral in the manufacture of safety glass and as a polyvinyl chloride plasticizer.

The polyethylene glycols may be obtained in a series ranging in molecular weights from 200 to over 6000 (*Carbowax*). The lower members in this series are soluble in water, whereas the higher species form dispersions in water. Carbowax is often used more for its waxy properties than for its plasticizing ability.

graft polymer and copolymer A graft polymer is a polymer that has one or more species or blocks connected to the main chain as side chains. These chains will have constitutional or configurational features that are different from the constitutional units composing the main chain. An example of a graft copolymer is polymerizing butadiene and styrene monomers at the same time to form styrene butadiene.

granular structure A granular structure is a nonuniform appearance of finished plastic material caused by the retention of, or incomplete fusion of, particles of composition, either within the mass or on the surface.

granulating machine A granulating machine is a mechanical device using extra heavy steel knives, stationary and rotary, for cutting thermoplastic scrap into small pieces for remolding. Granulators are based primarily on two or more rotary knives cutting against two or three stationary knives in a special cutting chamber. They are more commonly used in reclaim or reprocessing, but hot-melt granulators can provide a relatively simple and economic method of size reduction for short runs, or for plastics that do not pelletize easily.

Major suppliers of granulating machines include C. W. Barbender Instruments Inc.; Conair Group; International Process Equipment Co.; Polymer Systems; Regency Sales Inc.; and Videx Machinery Corp.

graphite fiber Graphite fibers (also called *carbon fibers*) have demonstrated a wide variety of strengths and moduli. They are fibers made from a pitch or polyacrylonitrile (PAN) precursor by an oxidation, carbonization, and graphitization process.

The fibers begin as an organic fiber (rayon, polyacrylonitrile, or pitch, a derivative of crude oil) called the precursor. The precursor is then stretched, oxidized, carbonized, and graphitized. There are many ways to produce these fibers, but the relative amount of exposure at temperatures from 2500 to 3000°C results in greater or less graphitization of the fiber. Higher degrees of graphitization usually result in a stiffer fiber (higher modulus) with greater electrical and thermal conductivities.

The fiber produced from rayon precursor is made by stretching the fiber at temperatures higher than 2800°C to impart the high strength characteristics. PAN-based fibers are produced by wet, dry, or melt spinning. Melt spinning bypasses conventional solvent processing and provides more radially uniform structures with improved molecular orientation. It also yields a variety of fiber shapes such as rectangular, trilobal, hexalobal, and tetralobal. Pitch fibers above 689 GPa (10^8 psi) tensile modulus have thermal conductivity greater than copper and have been used in spacecraft for thermal control applications.

These are relative newcomers in reinforcing plastics, but they are now used in such areas as plastic composites for automotive, aerospace, and sporting goods. Carbon fibers can be used to reinforce both thermosets and thermoplastics.

Carbon fiber reinforcements enhance the modulus and strength of a plastic and reduce the density and thermal coefficient of expansion. They also lower the coefficient of friction and provide excellent resistance to most environmental exposure conditions and chemicals. The properties of the final composite are very much dependent on the degree of orientation of the fibers within the resin matrix. When the fibers are in complete alignment (e.g., unidirectional or all fibers are at an orientation of 0°), the properties of the composite are more affected by the fiber than if the fibers are randomly aligned.

Compared with glass fiber-reinforced plastics, the *carbon fiber composites* generally feature greatly improved tensile and flexural strengths and moduli. Thermal expansion of the carbon formulations is lower, and mold shrinkage ranges from about one-half to one-fifth that exhibited by the nonreinforced resin. Thermal conductivity of carbon composites is about twice that of equivalent glass-reinforced formulations.

Electrical conductivity of the carbon composites is high; this can be advantageous for many applications such as parts requiring electrostatic painting or electromechanical components in which it is desirable to dissipate static charges. Conductivity makes these composites unsuitable for applications that require a good insulator.

The degree to which carbon fibers reduce the coefficient of friction of thermoplastic resins is largely determined by the type of matrix resin used. Coefficient of friction of carbon fibers against steel is about 0.25 compared with 0.8 for glass fiber. Polymers reinforced with carbon fibers cause only about one-tenth of the wear on a relatively soft counterface such as mild steel than glass fiber-reinforced plastics.

Carbon fibers are available in various forms including fiber mats, with relatively low strengths and moduli, to chopped fibers and continuous filaments with high tensile strength and moduli. Current high-modulus filaments range up to a modulus of 75 million psi, with tensile strengths of approximately 300,000 psi. High-strength types feature tensile strength of about 400,000 psi and modulus from 30 million to approximately 50 million psi. Fiber mats have tensile strength of about 15,000 psi and a modulus of 5 million psi. Density of these products usually ranges from 1.6 to 1.9 g/cm^3.

A number of companies supply carbon filaments that have been impregnated with a thermoset resin. A common configuration consists of unidirectional thin tape, with the resin partially cured to a *B-stage* condition. The use of these *prepregs* permits better quality control of the resin and the resin content in the molded part. Unidirectional carbon filament prepreg composites offer very high strength and moduli and relatively low density.

In thermoplastics, carbon fiber compounds have been developed with nylon, polysulfone, thermoplastic, polyester, polyphenylene sulfide, polycarbonate, polypropylene, polyamide-imide, and ethylene/tetrafluoroethylene copolymer. Carbon fiber-reinforced molding compounds are available with carbon fiber contents of various levels such as 20, 30, and 40 weight percent. Nylon 66 molding compounds have also been developed with hybrid combinations of carbon and glass fiber reinforcements.

Major suppliers of carbon fiber include Akzo Fortafil Fibers Inc., Amoco Performance Products, Ashland Chemical Inc., BASF Structural Materials (*Celion*), Fibertec, GCA Chemical Corp., Toray Corp., and Zoltek Corp.

gravure printing Gravure (also called *rotogravure*) printing transfers ink from cells etched or engraved on the copper- and chrome-plated cylinder to the material being printed. The cylinder rotates in an ink fountain, and the cells pick up the liquid ink. A doctor blade wipes excess ink from the roller, leaving ink only in the cells. The low-viscosity liquid inks used in this process contain volatile solvent.

Gravure is mainly used when the design requires good continuity of sharp pattern details and rich color effects. It is a high-speed process; however, it can be expensive for short runs because of the cost of cylinders.

See also printing on plastics.

green strength Green strength is a term that refers to the stage of mechanical strength of a curing material that, while cure is not complete, allows removal of a part from the mold and handling without tearing or permanent distortion.

In adhesive bonding, green strength refers to the first stage of adhesive strength development (although not fully cured) where the operator can first handle the bonded joint without fear of bond failure.

Grignard process The Grignard process is an extremely flexible method of producing silicone resins. In this process, the monomers are prepared from silicone tetrachloride by the stepwise substitution of chlorine. The Grignard process can be used in the preparation of alkyl- and aryltrichlorosilanes as readily as for the preparation of the dialkyl- or diaryldichlorosilanes. A wide variety of organic groups may be attached to silicone by this one general procedure.

grinding Grinding, or sanding, is a process used to finish plastic parts by removing material from the surfaces of the part. Thermosetting plastic parts are relatively hard and brittle and as such are relatively easy to grind. On the other hand, many thermoplastics are tough and flexible materials. These have a tendency to clog tools. Grinding is not generally done on plastic parts unless open grit wheels with a coolant are used. Plastics are generally ground more slowly than metals, and the grinding is kept to a minimum to avoid unnecessary polishing later. Thermosets can be ground at speeds of 4–8 ft/s after a rough belt grinding. Thermoplastics are preferably ground wet because of better cooling at speeds of 3–5 ft/s, using thicker applications of grinding media.

Thermoplastics can be ground or sanded to a finished edge for fabrication fit-up or for close dimensional tolerance. The work is generally done on a machine (belt, disk, or band) by wet sanding using water for cooling and removing the heat buildup. High tool speed and light pressure is recommended. This will prevent softening of the plastic and subsequent buildup of viscous material on the grinding wheel. Wet grinding is used to square edges and to touch up angles, arcs, or curves for fit-up. Beveling can be done on a tilt bed wet sander.

A number-80 grit silicon-carbide abrasive is recommended for rough sanding. Progressively finer abrasives are then used in finishing. In any machine sanding, light pressure is used to prevent overheating. Disk sanders should be operated at speeds of 1750 rpm and belt sanders at a surface speed of 3600 ft/min. After sanding, further finishing operations can be completed.

See also filing; grit blasting.

grit blasting Mechanical methods for surface preparation include grit blasting (or *abrasive blasting*), *wire brushing*, and *abrasion* with sandpaper, emery cloth, or metal wool. These methods are most effective for removing heavy, loose particles such as dirt, scale, tarnish, and oxide layers. Cleaning is generally required both before and after mechanical surface preparation, especially if the abrasion process is being used as a pretreatment to coating or adhesive bonding. The parts should be degreased before abrasive treatment to prevent contaminants from being rubbed deeper into the surface. Solid particles left on the surfaces after abrading can be removed by blasts of clean, dry air and solvent wiping.

Grit or abrasive blasting is generally the preferred method for removing contamination from most metal surfaces. It is particularly appropriate for removal of rust, oxide layers, old coatings, and other heavy contamination. Blasting is a fast, efficient, and easily controlled process. It requires containment of the blast media and resulting dust, and the media must be regularly renewed and/or cleaned to maintain efficiency and avoid contamination. Blasting is impractical for thin or delicate parts because of warping and possible physical damage to the part. Blasting is also a line-of-sight process, and certain part geometries may be inappropriate.

Dry abrasive blast consists of a uniform blasting of the surface with a clean, fine, nonmetallic grit such as flintstones, silica, silicon carbide, aluminum oxide, or glass beads. The particle size will vary with the surface and the material. The degree of blasting for metal substrates should be a “white metal blast”—complete removal of all visible rust, mill scale, paint, and foreign matter. Written definitions and visible standards as to the degree of surface abrasion are available. A white metal blast is defined as SSPC-SP 5 (Steel Structures Painting Council) or NACE No. 1 (National Association of Corrosion Engineers). The degree of blasting for polymeric substrates should be sufficient to remove the surface glaze from the part.

Each substrate reacts favorably with a specific range of abrasive sizes. In many applications the adhesive joint strength generally increases with the degree of surface roughness. Often the joint performance is more dependent on the type of mechanical abrasion than the depth of the abrasion. For stainless steel and aluminum, sandblasted surfaces provide greater adhesion than when the surface is only machined. However, excessively rough surfaces also increase the probability that voids will be left at the interface, causing stress risers that may be detrimental to the joint in service. Recommended abrasive sizes for metals are in the 80–325 grit range; abrasive sizes for polymeric substrates are in the 120–220 grit range.

Certain low-energy surfaces, such as the polyolefins and fluorocarbons, should not be abraded at all before application of an adhesive or sealant unless the surface will undergo an active surface treatment. Abrasion and the resulting roughness on a low-energy surface will only increase the probability of air pockets being trapped in the crevices and valleys at the interface. These air pockets contribute to stress concentration points and a generally weaker joint. A general rule of thumb is that unless the adhesive makes a contact angle of 90° or less with the substrate (i.e., wets the substrate well), mechanical abrasion and surface roughening should be avoided.

A *wet-abrasive blasting* process can be used that may be more adaptable than conventional dry blasting. Here a 20–325 grit aluminum oxide or glass bead abrasive slurry is used as the blasting medium. Generally, three parts by volume water to one part by volume of the abrasive is used. Wet-blasting units can handle a wider range of abrasive materials, and a spray rinse automatically removes the blasting residue.

Several specialty mechanical blasting systems have been developed over the years for applications where standard grit blasting is not appropriate. These methods include cryogenic, hydrodynamic, and polymeric blasting.

Cryogenic and *hydrodynamic abrasive-free blasting* have also been used for surface treatment of substrates before coating or adhesive bonding. Both processes are ideal when the abrasive medium itself provides a contaminant or when the collection and reprocessing of the abrasive are prohibitive. These processes are often used in the field for surface preparation of structures in the need of repair.

The cryogenic process uses pelletized carbon dioxide at −73°C as a fluidized abrasive cleaning agent for surface preparation and removal of corrosion and old coatings. Not only does this provide an abrasion mechanism, but certain inorganic salts and organic contaminants can be dissolved with supercritical carbon dioxide.

High-pressure water blast has been used for prebond surface treatments to eliminate hazardous materials. The combination of high-pressure water abrasion with subsequent application of an adhesive promoter/primer has been found to provide high strength and durable aluminum bonds.

Polymeric blasting medium has also been used for removal of paint, coatings, and other contaminants for a variety of different applications. The abrasive medium consists of hard plastic material. Various types of grits are available with a relatively wide hardness range. The grit hardness is usually sufficient to remove paint coatings and other organic contaminants from the surface, but it is not hard enough to cause abrasion of the base metal or damage to relatively delicate parts. Although polymer blasting is generally thought of as a coating removal process rather than a surface preparation process, it has found use as a prebond process in electrical and electronic applications where a conductive blast medium is not acceptable.

See also abrasive finishing.

GR rubber GR is a designation (now obsolete) to indicate "government rubber." This designates a government specification for certain classes of rubber. Generally the letter following the GR indicated the type of rubber that is specified (e.g., GR-I refers to government rubber—isobutylene, GR-P refers to government rubber—polysulfide, and so forth).

guide pin Guide pins are devices that are used to maintain proper alignment of the force plug and cavity as the mold closes. The bushing that guides it is called the *guide pin bushing*. The guide pin is also called the *leader pin*.

gum A gum is an amorphous substance or mixture that, at ordinary temperature, is either a very viscous liquid or solid that softens gradually on heating and that either swells in water or is soluble in it. Natural gums obtained from the cell walls of plants are carbohydrates or carbohydrate-derivatives of intermediate molecular weight. Natural gums are graded according to standards of the National Hardwood Lumber Association.

Gutta-percha is a gum obtained by boiling the sap of species of trees native to Borneo, New Guinea, and Malaysia. It is an impure form of *trans*-polyisoprene. Gutta-percha is harder and a better insulator than natural rubber. It will vulcanize with sulfur and form a hard material. It is used for mixing with rubber, but its chief application is as a covering for electrical wiring and transmission belting and for various adhesives. It is also used in golf balls and dental filling because of its resistance to water. It molds easily at 82°C.

H

hand Hand is a term used in the fabric industry referring to the “feel” of the fabric. It is very subjective and is not measured in a standard way. Generally fabrics having a good hand are drapable and can be used for producing reinforced parts having relatively complex geometries.

hand layup Hand lay-up or *contact layup* generally refers to a process of placing in position and working successive plies of uncured reinforced plastic on a mold by hand. The reinforced plastic built up on the mold is then cured and removed from the mold. It is the simplest and least capital-intensive method of making large reinforced plastic parts. Manufacturers of large parts, such as boat and swimming pools, frequently use it.

Hand layup can be used on either male or female molds. The molds can be wood, metal, plastic, or plaster. When wood or plaster is used, their pores must be sealed with varnishes or lacquers. After the sealing compound is dry, the mold must be coated or covered with a *release agent* such as floor wax or film-forming polymer like polyvinyl alcohol (PVA).

In many applications a *gel coat* is first applied to the mold surface. This will cure with the body of the reinforced part to form an integral outer coating. This coating is a thick, pigmented resin that contributes a smooth, colorful outer surface to the molding. Gel coats are usually 20–40 mil thick and are permitted to cure to a tacky surface. (*See also* gel coat.)

At this point, the reinforcing web (glass cloth, mat, or woven roving) is placed on the mold and a low-viscosity resin, generally a room-temperature curing

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polyester or epoxy, is painted or sprayed onto the reinforcement. The air from the reinforcement is removed carefully with a paint roller or a rubber squeegee. Additional layers of reinforcement and resin are added until the correct thickness is obtained.

The exposed topmost layer is covered with polyethylene, cellophane, or polyester film to make a smooth surface. Some polyester resins are slightly inhibited by air, and film overlays help to complete the cure. When the resin has hardened, the part is removed and sometimes given a postbake.

Although this process is inexpensive and easy to perform, the molded parts are not of the highest quality and may not completely have the properties expected. The laminates produced by this method contain more resin than those produced by other methods, and more voids may be present. Little control can be exercised over the uniformity of the wall thickness. Typical cure time for polyesters is about 10 h at room temperature. Epoxies are used in special applications. They can be cured in as little as 3 h at 82°C. Hand layup is very labor intensive, but it is an excellent molding process when large sizes and a few units are needed.

A special case of hand layup is the *spray-up process*. This is accomplished with a special type of spray gun. Molds similar to those used in hand layup are used. The gun chops glass fiber into predetermined lengths, mixes them with resin, and deposits them onto the mold surface. The mold surface is often pretreated with a mineral-filled resin that has been partially cured. This surface is called a gel coat. When enough glass has been deposited, an impregnated glass mat has been formed. From this point on, the process is identical to the hand layup process. The process is attractive because it makes use of glass fiber in its least expensive form. Parts with complicated shapes can be made, and size is not critical. Skilled operators are needed if control over wall thickness is required.

hand mold A hand mold is a mold that is taken out of the press after each shot for removal of the part.

hardener A hardener or *curing agent* is a chemical added to a thermosetting resin for the purpose of causing curing or hardening by taking part in the curing reaction. Amines and acid anhydrides are hardeners for epoxy resins. Note that hardeners differ from catalysts, promoters, and accelerators in that the hardener becomes a major component in the resulting polymer. The term *hardeners* is usually used for epoxy resins but can be used for other thermosetting resins as well.

Hardeners are specifically chosen to react with a certain resin. They will have a significant effect on the curing characteristics and on the ultimate properties of the system. Reactive polyamide resins are an example of a common hardener used in two-part epoxy systems. The criticality of the amount of hardener used in the formulation is dependent on the chemistry of the specific reaction involved. By over- or underusing a polyamide hardener, the resulting formulation will have more or less of the characteristics of the hardener, but a usable system generally results. For example, 10 percent by weight additional polyamide hardener in a two-part epoxy formulation will result in a system with greater flexibility and peel strength but lower temperature and environmental resistance because of the flexible nature of the polyamide molecule. Ten percent less hardener will provide higher shear strength and temperature resistance but poorer peel strength.

It must be noted, however, that certain hardeners (e.g., amines, acids, and anhydrides) do have critical mixing requirements, and slight deviations from the manufacturers' mixing instructions could drastically affect the adhesive system.

See also curing agent; epoxy resin curing agent.

hardness Hardness is the measure of resistance of a plastic material to compression and indentation. As usually conceived, hardness is a composite property combining concepts of resistance to penetration, scratching, marring, etc. Most hardness tests for plastics are based on resistance to penetration by an indentor pressed into the plastic surface under a constant load.

Hardness measurements can be very valuable, particularly for comparing similar materials. Hardness measurements are often indicative of scratch, wear, and abrasion resistance. They can also be used to determine relative degree of cure, and in this manner are sometimes used as quality control tools.

Hardness of plastics is difficult to establish and compare because there is an enormous range of values. Hardness measured by indentors is also difficult because there is an elastic recovery effect. Among the most important methods for testing this property are *Ball hardness*, *Rockwell hardness*, and *Shore hardness*. Other methods are also commonly used. The Rockwell hardness test determines the hardness after allowing for elastic recovery in the test specimen. Both Ball and Shore hardness tests exclude any elastic recovery effects.

A number of scales are used within the plastics industry. Figure H.1 illustrates the relationship between them.

The most commonly used instrument is the *durometer* made by Shore Instrument Co. Shore hardness values are scale numbers resulting from the indentation of a plastic material with a defined steel rod. ASTM D2240 describes Shore hardness measurements. There are several Shore instruments, identified by A to D and designed to give different readings from soft sponge up through glasslike polymers. Shore A durometer readings are the most common, and those are the readings appearing in most specifications. On the Shore A scale, 0 would be soft and 100 hard. For example, a rubber band would be about 35 and a rubber tire tread about 70. Hard rubber and thermoset and thermoplastic materials are generally read on the Shore D scale. Most products will fall between 40 and 90. No simple relationship exists between this test method and any fundamental property of the material tested.

In the Ball hardness test (ISO 2039-1), a polished steel ball is pressed into the surface of the test specimen. After 30 s of load application, the depth of the impression is measured. Ball hardness is calculated as applied load divided by surface area of the impression (newtons per mm^2). Typical values for relatively soft and stiff engineering plastics are 100 N/mm^2 and 150 N/mm^2, respectively.

Rockwell hardness (ASTM D785) is directly related to the indentation hardness of a plastic material. The indentor, a polished steel ball, is pressed into the surface

Figure H.1 Range of hardness common to plastics. (Ref: Rosato, D.V., *Rosato's Plastics Encyclopedia and Dictionary*, Carl Hanser Verlag, Munich, 1993)

of a test specimen. The specimen is loaded by a minor load, followed by a major load, and then again by the same minor load. The actual measurement is based on the total depth of penetration. The Rockwell hardness scales increase in severeness from R to M (increasing material hardness). Rigid thermosets often give Rockwell hardness in the range of M100–M120. Engineering thermoplastics are often in the range of R110–R120.

See also Barcol hardness, Shore hardness, Rockwell hardness.

hard rubber

See ebonite.

haze Haze is the degree of cloudiness in a plastic material. It can be affected by molecular structure, degree of crystallinity, or impurities at the surface or interior of the polymer. The effect of haze is to impart a cloudy or milky appearance to the sample, but its transparency need not be reduced. The term haze is appropriate for translucent or transparent materials and not for opaque materials.

For transparent materials, haze is that percentage of transmitted light which when passing through the specimen deviates from the incident beam by forward scattering. In commercial haze meters, only light deviating more than 2.5° from the transmitted beam direction is considered haze.

The haze test method (ASTM D1003) actually measures absorption, transmittance, and deviation of a direct beam in a translucent material. Haze is sometimes thought of as the opposite of gloss, which would properly be absorption of an incident beam.

See also gloss; transparency.

head The head refers to the end section of a blow molding machine (in a general extruder) in which the melt is transformed into a hollow parison.

heat aging Heat aging is a general term for procedures and test methods that can be used to assess long-term resistance of a plastic to aging, usually on the basis of accelerated heating tests at elevated temperatures. ASTM D794 describes tests that can be used to determine the permanent effect of heat on plastic materials.

See also relative temperature index; aging; thermal degradation.

heat capacity Heat capacity, or *specific heat*, is the amount of energy needed to change a unit mass of a material 1°C in temperature. The heat capacities of plastics, which are obtained at a constant pressure, are temperature dependent, especially near the glass transition temperature. The heat capacity of polymers at 25°C varies from 0.9 to 1.6 J/g°K for amorphous polymers and from 0.96 to 2.3 J/g°K for crystalline polymers.

In semicrystalline polymers, the heat capacity of the amorphous phase is larger than the heat capacity in the crystalline phase. This implies that the heat capacity values depend on the percentage of the polymer's crystallinity.

Reliable data regarding the heat capacity of amorphous and crystalline phases are available for only a limited number of polymers. The usual techniques for measuring specific heat are *differential thermal analysis* (DTA) and *differential scanning calorimetry* (DSC).

heat cleaning *Heat cleaning* is the process in which glass or other fibers are exposed to elevated temperatures to remove preliminary sizings or binders not compatible with the resin system to be supplied. Generally, fibers are heat cleaned before application of a resin-compatible finish.

See also finish.

heat deflection temperature (heat distortion point) The heat deflection temperature (HDT) or heat distortion point is the relative measure of a material's ability to perform for a short time at elevated temperatures while supporting load. It is the temperature at which a standard test bar (ASTM D648) deflects 0.010 in. under a flexural load of either 64 psi or 264 psi.

Although widely used to indicate high-temperature performance, the HDT test simulates only a very narrow range of conditions. Many high-temperature applications involve higher temperatures, greater loading, and unsupported conditions.

Therefore, the results obtained by this test method do not represent maximum-use temperatures, because in real life essential factors such as time, loading, and nominal surface stress may differ from the standard test conditions.

The sample is deflected to produce a defined surface stress and then placed in a temperature bath at 23°C. The force is allowed to act for 5 min, and then the temperature is raised at a uniform rate of 2°C/min. The deflection of the test bar is continuously observed; the temperature at which the deflection reaches 0.010 in. is reported as the heat deflection temperature. This is also known as the heat distortion temperature or the *deflection temperature under load* (DTUL).

It is one of several methods used to measure the softening temperature or temperature resistance of a plastic. It should be noted that the heat distortion point is generally lower than the glass transition temperature or melt temperature of the polymer because of the mechanical effect of the load. However, in amorphous polymers, HDT is generally the same as the glass transition temperature (T_g) of the material. The HDT test method is more reproducible with amorphous polymers than with crystalline polymers. With some polymers, it may be necessary to anneal the test specimens to obtain reliable results.

Addition of glass fibers to the polymer will increase the modulus. Because the HDT represents a temperature at which the material exhibits a defined modulus, increasing the modulus will also increase the HDT. Glass fibers have a more significant effect on the HDT of crystalline polymers than on amorphous polymers.

Heat deflection temperature data are dangerous to use in the respect that they often are the only temperature data provided on a resin in the supplier's data sheet. This leaves the impression that HDT is a reliable indicator of the limit to which the product can be used. However, it is only what is stated—the temperature at which a certain sized specimen will deflect a given amount at a given load. Other temperature tests are more useful in determining the maximum temperature at which a product can be exposed during its service life.

See also relative temperature index.

heated-manifold mold The heated-manifold mold is a thermoplastic injection mold in which the portion of the mold (the manifold) that contains the runner systems has its own heating elements. These keep the molding material in a plastic state ready for injection into the cavities from which the manifold is insulated.

See also hot runner mold.

heated-tool welding Heated-tool or *fusion welding* is an excellent method of joining many thermoplastics. In this method, the surfaces to be fused are heated by holding them against a hot surface. When the plastic becomes molten and a flash about half the thickness of the substrate is visible, the parts are removed from the hot surface. They are then immediately joined under slight pressure (5–15 psi) and allowed to cool and harden. The molten polymer acts as a hot-melt adhesive, providing a bond between the substrates. (See Fig. H.2.)

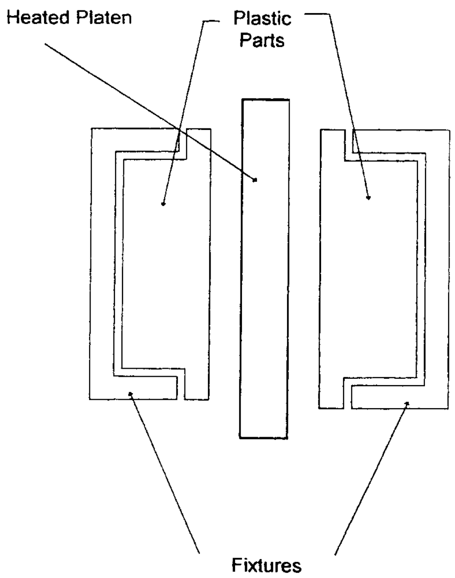

Figure H.2 In direct hot plate welding, two fixtures press components into a hot, movable plate, causing the plastic to melt at the interface. Subsequent removal of the plate, application of pressure on the joint, and cooling time allows the welded joint to form and gain strength.

This method is often used in high-volume operations where adhesive bonding is objectionably long. It is also often used to join low-surface-energy materials, such as polypropylene, where the cost and complexity required for substrate treatment and adhesive bonding cannot be tolerated. Heated-tool welding is a simple, economical technique in which high-strength joints can be achieved with large and small parts. Hermetic seals can also be achieved. Heated-tool welding does not introduce foreign materials into the part, and as a result plastic parts are more easily recycled.

Success in heated-tool welding depends primarily on having the proper temperature at the heating surface and on the timing of the various steps in the process. These periods include time for application of heat, time between removal of heat and joining of parts, and time the parts are under pressure. The tool should be hot enough to produce sufficient flow for fusion within 10 s. The parts are generally pressed against the heated tool with a certain degree of pressure. However, to avoid strain the pressure on the parts should be released for a period of time before they are removed from contact with the heated tool.

Although some rules of thumb can apply, the final process settings for temperature, duration of heating and cooling times, and pressures will depend on the polymer. Adjustments will be required until the desired bond quality is achieved. The thickness of the molten layer is an important determinant of weld strength. Dimensions are usually controlled through the incorporation of displacement stops at both the heating and mating steps in the process. If welds are wider than 1/4 in., the heated parts should be glided across each other during the mating step to prevent air entrapment in the joint.

Heated-tool welding is suitable for almost any thermoplastic but is most often used for softer, semicrystalline thermoplastics. Common plastic substrates that are suitable for heated-tool welding include polyethylene, polypropylene, polystyrene, acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and acetals. It is usually not suitable for nylon or other materials that have long molecular chains. Dissimilar yet chemically compatible materials that have different melting temperatures can be welded in heated-tool welding by using two heated platens, each heated to the melting temperature of the part to be welded.

Heated-tool welding can be accomplished with either no surface treatment or very minor surface preparation (degreasing and removal of mold release) depending on the strength and reliability dictated by the application. Generally, surface degreasing to remove mold release or other organic contaminants is the only prebond treatment necessary. Mechanical roughening or chemical treatment of the surface provides no advantage because the surface will be melted and a new surface will be formed. Plastic parts that have a significant degree of internal moisture may have to be dried before heated-tool welding, or the moisture will tend to escape the molten surface in the form of vapor bubbles.

Electric strip heaters, soldering irons, hot plates, and resistance blades are common methods of providing heat locally. Usually, the heating platen is coated with a fluorocarbon such as polytetrafluoroethylene (PTFE) for nonsticking. A simple hot plate has been used extensively with many plastics. Table H.1 lists typical hot plate temperatures for a variety of plastics. A similar technique involves butting flat plastic sheets on a flat table against a heated blade that runs the length of the sheet. Once the plastic begins to soften, the blade is raised and the sheets are pressed together and fused.

The direct heat welding operation can be completely manual, as in the case of producing a few prototypes, or it can be semi- or fully automatic for fast, high-volume production. For automated assembly, rotary machines are often used where there is an independent station for each process: (1) clamping into fixtures, (2) heating, (3) joining and cooling, (4) unloading.

Heated wheels or continuously moving heated bands are common tools used to bond thin plastic sheet and film. This is commonly used for sealing purposes such as packaging of food. Care must be taken, especially with thin film, not to apply excessive pressure or heat. This could result in melting through the plastic.

Heated-tool welding is commonly used in medium-to high-volume industries that can make use of the simplicity and speed of these joining processes. Industries that commonly use this fastening method include appliance and automotive. Welding times range from 10–20 s for small parts to up to 30 min for larger parts such as heavy-duty pipe. Typical cycle times are less than 60 s. Although heated-tool welding is faster than adhesive bonding, it is not as fast as other welding methods such as ultrasonic or induction welding.

The process is extremely useful for pipe and duct work, rods and bars, or continuous seals in films. However, irregular surfaces are difficult to heat unless complicated tools are provided. Special tooling configurations can be used for bonding any structural profile to a flat surface. In certain applications, the direct heating can also

Table H.1 Hot Plate Temperatures to Weld Plastics and Plastic Films (Ref: Gentle, D.F., "Bonding Sytems for Plastics", *Aspects of Adhesion,* vol. 5, University of London Press, London, 1969)

Plastic	Temperature, °F	Film	Temperature, °F
ABS	450	Coated cellophane	200–350
Acetal	500	Cellulose acetate	400–500
Phenoxy	550	Coated polyester	490
Polyethylene			
LD	360	Poly(chlorotrifluoroethylene)	415–450
HD	390	Polyethylene	250–375
Polycarbonate	650	Polystyrene (oriented)	220–300
PPO	650	Poly(vinyl alcohol)	300–400
Noryl[*]	525	Poly(vinyl chloride) and copolymers (nonrigid)	200–400
Polypropylene	400	Poly(vinyl chloride) and copolymers (rigid)	260–400
Polystyrene	420	Poly(vinyl chloride)—nitrile rubber blend	220–350
SAN	450	Poly(vinylidene chloride)	285
Nylon 6, 6	475	Rubber hydrochloride	225–350
PVC	450	Fluorinated ethylene-propylene copolymer	600–750

[*] Trademark of General Electric Company.

be used to shape the joint. With pipe, for example, a technique called *groove welding* is generally used. Groove welding involves two heating elements. One element melts a groove in one substrate that is the exact shape of the mating part, and the other element heats the edge of the mating substrate. The heated part is quickly placed into the heated groove and allowed to cool.

See also butt fusion.

heaters At one time most plastic molds were heated by steam or hot water circulating through channels drilled in the chase or force plates or in heating platens. They were also heated electrically, as they usually are in automatic self-contained presses. Today, however, electric heaters are used on almost every functional component of plastic processing equipment.

Different styles of electric heaters are available, many of which can be custom designed and manufactured to meet exacting requirements. It is essential to operate electric heating elements with temperature-controlling provisions. Heaters that are not properly controlled are subject to premature failure or may yield substandard processing performance.

Band heaters are generally used on barrels of injection molding and extrusion equipment, dies, blow molding heads, and feed pipes. Mica-insulated band heaters are the most common type and can operate up to 371°C. Ceramic-insulated band heaters have thermal insulation to improve efficiency and conserve power, and they achieve operating temperatures of 815°C. Aluminum shoe-style band heaters provide excellent thermal conductivity and long-lasting, chemical-resistant performance. They are very effective on large-diameter cylinders. Mineral-insulated heater bands are used on barrel or die applications to provide higher temperatures or watt densities needed in processing engineering resins.

Cartridge heaters are available in both high- and low-watt-density constructions, but the former predominates. Cartridge heaters are typically inserted into molds, hot runner nozzles, and extrusion-related auxiliaries. These heaters can be designed to operate at temperatures to 649°C (high watt density) and 538°C (low watt density).

Cast-in heaters are typically used in extrusion-related applications. For extruder barrels, cast-in heating and cooling bands precisely modulate the temperature of the plastic melt to control rheology. Made of various metal alloys in virtually any size or shape, with integral cooling tubes to accommodate liquid cooling or fined geometry for air cooling, they can meet the most diverse application requirements. Aluminum castings operate up to 371°C, and bronze or brass are used to 649°C.

Strip heaters present most of the same construction varieties as the band heaters. Strip heaters are commonly used to apply surface heating to dies and molds. Sometimes they act as a radiant heat source in thermoforming or plastic-bending applications.

Radiant heaters are nonconductive sources that work exceptionally well in plastic thermoforming and bending and welding applications by replasticizing the polymer before the final production processes. The more commonly accepted industry styles of radiant heaters are ceramic infrared units. Quartz-faced and black body panels are available.

Tubular heating elements are extremely durable, resistant to contamination, and quite economical. They can be used on dies, radiant, thermoforming, and hot runner manifold applications. Tubular heaters provide temperatures up to 649°C and offer tremendous design flexibility.

Mineral-insulated cable heaters are often coiled and used on hot sprue bushing/runnerless molding nozzles. The coil heaters are capable of high operating temperatures, up to 815°C.

heating chamber In molding, the heating chamber is that part of the machine in which the cold feed is reduced to a hot melt. This is also called the *heating cylinder*.

heat of fusion The heat of fusion is the energy involved during the formation and melting of crystalline regions. For semicrystalline polymer, the energy of fusion is proportional to the percentage of crystallinity. Amorphous polymers or amorphous polymer regions do not have heats of fusion, because amorphous structures show a smooth transition from the viscous liquid amorphous state to the true liquid state.

Experimental values of crystalline heat of fusion for common packaging plastics vary from 8.2 kJ/mol for polyethylene to 43 kJ/mol for nylon 66. ASTM D3417 describes a method for measuring the heat of fusion and crystallization of a polymer by differential scanning calorimetry (DSC).

heat sealing Heat sealing is a method of joining thermoplastic films by simultaneous applications of heat and pressure to areas in contact. The heat may be supplied conductively via heating elements or dielectrically via high-frequency electrodes. Dielectric heat sealing is used only on polymers that will heat readily in a high-frequency field (e.g., those that have a relatively high dielectric loss such as vinyl chloride).

In this process the seal is obtained by heating the area to be bonded to a temperature that is over the melt temperature of the plastic. The substrates are then held together until the seal has cooled and hardened. With thin films this can take only fractions of a second, and continuous processes have been developed for continuous plastic seams.

Heat sealing is commonly used with a continuous belt process for sealing plastic bags, film, etc. If the plastic film has too high a melt temperature or if it is a themoset material, thin thermoplastic films have been applied by coating or coextrusion to act as a "hot-melt adhesive" for sealing films. A *heat-sealing adhesive* is a thermoplastic film adhesive that is melted between adherend surfaces by application of heat to one or both of the surfaces.

heat-shrinkable tubing and film Heat-shrinkable tubing or heat-shrink tubing is plastic tubing that on heating shrinks radially so that its diameter is reduced a predetermined percentage. The characteristic is achieved by radial stretching of the tubing in a separate operation after extrusion at an elevated temperature corresponding to that used to ultimately shrink the tubing.

In most commercial versions of the tubing, the plastic material is lightly cross-linked either chemically or by radiation. This cross-linking gives the tubing a *plastic memory* for its original shape and assists shrinkability. Shrink tubing is usually made from PVC or polyethylene resins. The most common applications are packaging, medical products, and the sealing of lead wires in electrical assemblies.

Similar to tubing, film or tape can also be made to have heat shrinking characteristics. Prestretched polyvinylidene fluoride from Du Pont (*Teldlar*) is the most commonly used shrink film because it shrinks readily on application of heat. It is often used in filament or tape winding operations to maintain pressure on the winding during cure.

heat stabilizers Heat stabilizers are used to prevent the thermal degradation of resins during periods of exposure to elevated temperatures. Almost all heat stabilizers are used to stabilize polyvinyl chloride (PVC), polyvinylidene chloride, vinyl chloride copolymers, and PVC blends. Heat stabilizers are used primarily in PVC compounds to protect them from chemically breaking down under heat and discoloring or degrading further. Heat stabilizers help to prevent thermal degradation not only during processing but also during the useful life of the finished products.

On exposure to heat and/or light the allylic chlorine atoms in the PVC structure break down to release hydrogen chloride. This leads to discoloration and polymer degradation. Hydrogen chloride can also combine with moisture to form hydrochloric acid, which could corrode processing equipment. It is the function of the heat stabilizer to retard these unwanted chemical reactions so that PVC can be processed safely and offer a useful life as an end product.

Heat stabilizers belong to one of the two major classes: primary heat stabilizers and secondary heat stabilizers. *Primary heat stabilizers* function both by retarding the dehydrochlorination process and by reacting with the liberated HCl to delay progress degradation. Secondary heat stabilizers or costabilizers are used to scavenge liberated HCl from the PVC resin or to react with the metallic chloride by products of the primary mixed metal stabilizers.

There are three major types of primary heat stabilizers: mixed metal-salt blends, organo-tin compounds, and lead compounds. Of less importance are antimony mecaptides. Mixed metal stabilizers are primarily used in flexible or semirigid PVC products. The most common are barium/zinc metal salts. Organo-tin heat stabilizers are used primarily for PVC application. Lead heat stabilizers are used primarily for wire and cable applications. They may be either organic- or inorganic-based products. Antimony compounds are effective at low concentrations as primary heat stabilizers in rigid PVC applications. They can be used in potable water applications but have poor light stability.

The *secondary heat stabilizers* are usually organophosphites and epoxy compounds, but polyols and β-diketones are also used. Alky/aryl organophosphites are often used with liquid mixed-metal stabilizers in the stabilization of PVC resin. Epoxy compounds function both as plasticizers and stabilizers in flexible and semirigid PVC. β-Diketones are secondary heat stabilizers used in combination with Ca/Zn and Ba/Zn metallic heat stabilizers to improve initial color. Polyfunctional alcohols are secondary heat stabilizers used in combination with mixed-metal products.

The selection of which heat stabilizer or combination of heat stabilizers to use will depend on the processing system, the end use application, and the effect on processing properties of the resin. There are over 100 suppliers of primary heat stabilizers. Among the major suppliers are Witco Corp., Akzo Chemical Inc., and Ferro Corp.

heat treating *Heat treating* is a term used to describe any heating process, usually occurring after the part has been manufactured (e.g., annealing, postcuring).

See also annealing.

heat welding (direct) Welding by the direct application of heat provides an advantageous method of joining many thermoplastic materials that do not degrade rapidly at their melt temperatures. The principal methods of direct welding are:

- Heated tool
- Hot gas
- Resistance wire
- Laser
- Infrared

These methods are generally capable of joining thermoplastics to themselves and other thermoplastics, and in certain cases they may also be used to weld thermoplastics to nonplastic substrates.

In the heat welding processes, the plastic resin that makes up the substrate itself acts as the adhesive. These processes require that the surface region of the substrate be made fluid, so that it can wet the mating substrate. If the mating substrate is also a polymer, both substrate surfaces can be made fluid so that the resin can molecularly diffuse into the opposite interface. This fluid interface region is usually achieved by thermally heating the surface areas of one or both substrates. Once the substrate surface is in a fluid condition, they are brought together and held in place with moderate pressure. At this point the molecules of substrate A and substrate B will diffuse into one another and form a very tight bond. The fluid polymer mix then returns back to the solid state, usually by cooling from the molten condition.

Thermal welding can also be used to bond one polymeric substrate to another substrate that is not polymeric. In these cases, the molten polymer surface wets the other substrate and acts as a hot-melt type of adhesive. Internal stresses that occur on cooling the interface from the molten condition are the greatest detriment to this method of bonding.

See also heated tool welding; hot-gas welding; resistance wire welding; laser welding; infrared welding.

heat welding (indirect) Many plastic parts may be joined by indirect heating. With these methods the materials are heated by external energy sources. The heat is induced in the polymer or at the interface. Indirect methods of heating consist of *induction welding* and *dielectric welding*. For induction welding the source is an electromagnetic field, and for dielectric welding the source is an electric field of high frequency.

Indirect heat joining is possible for almost all thermoplastics; however, it is most often used with the newer engineering thermoplastics. The engineering thermoplastics generally have greater heat and chemical resistance than the more conventional plastics. In many applications they are reinforced to improve structural characteristics. They are generally stronger and have excellent strength-to-weight ratios. However, many of these plastics are not well suited to joining by direct heat because of the high melt temperatures. Indirect heating methods and frictional heating methods must be used to obtain fast, high-quality bonds with these useful plastic materials.

See also induction welding; dielectric heat sealing/welding; vibration welding; spin welding.

heel In molding of bottles or containers, the heel is the part of a container between the bottom bearing surface and the side wall. The *heel radius* is the degree of curvature at the extreme bottom end of a container extending upward from the bearing surface. This is also known as the *base radius*. A *heel tap* is the bottle imperfection resulting from one area of the bottom having excess thickness.

helical pattern In filament winding, a helical pattern is a pattern generated when a filament band advances along a helical path, not necessarily at a constant angle except in the case of a cylinder.

high-flow resin High-flow resins are liquid or B-stage resins, such as epoxies, that have, or can be heated to provide low viscosity and resultant high flow rate into and around intricate parts, especially high-density electronic assemblies. This best ensures complete resin fill without leaving air voids in the molded part. High-flow resins are desirable for casting, potting, impregnation, and transfer molding processes.

See also casting resin; potting resin; impregnating resin; transfer molding.

high-frequency heating High-frequency heating is the heating of materials by their dielectric loss in a high-frequency (20–80 MHz) electrostatic field. The material is exposed between electrodes and, by absorption of energy from the electric field, is heated quickly and uniformly throughout. Materials with a high dielectric loss (high dielectric constant and/or dissipation factor) such as cellulosics, vinyl polymers, and phenolic will heat rapidly in a high-frequency electrical field. Materials with a low dielectric constant or dissipation factor such as polyethylene and fluorocarbons will show very little heating when placed in such a field.

High-frequency heating is generally used for *drying* moisture from hydroscopic polymers such as nylon and polycarbonate. Here the adsorbed moisture has high dielectric constant and dissipation factor and will heat within the material until it is volatilized. High-frequency heating is also used for *heat welding* thermoplastics that have high dielectric losses (e.g., polyvinyl chloride films).

See also dielectric heat sealing/welding; dielectric curing or heating.

high-performance plastic High-performance plastics are those that are generally recognized to be suitable for use at operating temperatures above 175°C. These include both thermoplastic and thermosetting plastics. Indicative high-performance plastics include:

- Polybenzimidazole
- Polyimide
- Polyamide-imide
- Polyetherimide
- Polyetherether ketone
- Polyphenylene sulfide
- Polyarylene sulfide
- Polyether sulfone

See also engineering plastic.

high-pressure laminate High-pressure laminates are reinforced polymeric sheets made up of layers of thermosetting resin reinforced with fabric, mat, or paper that are molded and cured at pressures not lower than 1000 psi and more commonly in the range of 1200 to 2000 psi. The laminating process consists of:

1. Impregnating the base material of the continuous construction type with a resin or combination of resins
2. Advancing the resin-impregnated sheet to the B-stage
3. Stacking up the impregnated sheets to achieve the desired form
4. Applying heat and pressure to bond the layers together and cure the resin

Because of the limitation of size and cost of molding presses and equipment, most high-pressure laminates are restricted to the form of sheets, rods, tubes, and simple cross sections. They are notable for excellent electrical characteristics, low heat conductivity, good heat resistance, a favorable strength-to-weight ratio, light weight, good dimensional stability over a wide range of temperatures, inertness to the vast majority of chemicals, and excellent surface appearance. The machinability of most laminates is excellent, and they can usually be machined with standard wood- or metal-working tools.

High-pressure laminates are commonly used for electrical, industrial, and decorative laminates. Where high mechanical strength-to-weight ratio is required, the fabric-based laminates are necessary. Laminates can also be used for marine applications because of their moisture resistance (except for cut edges where the reinforcing material is exposed and water can ingress via wicking).

See also decorative laminate; NEMA.

high-pressure liquid chromatograph The high-pressure liquid chromatograph (HPLC) is available in two forms: gel permeation and liquid. In gel permeation HPLC, the molecular weight distribution and average molecular weight of the molecules in a sample compound can be determined. In the liquid HPLC, the type and amount of chemical constituents present in a compound can be determined.

Gel permeation chromatography makes use of a column packed with gel. The column is equilibrated with the solvent, and then a small amount of a solution of the polymer under investigation is introduced at the top. A constant flow of pure solvent is then initiated, washing the polymer sample downward. The smaller the molecules in the sample are, the more easily they can become entangled in the swollen structure of the gel substrate and the more difficult will be their progress toward the bottom of the column. The large molecules, too big to become entrapped in the gel pores, wash through quickly. Thus a separation is obtained; the largest molecules are washed through the column first, followed by successively smaller ones.

See also chromatography.

high-resistivity plastic

See resistance (electrical); resistivity.

high-thermal-conductivity plastic High-thermal-conductivity plastics are those that have been formulated to provide higher thermal conductivity of the plastic while maintaining good electrical insulating properties. This is important to improve the heat dissipation from the normally poorly conductive plastics used in electronic and electrical systems. This is not to be confused with conductive polymers, which are somewhat electrically conductive, based on the chemistry of the polymer.

Improved thermal conductivity in plastics is usually achieved by the addition of powder fillers into the plastic formulation. Although silica filler is often used and is effective, some other fillers have higher thermal conductivity. Fillers that are noted to improve the thermal conductivity of plastics are metals, such as aluminum and copper; metal fibers; and boron and aluminum nitride.

Greatest improvement is achieved by using the largest practical concentration of fillers and by using fillers having highest thermal conductivity. Filler particle size and distribution is also a factor. Technical and practical reasons determine the filler selection and filled plastic formulation.

See also electronic plastic; thermal conductivity; thermally stable plastic.

high voltage High voltage is any elevated voltage level that deteriorates the insulating materials of the system. Plastics are especially susceptible, particularly at operating voltages in the kilovolt levels. Plastics are also especially susceptible if they contain gaseous voids or defects that can cause partial discharge and corona.

See also corona resistance; high-voltage-resistant plastic; arc- and track-resistant plastic.

high-voltage-resistant plastic High-voltage-resistant plastics are those plastics that, by basic polymer structure or by formulation, exhibit greatest resistance to degradation in high-voltage operating conditions. High voltage normally degrades plastics by one or both of two mechanisms: (1) dielectric breakdown when the voltage level exceeds the dielectric strength of the plastic and (2) carbon tracking of the plastic. Dielectric breakdown results in undesirable leakage currents at a minimum and totally destructive puncture of the plastic in worst cases. Corona can also occur.

See also corona resistance; dielectric strength; arc- and track-resistant plastic; high voltage.

hindered amine light stabilizer Hindered amine light stabilizers (HALS) are a group of useful ultraviolet (UV) stabilizers. They are particularly effective in polyolefin formulations. They are structurally characterized by the presence of amine groups sterically protected by other adjacent groups. HALS are effective at relatively low concentrations. A useful feature of this type of stabilizer is its effectiveness in thin polyolefin products such as films and in surface layers.

See also ultraviolet stabilizer.

HMC HMC is a type of a bulk molding compound produced by PPG Industries. It has strength greater than other bulk molding compounds because of its relatively higher reinforcement content. It is similar to *XMC*.

See also bulk molding compound (BMC); XMC.

hobbing Hobbing, as it is known to the mold maker, is essentially the coining or cold forging of a desired impression into prepared blocks of steel. This method is most practical and economical for forming or shaping multiple-cavity molds. It can also be used to advantage with single-cavity molds where unusual contours or depth of the mold preclude cavity machining.

The *hob* or a master model is usually made of a good quality, hardened steel. Its face is machined to the exact size and contour of the reproduction desired. All surfaces of the hob are highly polished after hardening. The blanks for the impressions are made from soft steel (or beryllium-copper) and are prepared by grinding and polishing the surface that is to come in contact with the hob. Depending on the size and the contour of the hob, it is advisable to remove some of the material from the bottom of the blank. After preparation the blank is placed in a hydraulic press, and the hob is placed in position over the blank before the press is closed. The actual hob pin is done in the press at a very slow rate of speed. The pressure required for hobbing varies from 50 to 150 tons/in^2 of die impression.

When properly applied, hobbing will result in a highly polished cavity with absolute uniformity in size and contour. As a rule, very little additional work is required on the finished product except machining the outside surfaces to the desired dimensions.

hollow part processes Hollow products can be made either by (1) assembling parts made in sections by most of the plastic joining processes or (2) one of the hollow part processes. The advantage of the hollow part processes is primarily that the part can be made in one piece. Most hollow parts made from traditional processes require that the part be made in two or more pieces and then assembled.

The cost effectiveness of hollow part processing vs. more conventional constructions will vary considerably according to the application and to the state of the art of the process being applied. The savings associated with molding the part in one piece may be offset by the use of robotics in automating the assembly process coupled with a more effective molding process.

For thermosets, the hollow part processes are *filament winding* and *pultrusion*. These processes are limited in shape and structure. There are three hollow part processes for thermoplastics: (1) *rotational molding*, (2) *twin sheet thermoforming*, and (3) *blow molding*.

See also filament winding; pultrusion; rotational molding; thermoforming; blow molding.

homopolymer A homopolymer is a polymer resulting from polymerization of a single *monomer*. An example is the polymerization of ethylene into polyethylene.

honeycomb A honeycomb is a manufactured product of resin-impregnated sheet material or metal foil, formed into hexagonal cells. The reinforcement to make the resin-impregnated sheet can be paper, glass, or aramid fabric, etc. This material is called the *honeycomb core*.

Honeycomb skins are bonded to the top and bottom surfaces of the core to achieve strength. The skins can likewise be resin-impregnated sheet materials or metal foil and do not have to be the same material as the core. Generally the honeycomb core and skins are bonded together to form a *sandwich construction*.

Honeycomb is noted for its very high compressive strength and low density. It is often used in airplane, railcar, and elevator manufacture where high strength is necessary but weight is at a premium.

Hooke's law A material that conforms to Hooke's law is one in which the stress is directly proportional to the strain. Perfectly elastic solids conform to Hooke's law.

hoop stress Hoop stress is the circumferential stress in a material of cylindrical form subjected to internal or external pressure. Hoop stress is a major characteristic of filament-wound and extruded pipes. Maximum hoop stress is generally obtained in filament winding when the fibers are wound circumferentially at a 90° angle to the axis of the part.

hopper The hopper is the conical feed reservoir into which the molding powder is loaded and from which it falls into a molding machine or extruder. Sometimes this flow of feed pellets occurs through a metering device. The *hopper dryer* is a combination feeding and drying device for extrusion and injection molding of thermoplastics. Hot air flows upward through the hopper containing the feed pellets. The *hopper loader* is a curved pipe through which molding powders are pneumatically conveyed from shipping drums to machine hoppers.

horizontal/vertical burning One of the most frequently used tests for the characterization of the flammability of rigid, self-supporting plastics involves a horizontal cantilever-held test specimen (ASTM D635). A Bunsen burner is used as an igniter. It is applied to the free end of the test specimen for 30 s and then removed. Data are reported as average burning rate in cm/min.

Materials not stiff enough to be self supporting in a cantilever specimen can be tested in a vertical position (ASTM D568). In this case, the Bunsen burner is applied to the low end of the specimen until the sample ignites, but not longer than 15 s.

Underwriters Laboratories (UL) subjects test specimens to flammability tests somewhat similar to ASTM D635 and ASTM D658 and issue ratings for materials satisfying certain criteria (UL 94).

See also flammability.

hot decorating Several decorating processes use heat to transfer a decoration or a printed image to the plastic part surface. These techniques generally use a carrier element, the decorative media, and an adhesive. In certain cases, the adhesive is the molten surface of the part that the decoration comes into contact. The primary processes for hot decorating are hot stamping, in-mold decorating, and heat transfer.

Because these technologies use no wet inks or paints, there are no offensive odors, environmental concerns over volatile emission, or storage problems. In addition, no ink mixing is necessary, and color or design changes involve merely changing a roll of dry printed foil, which minimizes setup time.

hot stamping The hot stamping process is the most widely used in plastics decorating because of its convenience, versatility, and performance. The process of hot stamping consists of placing the part to be decorated under a hot stamping die. The hot die then strikes the surface of the part through a metallized or painted roll-leaf carrier. The paint carried by the roll is fused into the impression made by the stamp. The stamp is programmed to be pressed down on the thermoplastic surface at a controlled pressure and temperature and set to penetrate a controlled distance.

Hot stamping is best suited for flat surfaces, although contoured dies could provide hot stamping for curved surfaces. The fit between the plastic part and the contoured die face must be very close to get uniform hot stampings. For the most part, hot stamping is used to apply small decorations and explanatory lettering, logos, etc. to plastic moldings. Hot stamping may be used to place gold, silver, or other metal foils (leaf) as well as paint pigments onto plastic parts. Because these foils and pigments are dry, they are easy to handle and may be placed over painted surfaces. No masking is required, and the process may be automatic or hand operated. Although hot stamping is used primarily on thermoplastics, the process is also applicable to thermosets.

Figure H.3 shows a typical metallized hot stamping foil. The carrier film supports the decorative coatings until they are pressed on the plastics part. A lacquer coating is passed over the releasing layer to provide protection for the metal foil. If paints are used, the lacquer and paint pigment are combined into one layer. The bottom layer functions as a heat- and pressure-sensitive hot-melt adhesive. Heat and pressure must have time to penetrate the various film coating and layers to bring the adhesive to a liquid state. Before the carrier film is stripped away, a short cooling time is required to ensure that the adhesive is solidified.

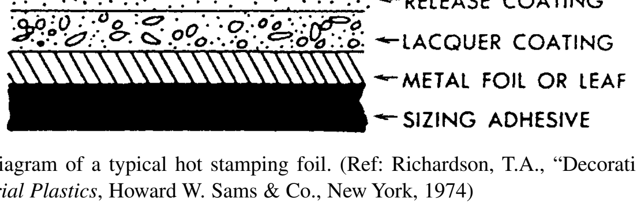

Figure H.3 Diagram of a typical hot stamping foil. (Ref: Richardson, T.A., "Decorating Processes", *Modern Industrial Plastics*, Howard W. Sams & Co., New York, 1974)

Typical hot stamping processes are shown in Fig. H.4. The major components of a hot stamping installation include the equipment, tooling, and hot stamp foil. The hot stamp die is generally either metal or silicone rubber mounted to a heater head. The die is heated to a temperature near the melting point of the plastic substrate. A typical application is an automotive tail light trim piece, where decorative bright silver graphics are stamped onto the exterior plastic surface.

Figure H.4 Hot stamping machines for (a) flat and (b) round plastic parts. (Ref: Muccio, E.A., “Finishing and Decorating Plastic Parts”, *Plastic Part Technology*, ASM International, Materials Park, OH, 1991)

in-mold decorating and coating Much like hot stamping, the in-mold decorating process uses an overlay or a coated foil to become part of the molded product. The decorative image and, if possible, the film carrier are made of the same materials as the part to be molded. The in-mold overlay is placed in the molding cavity either before the molding operation or when the material is partially cured (thermosets). The molding cycle is then completed, and the decoration becomes an integral part of the product.

The design of the mold should take into consideration placement of the gates to prevent wrinkled or washed overlays. The overlay may be held in place in the mold by cutting it so that it fits snugly or by electrostatic means. Blow-molded parts can also be printed or decorated by in-mold processes. The ink or paint image is placed on a carrier film or paper and placed in the mold. As the hot plastic expands, filling the mold cavity, the image is transferred from the carrier to the hot plastic surface.

In-mold coatings with either liquid or powder coating materials is becoming increasingly popular as primers and finish coats for sheet molding compounds and reaction injection-molded materials. In addition to providing decoration and color, in-mold coatings eliminate surface porosity and provide a hard, durable surface.

Liquid in-mold coatings primarily are two-component urethane systems. The liquid coating is injected into the mold at high pressure. The coating will cure somewhat faster than the parent plastic. The extent of the spread of the coating is dependent on the pressure of injection of the liquid in-mold coating. Film thickness will be dependent on the viscosity and compressibility of the parent plastic. To apply liquid in-mold coatings, injection ports must be cut into the molds.

Powder in-mold coating consists of unsaturated polyesters. Powder in-mold coatings are applied electrostatically to the mold surface. Immediately after the powder is applied, the resin charge is put in the mold and the mold is closed. Because the powder in the mold cures at a faster rate than the parent plastic, the powder in-mold coating process does not add additional time to the molding cycle time. With electrostatic spray techniques, powder in-mold coatings are applied in an even, predetermined film thickness without the hazards of solvents. Very thick coatings can be achieved. No modifications of the mold itself are required.

heat transfer In heat-transfer decorating, the image is transferred from a carrier film onto the plastic part. The structure of the heat transfer stock is shown in the following figure. The preheated carrier stock is transferred to the product by means of a heated rubber roller.

See also hot stamping.

hot forming
See thermoforming.

hot-gas welding An electrically heated welding gun can be used to bond many thermoplastic materials. An electrical heating element in the welding gun is capable of heating either compressed air or an inert gas to 218–371°C and forcing the heated gas onto the substrate surface. The pieces to be joined are beveled and positioned with a small gap between them. A welding rod made of the same plastic that is being bonded is laid in the joint with a steady pressure. The heat from the gun is directed to the tip of the rod, where it fills the gap. Several passes may be necessary with the rod to fill the pocket. See Fig. H.5.

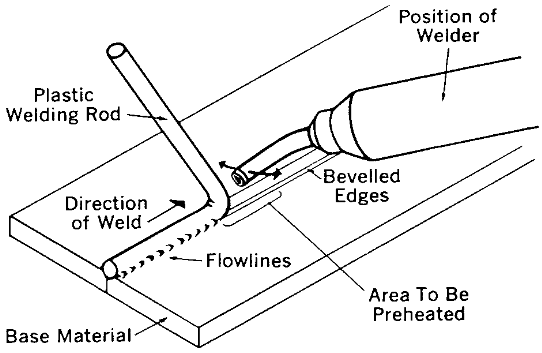

Figure H.5 Hot gas welding process. (Courtesy: Kamweld Plastics, Inc., Norwood, Mass)

Thin sheets that are to be butt welded together, as in the case of tank linings, use a flat strip instead of a rod. The strip is laid over the joint and is welded in place in a single pass. Usually the parts to be joined are held by fixtures so that they do not move during welding or while the weld is cooling. Alternatively, the parts can be first tacked together with a tool similar to a soldering iron.

Hot-gas welding is usually a manual operation in which the quality of the joint corresponds to the skill and experience of the operator. However, automatic welding machines are available and are used for overlap welding of seams or membranes. In either case, bond strength approximately 85 percent of the strength of the bulk material can be achieved. Hot-gas welding is a relatively fast operation. It can be used to weld a 1-in.-wide tank seam at rates up to 60 in./min. It can also be used to do temporary tack work and to repair faulty or damaged joints that are made by gas welding or other joining processes.

Hot-gas welding can be used to join most thermoplastics including polypropylene, polyethylene, acrylonitrile butadiene styrene, polyvinyl chloride, thermoplastic polyurethane, high-density polyethylene, polyamide, polycarbonate, and polymethylmethacrylate. For polyolefins and other plastics that are easily oxidized, the heated gas must be inert (e.g., nitrogen or argon) because hot air will oxidize the surface of the plastic.

Process parameters that are responsible for the strength of hot-gas weld include the type of plastic being welded, the temperature and type of gas, the pressure on the rod during welding, the preparation of the material before welding, and the skill of the welder. After welding, the joint should not be stressed for several hours. This is particularly true for polyolefins, nylons, and polyformaldehyde. Hot-gas welding is not recommended for filled materials or substrates that are less than 1/16 in. thick.

Ideally, the welding rod should have a triangular cross section to match the bevel in the joint. A joint can be filled in one pass with a triangular rod, saving time and material. Plastic welding rods of various types and cross sections are commercially available. However, it is also possible to cut the welding rod from the sheet of plastic that is being joined. Although this may require multiple passes for filling and the chance of air pockets are greater, the welding rod is very low cost, and the user is guaranteed material compatibility between the rod and the plastic being joined.

Hot-gas welding can be used in a wide variety of welding, sealing, and repair applications. Applications are usually large structural assemblies. Hot-gas welding is used very often in industrial applications such as chemical storage tank repair and pipe fittings. It is an ideal system for a small fabricator or anyone looking for an inexpensive welding system. Welders are available for several hundred dollars. The weld may not be as cosmetically attractive as other joining methods, but fast processing and high joint strengths can easily be obtained.

Another form of hot-gas welding is *extrusion welding*. In this process, an extruder is used instead of a hot-gas gun. The molten welding material is expelled continuously from the extruder and fills a groove in the preheated weld area. A welding shoe follows the application of the hot extrudate and actually molds the seam in place. The main advantage with extrusion welding is the pressure that can be applied to the joint. This adds to the quality and consistency of the joint.

hot-melt adhesive The hot melt adhesive can be any polymer that melts at an appropriate temperature and has high adhesion forces. Various thermoplastic polyesters, polyamides, polyethylenes, etc., have been used for this type of adhesive.

The polymer is usually melted and applied to one surface. If the melting is done in bulk, generally the melt tank must be purged with nitrogen to prevent oxidation and the molten adhesive must be pumped to the site of the joint through a heated hose. The adhesive is then applied in the molten form, and the joint is closed and held during cooling for approximately 1 min. or until the adhesive gels. Full strength is not achieved until about 24 hrs. If the substrate has good thermal conductivity, such as a metal, for example, it is best to preheat the substrate before application of the molten adhesive. Otherwise, the cool substrate will cause the adhesive to gel before it has a chance to wet the substrate and develop maximum adhesion.

Hot-melt adhesives are also available in film form. In this form, the joint is assembled with the film in place. On heating, the hot-melt adhesive melts and flows. Some clothing items are bonded in this way with hot-melt fiber formed as a light mat. Hot-melt sealants are also available in rope form. These are often used as construction sealants with a special heat gun for on-site application.

Table H.2 Typical Properties of Hot Melt Adhesives (Ref: Gauthier, M.M., "Types of Adhesives", Adhesives and Sealants, vol. 3, *Engineered Materials Handbook*, ASM International, Materials Park, OH)

Property	EVA/polyolefin Homopolymers and Copolymers	Polyvinyl Acetate	Polyurethane	Polyamides	Polyamide Copolymer	Aromatic Polyamide
Brookfield viscosity, Pa·s.	1–30	1.6–10	2	0.5–7.5	11	2.2
Viscosity test temperature, °C (°F)	204 (400)	121 (250)	104 (220)	204 (400)	230 (446)	204 (400)
Softening temperature, °C (°F)	99–139 (211–282)	. . .	. . .	93–154 (200-310)	. . .	129–140 (265–285)
Application temperature, °C (°F)	. . .	121–177 (250-350)	. . .	. . .	. . .	. . .
Service temperature range, °C (°F)	−34 to 80 (−30 to 176)	−1 to 120 (30 to 248)	. . .	−40 to 185 (−40 to 365)	. . .	. . .
Relative cost[a].	Lowest	Low to medium	Medium to high	High	High	High
Bonding substrates. . . .	Paper, wood, selected thermoplastics, selected metals, selected glasses	Paper, wood, leather, glass, selected plastics, selected metals	Plastics	Wood, leather, selected plastics, selected metals	Selected metals, selected plastics	Selected metals, selected plastics
Applications.	Bookbinding, packaging, toys, automotive, furniture, electronics	Tray forming, packaging, binding, sealing cases and cartons, bottle labels, cans, jars	Laminates	Packaging, electronics, furniture, footwear	Packaging, electronics, binding	Electronics, packaging, binding

(a) Relative to other hot-melt adhesives

hot-runner mold A hot runner mold is a thermoplastic injection mold in which the runners are insulated from the chilled cavities and are kept hot. In this configuration, the center of the runner never cools during the molding. This type of mold is also called an *insulated-runner mold*. The parting line is at the gate of the cavity. The runners are separate plates, so they are not, as is the case usually, ejected with the part.

hot staking Similar to riveting with metals, hot staking is a process used to fasten plastics parts mechanically. A thermoplastic rod inserted through holes in the materials to be joined is melted at each end with a hot tool, leaving a rounded, flanged head at the point of contact.

With molded products, the stakes are usually molded into the part and then formed either by a hot tool or by ultrasonic staking with equipment similar to that used in ultrasonic welding. Often the tool has a specially shaped head that distributes the molten plastic in a uniform circle.

hot stamping

See hot decorating.

hybrid Hybrid is a term used to describe a composite laminate consisting of laminae of two or more composite material systems. Usually only the fibers are different, and the configured composite contains a combination of two or more different fibers, such as carbon and glass or carbon and aramid in a structure. Tapes, fabric, and other forms of reinforcement may be applied.

See also alloy.

hydrocarbon A hydrocarbon is an organic compound having hydrogen and carbon atoms in its chemical structure. Most organic compounds are hydrocarbons. *Aliphatic hydrocarbons* are straight-chained hydrocarbons, and *aromatic hydrocarbons* are ringed structures based on the benzene ring. Methyl alcohol, trichloroethylene, and the like are aliphatic. Benzene, xylene, toluene, and the like are aromatic.

Hydrocarbon plastics are plastics based on resins made by the polymerization of monomers composed of carbon and hydrogen only.

hydrolysis (hydrolytic stability) Hydrolysis is the chemical decomposition of a substance that occurs because of its affinity to water. Some polymeric materials, notably ester-based polyurethanes, will chemically change or *revert* when exposed to warm, high-humidity climates.

Reversion or hydrolysis causes the polymer to lose hardness and strength and, in the worst cases, transform to a fluid during exposure to warm, humid air. The rate of reversion or hydrolytic instability depends on the chemical structure of the polymer, the type and amount of catalyst used, and the permeability of the material. Certain chemical linkages such as ester, urethane, amide, and urea can be hydrolyzed. The rate of attack is fastest for ester-based linkages. Ester linkages are present in certain types of polyurethanes and anhydride-cured epoxies. Generally, amine-cured epoxies offer better hydrolytic stability than anhydride-cured types.

The *hydrolytic stability* of various polymeric materials can be determined by a hardness measurement before and after exposure to high relative humidity aging. This technique for comparing hydrolytic stability is known as the Gahimer and Nieske procedure. See Fig. H. 6. A time period of 30 days in the 100°C, 95 percent RH test environment corresponds to a period from 2 to 4 years in a hot, humid climate.

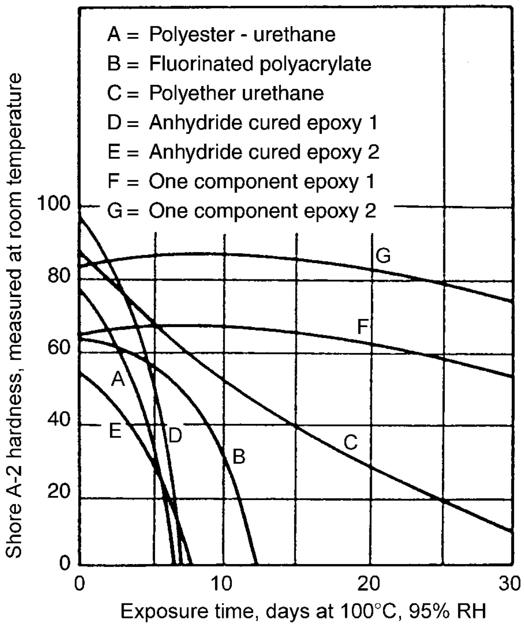

Figure H.6 Hydrolytic stability of potting compounds. Materials showing rapid loss of hardness in this test soften similarly after 2-4 years in high temperature, high humidity climate zones. (Ref: Bolger, J.C., "New One Part Epoxies are Flexible and Reversion Resistant", *Insulation*, October, 1969).

The hydrolytic stability of certain urethane potting compounds was not believed to be a problem until it resulted in the failure of many potted electronic devices during the 1960s military action in Vietnam. The reversion rate also depends on the amount of catalyst used in the formulations. Best hydrolytic properties are obtained when the proper stoichiometric ratio of base material to catalyst is used. Reversion is usually much faster in flexible materials because water permeates it more easily.

Hydrolysis has been established for epoxy, polyurethane, and cyanoacrylate resins. In the case of conventional elastomers, polysulfides, polyurethanes, and acrylic rubbers have all shown sensitivity to moisture. Hydrolysis causes the breaking of bonds within the polymer. Thus the strength decreases. However, before this occurs the part usually swells and may cause deformation before hydrolysis can completely act. For electronic sealants and casting materials, it is highly desirable to keep moisture from penetrating into critical areas. Hydrophobic polymers have been developed to accomplish this task. They are siloxyimides, fluorosilicones, fluoroacrylics, phenylated silicone, and silastyrene.

hydrophilic Hydrophilic literally means a love of water. It refers to substances with an affinity for water. Hydrophilic materials have a tendency to absorb water or to be wetted by water. The term *hydroscopic* is sometimes also used, but this term refers strictly to materials that have a tendency to absorb moisture.

Hydrophilic polymers such as nylon or the cellulosic plastics will absorb relatively large amounts of water. This could cause dimension stability problems or processing problems. It could also lead to hydrophilic degradation in certain polymers such as polyester-based urethanes. On prolonged exposure to high humidity and high temperatures, these polymers will revert back to a liquid state through *hydrolysis*.

Hydrophobic materials behave with the opposite tendency; they repel water.

hydrophobic Hydrophobic materials have a tendency to repel water. They do not adsorb water readily and are not wetted by water. Hydrophobic materials usually exhibit a low surface energy. Polyethylene, polypropylene, and the fluorocarbons are said to be hydrophobic materials. Surface treatment with silanes or fluoropolymers, for example, will give parts the appearance of hydrophobicity. *Hydrophilic* materials have the opposite tendency; they absorb water.

hydroxyl group The hydroxyl group is a chemical group consisting of one hydrogen atom plus an oxygen atom (i.e., —OH).

hygroscopic A hygroscopic material is one that has the tendency to attract, absorb, and retain moisture from air. Plastics such as ABS and nylons are hygroscopic and must be dried before processing. Resins in liquid forms such as certain epoxy and polyurethane curing agents are also hygroscopic materials. They must be kept covered when not in use and in some cases even blanked with nitrogen gas.

The change in properties due to moisture absorption and temperature change is referred to as a *hygrothermal* effect.

See also hydrophilic.

hysteresis *Hysteresis* is a term that denotes energy loss per loading cycle. It is the cyclic noncoincidence of elastic loading and the unloading curves under cycle testing. Hysteresis may also be considered the incomplete recovery of strain during the unloading cycle because of energy consumption within the material.

In dynamic mechanical measurements, the closed curve representing successive stress-strain cycles during cyclic deformation is called the *hysteresis loop*. The area of the resulting elliptical loop is equal to the heat generated in the system.

This mechanical loss of energy is converted into heating of the rubber product and could reach destructive temperatures. Materials that have high hysteresis have good vibration and sound deadening characteristics because the mechanical energy of vibration is effectively converted to thermal energy. *Heat buildup* is the term used to express the temperature rise in a rubber product resulting from hysteresis.

I

IEEE thermal rating A system of thermal ratings has been established by IEEE (Institute of Electrical and Electronic Engineers) as standards for the insulation and polymeric materials that are used in the electrical and electronic industries. In these ratings, materials must have been proven, by IEEE tests, to perform reliably, with minimal electrical property changes and material thermal degradation, for set time periods (thousands of hours of operation).

Performance is based on tests appropriate to the application. Perhaps the most widely used set of IEEE thermal ratings are those used in the magnet wire industry. The IEEE thermal classes are 105°C, 130°C, 155°C, 200°C, and 220°C. IEEE magnet wire standards are described in Appendix D.

See also thermally stable plastic.

ignition temperature The tendency for materials to catch fire (ignite) in air at high temperatures can be assessed through a small-scale test using a so-called hot air ignition furnace or *Stechkin apparatus* (ASTM D1929). The minimum temperature required to produce gases that can be ignited with a pilot (igniter) flame is referred to as the *flash ignition temperature*.

The minimum temperature required to cause the spontaneous ignition of the test specimen is referred to as the *self-ignition temperature*. Ignition may correspond to an explosion, flame, or sustained glow. Table I.1 shows flash and self-ignition temperatures for several polymers.

See also flammability.

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Table I.1 Flash-lgnition and Self-lgnition Temperatures of Several Polymers.

Polymer	Flash Ignition Temperature, °C	Self-lgnition Temperature, °C
Polyethylene	341	349
Polyvinyl chloride	390	455
Polystyrene	350	496
Polypropylene		570
Polycarbonate		580
Polyamide (Nylon)		530

impact modifiers Impact modifiers are used to improve the impact strength of both thermoplastics and thermosets. They absorb the energy generated by impact and dissipate it in a nondestructive fashion.

For good room-temperature and low-temperature impact strength in a rigid, glassy polymer, it must be made heterogeneous (containing two distinct phases) by incorporating a rubbery polymer. The particle size of the rubber polymer must be carefully controlled, and there must be good adhesion between the continuous glassy phase and the dispersed rubbery phase. The rubbery phase must, therefore, be semi-compatible with the glass polymer. The selection of an impact modifier is also dependent on compatibility, physical solubility, impact performance, and cost.

Impact modifiers are primarily used in polyvinyl chloride (PVC), engineering resins, and polyolefins. The use levels of impact modifiers vary widely depending on the modifiers, matrix, and properties desired. The major types are shown in Table I.2 along with the resins in which they are primarily used.

Methacrylate butadiene styrene (*MBS*) impact modifiers represent the highest volume of styrenic-type impact modifiers. The modifier is used in transparent packaging applications because of its clarity. MBS modifiers have FDA clearance and deliver impact efficiency and low temperature impact, with slight improvements over acrylonitrile butadiene styrene (ABS) impact modifiers in color, heat stability, clarity and weatherability.

Acrylonitrile butadiene styrene (*ABS*) is used in a variety of thermoplastic and thermosetting resins, with the majority being in PVC. The primary ABS applications are in automotive parts, credit cards, and packaging. ABS, like MBS, is not suitable for outdoor applications unless it is protected by a UV-resistant cap. Different grades of ABS exhibit significantly different properties, and differing ratios of the three components result in varying amounts of impact strength and opacity. (*See also* acrylonitrile butadiene styrene.)

Acrylics are similar to MBS and ABS but have butyl acrylate or 2-ethyl-hexyl acrylate graft phases. Acrylic modifiers are typically methyl methacrylate butylacrylate styrene or methyl methacrylate ethylhexylacrylate styrene. Acrylics offer greater resistance to UV degradation and are typically used in opaque, outdoor applications such as siding, window profiles, shutters, and gutters. Both all-acrylic and modified-acrylic impact modifiers are available. (*See also* acrylics.)

Table I.2 Major Types of Impact Modifiers by Resin (Ref: Kattas, L, et. al., “Plastics Additives”, *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

	Resin					
Type	PVC*	PE**	PP†	PA‡	PET/PBT§	Other
MBS (methacrylate butadiene styrene)	×	—	—	—	—	—
MABS (methacrylate/acrylonitrile-butadiene-styrene)	×	—	—	—	×	—
ABS (acrylonitrile-butadiene-styrene)	×	—	—	—	×	—
CPE (chlorinated polyethylene)	×	×	×	—	—	—
EVA (ethylene vinyl acetate)	×	—	—	—	—	×
PMMA (polymethylmethacrylate)	×	—	—	—	—	×
EPDM (ethylene propylene diene monomer)	×	×	×	—	—	—
EPR (ethylene propylene rubber)	×	×	×	—	—	—
SBR (styrene butadiene rubber)	—	—	—	—	—	×
Others	—	—	—	—	—	—
Maleated EPDM	—	—	—	×	×	—
Maleated PP and PE	—	—	—	×	×	—
PUR (Polyurethane)	—	—	—	—	—	×
SAN-g-EPDM	—	—	—	—	×	—

*PVC—polyvinylchloride.

**PE—polyethylene.

†PP—polypropylene.

‡PA—polyamide.

§PET—polyethylene terephthalate; PBT—polybutylene terephthalate.

Chlorinated polyethylene (*CPE*) modifiers have good impact resistance at low temperatures, chemical resistance, heat and light stability, and FDA clearance. These modifiers are most commonly used in pipe, fittings, siding, and weatherable profiles. CPE modifiers compete primarily with acrylics in siding applications. (*See also* chlorinated polyethylene.)

Ethylene vinyl acetate (*EVA*) impact modifiers exhibit impact properties that improve with the vinyl acetate (VA) content. The most efficient EVA modifiers are those in the range of 40–50 percent VA. Advantages include good heat and light stability, improved processing, weathering approaching that of acrylics, chemical resistance, and good low-temperature performance. These modifiers are used for opaque weatherable products. (*See also* ethylene vinyl acetate.)

Ethylene propylene diene monomer (*EPDM*) modifiers are used in thermoplastic olefins for automotive bumpers and parts as well as scattered consumer durable products. Maleic anhydride-grafted EPDM reacts with the matrix resin, typically nylon, to become its own compatibilizer. This type of modifier provides for excellent balance in impact, hardness, modulus, and tensile strength, and it is the major additive component of "super tough" nylon. (*See also* ethylene propylene diene monomer.)

One of the largest users of impact modifiers is rigid PVC. In general, impact modifiers are more expensive than PVC. Therefore, they are generally used in the range of less than 1–15 phr. Their effect on processing and end use properties also dictates very careful selection in choosing the right impact modifier.

Recently, impact modifiers have been developed for plastics other than PVC. Polybutylene and other olefinic thermoplastic elastomers, for example, are being used to enhance the processability, toughness, and heat stability of polypropylene film. Hydroxy-terminated polyethers are being used to increase the impact resistance of polystyrene. Other common applications are polycarbonate, polyurethane, thermoplastic polyester, epoxy, and polysulfone.

Rohm and Hass, Kaneka, and Elf Atochem are the leading suppliers of impact modifiers worldwide. Each has a strong position in both the acrylic and MBS-related modifiers. Other major suppliers include Akzo, BASF, Ferro, Morton International, Sakai Chemical, and Witco.

impact resistance Impact resistance is the resistance of a plastic to fracture by shock loading. It is generally measured empirically by tests to determine the *impact strength* of the plastic. The ability of a plastic to withstand an impact load depends on its toughness. Toughness can be approximated from the area under the stress-strain curve. The major difference is that in an impact test the rate of applied load is significantly faster than that typically used in a tensile test.

The impact strength is related to the temperature of the polymer in that the test temperature significantly affects the toughness of the polymer. Impact strength is also related to the rate of applied loading. Generally the higher the rate of loading the more the polymer will fail like a brittle material because of the lack of time for intermolecular forces to be affective. Brittle plastics tested at low temperatures and fast loading rates will have the lowest impact resistance.

Impact strength of plastics is commonly measured by tests in which a pendulum with a massive striking edge is allowed to hit the specimen. From the travel of the pendulum after breaking the specimen, impact strength can be calculated as the energy required to cause the break. The plastic specimen is often notched in an effort to improve the reproducibility of the mode of failure.

Widely used impact tests are for rigid materials, *Izod* (ASTM D256) and *Charpy* (ASTM D256) and for flexible structures, *falling dart impact* (ASTM D3029) and *pendulum impact* resistance (ASTM D3420).

The *Izod impact test* is the most common variety of impact test. It is a pendulum test with the pendulum dropping from the 12 o'clock position to hit a sample held in a clamp at the 6 o'clock position. The pendulum breaks the sample, and the distance it travels beyond the specimen is a measure of the energy absorbed in breaking the sample. The value calculated from this test is usually expressed in ft-lb/in. of sample width. There are five different ways of performing this test.

The *falling dart test*, ASTM D3029, reveals the behavior of materials on impact from many product applications such as appliance housings and the like. For testing, a flat specimen is suspended over a circular opening below a graduated column with a cantilever arm attached. A weight, also known as a dart or tup, is attached to the arm from which it is released to strike the sample. The arm can be raised or lowered and the width of the tup varied until 50 percent of the sample quantity fails the test.

A free-falling dart method for polyethylene films is described in ASTM D1709. Unlike low-speed uniaxial tensile tests, the pendulum impact test measures the resistance of film to impact puncture, simulating high-speed end use application. Dart drop measures the energy lost by a moderate velocity blunt impact passing through the film.

The *tensile impact strength test*, ASTM D1822, uses an apparatus very similar to that used for the Izod tests except that in this case the specimen is attached to the pendulum on one end and has a T-bar attached on the other end. When the pendulum drops the T-bar catches on the apparatus at its base, causing the specimen to undergo tensile impact. This test is typically performed on materials that are too elastic to fail in the Izod test.

It should be noted that plastics and elastomers have impact strengths that are very dependent on temperature and rate of impact. At low temperatures, below the glass transition temperature, most plastics and elastomers will behave as brittle materials with a significant reduction in impact strength. Likewise, when tested at very fast rates, most plastics and elastomers will act as brittle materials because the polymeric molecules are not allowed to slip by on another but simply break. At times, low temperatures have been used to simulate fast rates of strain (e.g., explosive discharge) that cannot be accomplished easily on standard laboratory test machines.

impregnating resin Impregnating resins are low-viscosity liquid plastics that can be forced, usually under pressure and/or vacuum, into dense assemblies (such as transformer and motor windings and fabrics) to completely fill all void areas, resulting in a thoroughly filled assembly. In the case of thermosetting impregnating resins, after the impregnation is complete, the entire assembly is put through a curing cycle to harden the resin, resulting in a dense, ruggedized structure.

Most impregnating resins are very low-viscosity thermosetting liquids such as epoxy resins. However, thermoplastic resins may also be used as impregnating resins. They are usually used in their melt form or solution form to achieve impregnation.

See also potting resin; casting resin.

impregnation Impregnation is the process of thoroughly soaking a material such as wood, paper, or fabric with a synthetic resin so that the resin gets within the body of the material by absorption and/or wetting. The process is usually carried out so that any entrapment of air in the specimen is minimized. Often a vacuum is used to facilitate the removal or air and gases. Usually a forming and curing process follows the impregnation process.

See also impregnating resin.

impulse sealing Impulse sealing is a sealing technique for use on thermoplastic materials. With impulse sealing a pulse of intense thermal energy is applied to the sealing area for a very short time, followed immediately by cooling. It is usually accomplished by using a resistive, inductive, or high-frequency heated metal bar, which is cored for water cooling or with such a mass that it will cool rapidly at ambient temperatures. Thermal impulse sealing is also sometimes known as *heated tool welding* or *hot plate welding*.

See also heated-tool welding; dielectric heat sealing/welding.

incandescent contact The assessment of the resistance of rigid plastics to contact with an incandescent surface (ASTM D757) is of special importance for applications involving electric heating elements and particularly concerns materials used for insulation purposes. A horizontal silicon carbide rod, heated to a temperature of 950°C by an electric current, is used as the incandescent surface. The horizontal test specimen is gently pressed against the rod for a period of 3 min. The test specimen may burn, fuse, char, or shrink. Depending on the burning mode, results are reported as average burning rate, average time of burning, or average extent of burning.

See also flammability.

inclusion An inclusion is a physical and mechanical discontinuity occurring within a material or part, usually consisting of solid, encapsulated foreign material. Inclusions are often capable of transmitting some structural stresses and energy fields, but to a noticeably different degree than the parent material.

index of refraction The index of refraction in a transparent plastic material is the ratio of the velocity of light in vacuum or air to its velocity in the transparent medium.

See also transparency.

induction welding The electromagnetic induction field can be used to heat a metal grid or insert placed between mating thermoplastic substrates. Radio frequency energy from the electromagnetic field induces eddy currents in the conductive material, and the material's resistance to these currents produces heat. When the thermoplastic is positioned between induction coils, the hot insert causes the plastic to melt and fuse together. Slight pressure is maintained as the induction field is turned off and the joint hardens. The main advantage is that heating only occurs where the electromagnetic insert is applied. The bulk substrate remains at room temperature, avoiding degradation or distortion.

Induction welding is very much like resistance wire welding. An implant is heated to melt the surrounding polymer. Rather than heating the implant resistively, in induction welding the implant is heated with an electromagnetic field. More popular forms of induction welding have been developed that use a bonding agent consisting of a thermoplastic resin filled with metal particles. This bonding agent melts in the induction field and forms the adhesive joint. The advantage of this method is that stresses caused by large metal inserts are avoided.

The bonding agent should be similar to the substrates. When joining polyethylene, for example, the bonding agent may be a polyethylene resin containing 0.5–0.6 percent by volume magnetic iron oxide powder. Electromagnetic adhesives can be made from iron oxide-filled thermoplastics. These adhesives can be shaped into gaskets or film that will melt in the induction field.

Four basic components comprise the electromagnetic welding process:

- An induction generator converts 60-Hz electrical supply to 3 to 40-MHz output frequency and output power from 1 to 5kW.
- The induction heating coil, consisting of water-cooled copper tubing, is usually formed into hairpin-shaped loops.
- Fixturing is used to hold parts in place.
- The bonding material is in the form of molded or extruded preforms, which become an integral part of the welded product.

Induction heating coils should be placed as close as possible to the joint. For complex designs, coils can be contoured to the joint. Electromagnetic welding systems can be designed for semi automatic or completely automatic operation. With automated equipment, a sealing rate of up to 150 parts/min can be achieved. Equipment costs are generally in the ten thousand to hundreds of thousands of dollars range depending on the degree of automation required.

The bonding agent is usually produced for the particular application to ensure compatibility with the materials being joined. However, induction welding equipment suppliers also offer proprietary compounds for joining dissimilar materials. The bonding agent is often shaped into a profile to match the joint design (i.e., gaskets, rings, ribbon). The fillers used in the bonding agents are micrometer-sized ferromagnetic powders. They can be metallic, such as iron or stainless steel, or a ceramic ferrite material.

Quick bonding rates are generally obtainable because heating occurs only at the interface. Heat does not have to flow from an outside source or through the substrate material to the point of need. Polyethylene joints can be made in as fast as 3 s with electromagnetic welding. Depending on the weld area, most plastics can be joined by electromagnetic welding in 3 to 12-s cycle times.

Induction welding is especially useful on plastics that have a high melt temperature such as the modern engineering plastics. Thus induction welding is used in many under-the-hood automotive applications. It is also frequently used for welding large or irregularly shaped parts.

Plastics that are readily bonded with induction methods include all grades of acrylonitrile butadiene styrene (ABS), nylon, polyester, polyethylene, polypropylene, and polystyrene, as well as those materials often considered more difficult to bond such as acetals, modified polyphenylene oxide, and polycarbonate. Reinforced thermoplastics with filler levels up to 65 percent have been joined successfully. Many combinations of dissimilar materials can be bonded with induction welding processes.

Table I.3 shows compatible plastic combinations for electromagnetic adhesives. Thermoset and other nonmetallic substrates can also be electromagnetically bonded. In these applications the bonding agent acts as a hot-melt adhesive.

Advantages of induction welding include:

- Heat damage, distortion, and oversoftening of the parts are reduced.
- Squeeze-out of fused material from the bond line is limited.
- Hermetic seals are possible.
- Control is easily maintained by adjusting the output of the power supply.
- No pretreatment of the substrates is required.
- Bonding agents have unlimited storage life.

The ability to produce hermetic seals is cited as one of the prime advantages in certain applications such as in medical equipment. Welds can also be disassembled by placing the bonded article in an electromagnetic field and remelting the joint. There are few limitations on part size or geometry. The only requirement is that the induction coils must be designed to apply a uniform field. The primary disadvantages of electromagnetic bonding are that the metal inserts remain in the finished product and they represent an added cost. The cost of induction welding equipment is high. The weld is generally not as strong as those obtained by other welding methods.

Electromagnetic induction methods have also been used to quickly cure thermosetting adhesives such as epoxies. Metal particle fillers or wire or mesh inserts are used to provide the heat source. These systems generally have to be formulated so that they cure with a low internal exotherm, or else the joint will overheat and the adhesive will thermally degrade.

See also heat welding (indirect).

infrared analysis Infrared analysis is a technique frequently used for polymer identification. An *infrared spectrometer* directs infrared radiation through a film or

Table I.3 Compatible Plastic Combinations for Bonding with EMABOND® Electromagnetic Bonding Process. (Ref: "EMABOND® Thermoplastic Assembly Systems," Specialty Polymers and Adhesive Division, Ashland Specialty Chemical Company, Norwood, NJ)

		ABS	Acetals	Acrylic	Cellulosics	Ionomer (Surlyn)	Nylon 6.6, 11, 12	Polybutylene	Polycarbonate	Polyethylene	Polyphenylene Oxide (Noryl)	Polypropylene	Polystyrene	Polysulfone	Polyvinyl Chloride	Polyurethane	SAN	Thermoplastic Polyester	Thermo Plastic Elastomers		
● = Compatible																			Copolyester	Styrene Bl. Copolymer	Olefin Type
ABS		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Acetals			●																		
Acrylic		●		●					●				●				●				
Cellulosics					●																
Ionomer (Surlyn)						●															
Nylon 6.6, 11, 12							●														
Polybutylene								●													
Polycarbonate		●		●					●				●	●			●				
Polyethylene										●										●	
Polyphenylene Oxide (Noryl)											●		●								
Polypropylene												●									●
Polystyrene				●					●		●		●				●				
Polysulfone									●					●							
Polyvinyl Chloride															●						
Polyurethane																●					
SAN		●		●					●				●				●				
Thermoplastic Polyester																		●			
Thermo-Plastic Elastomers	Copolymer																		●		●
	Styrene Bl. Copolymer										●									●	
	Olefin Type												●						●		●

layer of specimen and measures and records the relative amount of energy absorbed by the specimen as a function of wavelength or frequency of infrared radiation. The chart produced is compared with correlation charts for known substances to identify specimens.

The infrared spectrophotometer can provide information concerning the composition of a compound as well as its degradation products, fillers, reinforcing agents, etc. It can also be used to evaluate the purity of organic components that are used in a plastic's manufacturing or processing.

infrared welding Infrared radiation is a noncontact alternative to hot-plate welding. Infrared is particularly promising for higher-melting polymers, because the parts do not contact and stick to the heat source. Infrared radiation can penetrate into a polymer and create a melt zone quickly. By contrast, hot-plate welding involves heating the polymer surface and relying on conduction to create the required melt zone.

Infrared welding is at least 30 percent faster than heated-tool welding. High reproducibility and bond quality can be obtained. Infrared welding can be easily automated, and it can be used for continuous joining. Often, heated-tool welding equipment can be modified to accept infrared heating elements.

Infrared radiation can be supplied by high-intensity quartz heat lamps. The lamps are removed after melting the polymer, and the parts are forced together, as with hot-plate welding. The depth of the melt zone depends on many factors including minor changes in polymer formulation. For example, colorants and pigments will change a polymer's absorption properties and will affect the quality of the infrared welding process. Generally, the darker the polymer, the less infrared energy is transferred down through a melt zone, and the more likely is surface degradation to occur through overheating.

inhibitor An inhibitor is a substance that slows down the chemical reaction. Inhibitors are sometimes used in certain types of monomers (e.g., styrene monomer) and resins (e.g., polyester resin) to prolong storage life. These are critical components that control the curing rate and working life as well as the storage life of certain resins.

Inhibitors are useful in determining *induction rates*, because their reaction with radicals is so rapid that the decomposition of the inhibitor is not dependent on its concentration but gives the rate of generation of radicals directly. As a result, the length of the *induction period* before polymerization starts is directly proportional to the number of inhibitor molecules initially present. This number then represents the number of radicals produced during the time of the induction period.

Resins most in need of inhibitors to control the reaction are those that cure by free radical polymerization. Here light, contaminants, etc. can start the polymerization reaction. The inhibitor will react with a radical to form products incapable of adding monomer. If the inhibitor is very effective, no polymer will be formed; this condition is sometimes called *inhibition*. Benzoquinone is an inhibitor for the polymerization of styrene.

initiation Initiation is the first step in the free radical polymerization process. During initiation, free radicals are generated, usually by the decomposition of an initiator. The free radicals that are formed then react with the monomer to form other free radicals that are capable of chain growth.

See also free radical polymerization.

initiator The initiator is a substance that speeds up the polymerization of a monomer and becomes a component of the chain. The efficiency with which radicals initiate chains can be estimated by comparing the amount of initiator decomposed with the number of polymer chains formed. Most initiators in typical vinyl polymerizations have efficiencies between 0.6 and 1.0 (i.e., between 60 and 100% of all the radicals formed ultimately initiate polymer chains).

injection blow molding Injection blow molding, as the name implies, uses an injection molding press to produce the parison; however, this is not accomplished in the same manner as with the *extrusion blow molding process*.

In injection blow molding, the parison is injected into a preform cavity and around a core pin in the exact quantity required to form a container. The preform mold is kept at a precisely controlled temperature, which is just a little cooler than the melt temperature. After injection, the mold opens, and the core pin and the still warm preform are rotated 120°. A blow mold then closes over the preform, and air is injected through the core pin. After the container is blown, it is rapidly cooled by contact with the walls of the blow mold, which are kept at around 102–122°C by cold air or fluid circulating through the mold passageway. The mold then opens, a second 120° rotation occurs, and the part is stripped from the core pin. Then a third 120° rotation of the transfer head returns the core pin to the preform injection mold, and the cycle is repeated.

The injection blow molding process has several advantages. It produces parts that can be completely finished, with no scrap to be removed from the process. The parts can be made with closer-tolerance neck finishes than by extrusion blow molding. Uniform wall thickness can be obtained and held during long production runs. Preforms can be used for unsymmetrical parts. There is no pinch-off seam at the bottom, which might become a weak area. The major disadvantage is the limitation in size of the part that can be produced. Also, the technique is not suited for the production of containers with handles. Mold costs are higher than extrusion blow molding because two molds are required.

injection molding Injection molding, shown schematically in Fig. I.1, is a versatile process for molding primarily thermoplastic materials. (Thermoset injection molding, as described below, has been developed but is not as commonly used as other methods for processing thermoset resins.) Injection molding accounts for one-third of all resins consumed in thermoplastic processing.

During the injection molding process, the molten plastic is forced (injected) into a mold and cooled until the melt solidifies. When the part is cooled sufficiently, the mold is opened, the part is ejected from the mold, and the mold is closed again to

Figure I.1 Diagram of an injection molding machine. (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience Publishers, New York, 1965)

repeat this cycle. Thus injection molding permits mass production, high precision, and three-dimensional virtual net shape manufacturing of plastic parts. The cycle speed is determined by the rapidity with which the temperature of the material used can be reduced, which in turn depends on the thermal conductivity of that material. Acrylics are slow performers, and styrenes are among the fastest.

Injection molding requires an injection molding machine, a mold, and ancillary equipment such as materials feeding and conveying equipment, dryers, mold temperature controllers, chillers, and robotics and conveyors.

Injection molding temperatures are higher than those for compression molding, rising well above 250°C for many materials. Pressures applied to the plunger may range from 10,000 to 30,000 psi. An outstanding feature of injection molding is the speed with which finished articles can be produced. Cycle times of 10–30 s are common. The method has been used in the past for small articles, with a few ounces of polymer for a single molding. Today, however, large objects such as television and computer cabinets and door liners for refrigerators, weighing many pounds, are being successfully injection molded.

Advances in injection molding equipment and in thermosetting molding compounds have resulted in a rapid transition to *screw-injection*, in-line injection molding of thermosetting resins. This has been especially prominent with phenolics, but other thermosets are also included to varying degrees. The growth in screw-injection molding of thermosetting resins has been extremely rapid because of advances from automation, reduction in labor costs, improved quality, reduced rejects, and overall molding cycle efficiently. (*See* screw-injection molding.)

Jet molding is a modification of injection molding that is adaptable to both thermoplastic and thermosetting resins. In this process, after the resin is warmed in a cylinder to incipient fusion, it is forced under very high pressure by a plunger through a very hot nozzle into the mold. The nozzle is heated rapidly by induction at the instant of injection and then chilled equally rapidly at the completion of the injection stroke. By this means, the resin is almost instantaneously heated to very high temperature immediately before injection, forced into the mold, and allowed to cool. Thermosetting material can, by proper choice of conditions, be given time to cross-link before cooling.

injection molding machines Injection molding machines have three basic components: the injection unit, the clamping unit, and the control system. The *injection unit* plasticates and injects the polymer melt whereas the clamping unit supports the mold, opens and closes the mold, and contains the part ejection system. The machine itself is usually a horizontal cylinder, the bore of which determines the capacity. Within the bore is a piston that, when retracted, opens a hole in the top of the cylinder through which new material can be added to replace the charge shot into the mold. The cylinder is heated by electric bands that permit temperature variation along its length. Inside the exit end of the cylinder is a *torpedo* over which the hot material is forced just before coming out of the nozzle into the channel leading to the mold cavities. This gives the material a final churning and ensures thorough heating.

The injection unit has two major components: the *plasticating unit* and the sled. The former melts and injects the resin, whereas the latter translates the plasticating unit. The plasticating unit consists of hopper, a feed throat, barrel, screw, screw drive, motor, and nozzles.

Several devices for mixing or plasticating the melt within the injection molding cylinder have gained popularity. One is a *rotating spreader*, in which the spreader or *torpedo* is fitted with blades and rotated by means of a shaft passing through the ram to an external drive. A second technique is to replace the ram with a movable *screw*, much like an extruder screw, which runs during part of the cycle to provide plastication and then moves forward to deliver the molten polymer to the die. In a further variation, an essentially conventional extruder feeds plasticated molten polymer into the chamber of an essentially conventional injection molding machine ahead of the ram. The feed can be from the top or the side.

Injection molding barrels are shorter than extruder barrels. The typical L to D ratio is 22:1 to 26:1 for fast-running machines and 28:1 for vented barrel injection machines. Unlike extruder barrels, the feed port is cut through the barrel and connects with water-cooled feed housing. The discharge end of the barrel fastens directly to the end cap or nozzle adapter, the counter bore at the end of the barrel centers the end cap.

Screw designs are similar to those used in extrusion, except that the screw does not end in a nose cone. Instead it has a counter bore that accepts a smear tip or nonreturn valve. During injection and holding, the nonreturn valve prevents melt from

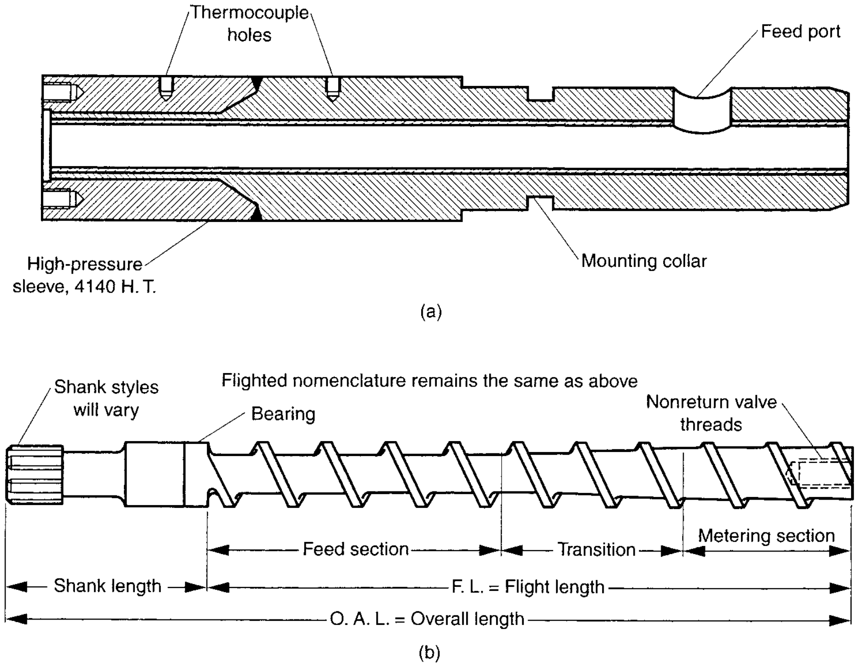

Figure I.2 Components of an injection unit: (a) barrel and (b) screw. (Ref: Barry, C.M.F. and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

flowing back along the screw. The injection molding screw is rotated with an electric motor coupled with a reducer or gearbox or a direct hydraulic drive.

The *injection unit* (or *sled*) retracts away from the mold along its rails. This permits purging of material from the barrel when changing the resin type or getting rid of contaminated or degraded material.

Injection units are specified by shot size, maximum injection pressure, plasticating capacity and recovery rate, maximum injection velocity, and other less important factors. The maximum injection pressure is the maximum available pressure for injections.

Clamping units support the mold, hold the mold closed during injection, open and close the mold as rapidly as possible, provide for part ejection, and provide mold close protection. The four types of clamps are hydraulic, hydraulically actuated toggle (mechanical), electrically actuated toggle, and hydromechanical.

injection mold resin flow The basic resin flow parts of the injection mold are illustrated in Fig. I.3. The *sprue* receives the polymer melt from the *nozzle* and delivers it to the *runner*. Runners deliver melt to the mold cavity. (*See also* sprue, runner.)

A *gate* connects the runner to each mold cavity. With a sprue gate, the gate connects directly to the cavity. This type is commonly used on larger parts in single

Figure I.3 Sprue, runners, gates, and cavities. (Ref: Belofsky, H., *Plastics: Product Design and Process Engineering*, Hanser Publications, New York, 1995)

cavity molds to reduce the pressure losses and residual stresses. However, the gate leaves a mark on the surface of the part. (*See also* gate.)

injection molds *Injection molds* distribute the melt, give final shape to the part, cool the material, and eject the final part. They must also withstand the forces of injection and ejection, transfer motion, such as ejector plates, and guide the moving parts of the mold. A standard two-plate mold has two halves. The division between these halves is called the *parting line*. The mold opens and closes automatically, and timers control the whole cycle.

The mold halves are designated the "A" side and the "B" side. The A side or cavity half of the mold contains the *top clamp plate* A or *cavity plate*, *sprue bushing*, *locating ring*, and *leader pins*. The B side or core half includes the *support plate*, *bottom clamp plate* B or core plate, leader bushings, and ejection systems. Because the A and B plates define the shape of the molded parts, they contain the machined mold cavity, parts of the delivery systems, and coolant lines. The top and bottom clamp plates support the mold and are used to attach the mold to the machine platens. Figure I.4 illustrates a generic type of injection mold configuration.

The *support plate* backs up the B plate in the mold, and melt is delivered from the nozzle to the sprue bushing. The locating ring aligns the mold with the nozzle, whereas the leader pins and bushing align the two sides of the mold. In the ejection system, the *sprue puller* and *ejector pins*, are attached to the *ejector plate*, which is, in turn, connected to the machine's ejection plates by the *ejector rod*. When the mold is opened, the sprue puller draws the part to the B side of the mold, whereas the

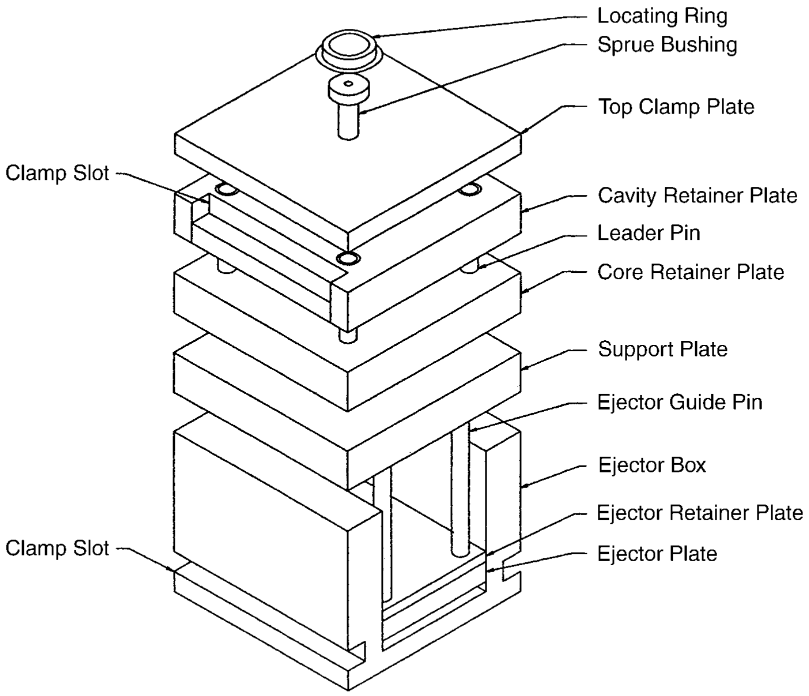

Figure I.4 Generic Parts and Construction of an Injection Mold (Ref: Muccio, E.A., *Plastic Part Technology*, ASM International, Materials Park, OH)

ejection pins push the part out of the mold during ejection. The ejection system also contains supports and guide systems for ejector plate movements.

Injection molds are often classified by the basic design of the mold. A *standard two-plate mold* opens in one direction, and the part is demolded by gravity, ejector pins, or ejector sleeves. The sprue, runner, and parts are connected after ejection with the sprue and runners forming part scrap. Two-plate molds are used for all kinds of moldings that do not contain undercuts and provide the best overall part properties.

A *stripper plate mold* is a two-plate mold in which the core and ejector plates are combined into a stripper plate. It is used for thin wall parts and parts with symmetry and no undercuts. A *three-plate mold* has two parting lines, thereby providing automatic separation of the parts and runner system. This does not work with all materials; brittle materials tend to fracture on ejection. It also limits the selection of gate locations and does not eliminate scrap. A *stack mold* is used to mold two layers of parts without increasing clamp force. Because stack molds are not as precise as two-plate molds, they are used for low-tolerance parts such as polystyrene drinking cups.

Parts containing undercuts are not usually ejected directly after the mold is open. With flexible polymers, the part can be stripped off the core. For vinyls, polyruethanes, polyolefins, and elastomers, this requires an angle of 33° on molded threads, and the threads should be interrupted to give better flexing of the outer wall. *Slide core molds* are used for parts with internal and external undercuts such as ribs, gaps, openings, blind holes, and threads. These contain a slide and a cam lifter. During the mold opening, the slide on the cam lifter moves and releases the undercuts.

Split-cavity molds are used when the threads or other undercuts are on the outside of the part and fast molding cycles are desired or when large areas of the parts have to be formed by the split-cavity block. In this mold, an ejector rod or a hydraulic cylinder moves the split-cavity block, thereby releasing the undercuts. Collapsing cores and expanding cavities are used for inside and outside threads, respectively. These are threads or undercuts machined into spring steel inserts. The inserts are held in place by a rod or expansion limiter sleeve during molding but are released and therefore spring out of the way for injection. During the closing of the mold, expanding cavities are pushed back into position by a *striker insert*. Threads are also made with unscrewing (or twist-off) molds. The cavity elements unscrew during the mold opening. The turning mechanism is hydraulic, pneumatic, or mechanical.

Molds are also classified by their runner systems. In a *cold-runner mold*, the sprue and runner solidify and are ejected with the part. Insulated runners have much larger diameters than standard runners. As a result, the outer part of the runner solidifies while the center remains fluid. This reduces the scrap generated during molding and facilitates the changing of materials or colors. *Insulated-runner molds* are more difficult to operate because the gate tends to freeze off. With hot-runner molds, the runner is always in the melt state.

Molds are also distinguished by the number of cavities cut in the mold. *Single-cavity molds* contain one cavity, whereas multiple cavity molds can mold several parts simultaneously. In *family molds*, several different parts are molded at one time.

Injection molds are machined from a variety of tool steels and then hardened or in some cases plated with chromium, nickel, or proprietary materials. Large molds use prehardened tool steels because they cannot be hardened after machining. Stainless steel is used for some smaller molds, particularly those used for optical and medical parts and for corrosion resistance. Because they provide better heat transfer and thus shorter molding cycles, materials such as beryllium copper are used as inserts in critical areas.

Injection molds are usually cooled or heated with water, although oil or electric heater cartridges are used for high mold temperatures. Mold temperature controllers pump water into the manifolds and then into cooling lines machined into the mold.

inserts Inserts are components incorporated into plastic parts to add to their mechanical or electrical effectiveness and sometimes to enhance their appearance. More specifically, they are used to provide internal and external threaded sections, terminal studs, wire attachments, shafts for rotating parts, contacts, rivets for attachments, bearing, etc. Inserts are usually made of metals, but other materials have also been used. Generally inserts are molded into the part, but in some cases they are pressed in afterwards with one of the heat welding techniques such as heated-tool or ultrasonic welding.

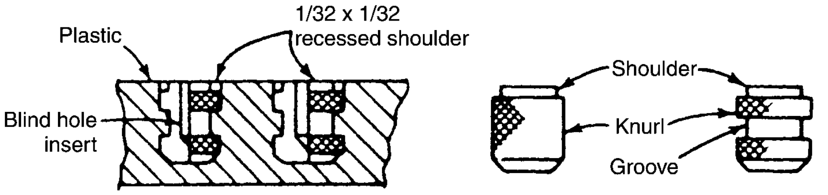

Figure I.5 Molded-in inserts. (Ref: Hull, J.L., "Design and Processing of Plastic Parts", *Handbook of Plastics, Elastomers, and Composites*, C.A. Harper, ed., McGraw-Hill, New York, 1996)

An adequate plastic wall thickness must be designed around the insert to prevent cracking of the plastic due to differences in coefficient of thermal expansion. Location of a *molded-in insert* is governed in part by flow conditions during the molding operation. Because the plastic flow exerts tremendous pressure on any obstruction, delicate inserts should not be placed in its path. Molded-in inserts should be anchored by means of a diamond knurl or an undercut. *Pressed-in inserts* should be provided with a straight knurl or serration, which will prevent them from turning relative to the plastic. Insets should be provided with a sealing surface to prevent the plastic from flowing into certain sections, such as threads.

in situ joint An in situ joint is a joint made between a composite and another surface that is formed during cure of the composite part, as opposed to a conventional adhesive joint made after the parts are formed and cured.

Instron tester Instron testers measure the flexural, tensile, and compressive strength of plastics as well as the stress-strain curves at ambient temperatures. They are commonly found in most materials testing laboratories. Instron testers come in a range of sizes (generally related to the maximum tensile pull that can be exerted) and types. They are manufactured by the Instron Machine Company.

Instron testers comprise two arms that move apart (or close) with a predetermined speed. A variety of grips and attachments are available depending on the property to be measured. When fitted with an environmental chamber, the flexural and tensile tests can run at elevated or reduced temperatures.

insulating materials (electrical) Insulating materials are materials that will not conduct an electrical current. Most plastics are insulating materials. These materials are used to confine the flow of current within a conductor, or to separate or isolate conductors, so that current flow is restricted to the conductor to the maximum extent possible.

Isolating current flow and maintaining stable, controlled electrical properties becomes increasingly difficult under extreme electrical and operating or environmental stresses. This leads to major requirements on the electrical or electronic properties of plastics, and on the stability of these properties to various service conditions.

See also electronic plastics, dielectric.

insulating materials (thermal) Thermal insulation is a barrier to the flow of heat. Thermal insulation is usually a cellular material such as a mat, foam, or composite having many gas cells.

See also thermal conductivity.

insulation resistance Insulation resistance is the electrical resistance of an insulating material to a direct voltage. It is determined by measuring the leakage of current, which flows through the insulation when the insulation is placed between two conductors or systems of conductors. As determined by ASTM D257, it is the ratio of the applied voltage to the total current between two electrodes that are fastened to or embedded in a dielectric material.

See also resistance (electrical); resistivity; high-resistivity plastics.

insulators Insulators are materials, such as plastics, that have low electrical or thermal conductivity. Electrical insulators have such low electrical conductivity that the flow of current can usually be neglected. They are used for supporting conductors, covering conductors, or separating conductors. Similarly, thermal insulators are materials of low thermal conductivity, such as used to insulate ovens or coolers.

See also insulating materials (thermal); insulating material (electrical).

integral skin molding An approach to foam molding that has seen rapid acceptance is integral skin molding. In this process, a single foaming composition is charged into a mold and forms a tough, continuous outer skin while the core is expanded to a cellular structure. Thus the foam's outer skin has a higher density than the core.

interface The interface is the boundary surface between two different, physically distinguishable media. With fiber-reinforced plastic the interface is the contact area between the fibers and the sizing or finish. In a laminate, the interface is the contact area between the reinforcement and the laminating resin. In an adhesive joint, the interface in the plane between the adhesive and adherend.

interference fit Interference fits are used to join or mate two parts in which a male part has an external dimension larger than the internal dimension of the mating female part. Distension of the female by the male creates a stress, which supplies the bonding force for the joint.

See also mechanical joining of plastics.

interpenetrating polymer network (IPN) An interpenetrating polymer network (IPN) refers to a polymer configuration where two or more polymers have been formed together so that they penetrate each other in the final polymer configuration.

interphase The interphase is the boundary region between a bulk resin or polymer and an adherend in which the polymer has a high degree of orientation to the adherend on a molecular basis. It plays a major role in the load transfer process between the bulk of the adhesive and the adherend or the fiber and the laminate matrix resin. The interphase region is larger than and different from the *interface*. Generally the interphase is considered a three-dimensional volume, whereas the interface is a plane or two-dimensional area.

intrinsic viscosity Intrinsic viscosity of a polymer is the limiting value at infinite dilution of the ratio of the *specific viscosity* of the polymer solution to its concentration in moles per liter.

$$\text{Intrinsic viscosity} = (\text{viscosity}_{\text{specific}}/\text{concentration})_{\text{concentration} = 0}$$

Intrinsic viscosity is usually estimated by determining the specific viscosity at several low concentrations and extrapolating the values of the specific viscosity to concentration (c) = 0. The intrinsic viscosity is independent of concentration by virtue of extrapolation to c = 0. Intrinsic viscosity measurement leads to the viscosity average molecule weight.

See also specific viscosity.

intumescent coating Intumescent coatings are fire-resistant coatings applied to a part in a thickness of 50–60 mil, which, during a fire, will foam to a thickness of 1/2 to 1 in. and protect the part from the flame and high temperature. Intumescent coatings are usually formulated from silicone base resins.

See also ablative materials.

ion exchange resin Ion exchange is a process that makes possible either the substitution of one ion for another or the removal of practically all ions from a dilute solution. Because most natural fluids, including water, contain inorganic or organic acids, bases, or salts that are present as ions, the potential purification uses of the ion exchange process are significant.

Ion exchange resins are cross-linked polymers that form salts with ions from aqueous solutions. The ion exchange resins that are used to effect such exchanges are of two types: cation exchange and anion exchange resins. By using the two types either singly or in combination, it is relatively simple to alter, remove, or recover the ionic content of dilute solutions at will.

A *cation exchange resin* may be described as a solid organic acid, resinified and containing replaceable hydrogen (or sodium), which it will readily release in exchange for any other cation (sodium, potassium, ammonium, etc.). This exchange involves no change of structure in the resin itself. Synthetic cation exchange resins are generally derived from phenol and similar aromatic compounds and contain sulfonic or carbolic acid groups.

Anion exchange resins are resinous organic bases that can be activated for use in either of two ways: (1) acid removal and (2) anion exchange. Anion exchange resins are generally polyamino compounds, such as the type obtained from the reaction between phenol, ethylenediamine, and formaldehyde.

When the copolymer of styrene and divinyl benzene is treated with chlorosulfonic acid, a polymer is produced that has cation-capturing properties because of the free sulfonic acid groups. The product is polymerized in bead form. It is easy to handle and remains insoluble during all phases of an ion exchange reaction. Anion exchanges may be made by including a chloride-bearing monomer with the styrene divinyl benzene copolymer. Reaction with a tertiary base gives a salt, which yields a strong, insoluble polymeric hydroxide when treated with sodium hydroxide.

ionomer Ionomers are thermoplastic polymers that have ethylene as their major component but contain both covalent and ionic bonds. The polymer exhibits very strong interchain ionic forces. The anions hang from the hydrocarbon chain, and the cations are metallic (sodium, potassium, magnesium).

These resins have many of the same features of polyethylene plus high transparency, tenacity, reliance, and increased resistance to oils, greases, and solvents. Commercial ionomers are nonrigid, unplasticized plastics. Outstanding low-temperature flexibility, resilience, high elongation, and excellent impact strength typify the ionomer resins. Limitations of ionomers include low stiffness, susceptibility to creep, low heat distortion temperature, and poor ultraviolet resistance unless stabilizers are added. Most ionomers are very transparent.

Fabrication is carried out as with polyethylene. Ionomers have high melt strength for thermoforming and extrusion coating processes and a broad processing temperature range. There are resin grades for extrusion, films, injection molding, blow molding, and other thermoplastic processes.

Most ionomers have good dielectric characteristics over a broad frequency range. The combination of these electrical properties, high melt strength, and abrasion resistance qualifies these materials for insulation and jacketing of wire and cable. Their excellent mechanical and optical properties make them especially useful for thermoformed packaging and abrasion- and impact-resistant parts.

Ionomers are used in applications such as golf ball covers and bowling pin coatings, where their good abrasion resistance is important. The high puncture resistance of films allows these materials to be widely used in packaging applications. One of the early applications was the packaging of fish hooks. Ionomers are often used in composite products as an outer heat seal layer. Their ability to bond to aluminum foil is utilized in certain packaging applications. Ionomers also find application in footwear as shoe heels.

The major suppliers of ionomer resins include Du Pont (*Surlyn A*) and Union Carbide (*Bakelite*).

iridescence Iridescence is the loss of brilliance in metallized plastics and development of multicolor reflectance. Iridescence is cause by cold flow of the plastic or coating and by excess heat during vacuum metallizing.

irradiated film Irradiated film refers to a plastic film, normally polyethylene, that has been cross-linked by irradiation (γ-radiation or high-speed electrons). In this process free radicals are generated in the film by the displacement of hydrogen from the chain by the high-energy irradiation, and cross-linking occurs via a free radical mechanism. This is typically carried out in an inert atmosphere to prevent oxidative degradation. The irradiation process is limited to thickness compatible with the depth of penetration of the radiation.

There are two major markets for irradiated film. The first is packaging film for food and small parts. The irradiated film has improved strength and reduced permeability. When oriented the film shrinks to conform to the contours of the product and has crystal clarity. The second market is heat shrink tubing for electrical connectors. Here the polyethylene is used together with cross-linked polyethylene to form a protective sleeve. The interlayer is polyethylene, which, when heated, flows to fill voids and completely encapsulates the wire. The outer layer is cross-linked polyethylene, which shrinks to form a compact protective sheet over the connector.

Major suppliers of irradiated polyethylene film include Hitachi Chemical Co. (*Hiray*), Electronized Chemical Corp. (*Insulrad*), and General Electric Co. (*Irrathene*).

isoprene

See polyisoprene rubber.

isostatic pressing Isostatic pressing is the pressing of a powder under a gas or liquid so that pressure is transmitted equally in all direction, for example, in sintering.

isotactic Isotactic is one of three major types of polymer configurations. (See Fig. T.2 under tacticity.) The others are *atactic* and *syndiotactic*. Isotactic refers to a configuration in which the substituted groups are all above or all below the plane of the main polymer chain.

In addition to the polyolefins, polystyrene and polymethylmethacrylate are examples of polymers that can be made in the isotactic configuration.

See also atactic and syndiotactic.

isotropic Isotropic refers to a material that has uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing. In general, unfilled amorphous plastics are isotropic materials.

Izod Impact Test

See impact resistance.

J

jacket Jacket is a term to describe the tough sheath that protects an insulated *wire* or *cable*. A jacket may be used to permanently group two or more insulated wires or cables.

jet molding Jet molding is a processing technique characterized by the fact that most of the heat is applied to the material as it passes through the nozzle or jet, rather than in a heating cylinder as is done in a conventional process.

See also injection molding.

jet spinning In the spinning of fibers, hot-gas jet spinning uses a directed blast or jet of hot gas to "pull" molten polymer from the die lip and extend it into fine fibers. For most purposes, jet spinning is similar to *melt spinning*.

See also spinning; melt spinning.

jetting In injection molding, jetting occurs when the melt stream shoots straight into the cavity, only stopping when the stream contacts the end of the cavity. The remaining melt then fills the cavity as fountain flow. The jetting produces a weld line within the cavity, which is not aesthetically pleasing, and the weld line is not as strong as the surrounding material.

Jetting can be reduced or eliminated by reducing the velocity of the melt front. However, enlarging the gate and runner, reducing gate land length, and promoting mold wall contact by locating the gate so that the flow is directed against a cavity wall are more effective in eliminating jetting.

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jig A jig is a device that guides the work to the tool or the tool to the work. A *fixture* is a device that supports the work. In the plastics fabricating industry this distinction has been fading to the point where *jig* is the term currently used for both types as accessory equipment. Even in assembly operations where the device performs a purely holding function, such as in adhesive bonding, the word *jig* or *assembly jig* is in current use.

Although metal is a requisite for jigs applied to operations where close tolerance is a factor, in recent years there has been an increasing tendency to use plastic materials for the making of jigs.

joining (of plastic parts) Several processes are available for joining plastic materials:

- Mechanical fastening
- Adhesive bonding
- Thermal welding
- Solvent cementing

Solvent cementing and *thermal welding* use the resin in the part itself as the "fastener" to hold the assembly together. *Adhesive bonding* and *mechanical fastening* use another substance as the "fastener." Each design engineer must determine the joining method that best suits the purpose. The choice will often depend on the type of plastic, the service environment, economic and time constraints, and production parameters.

The designer should not force an assembly method on a plastic product originally designed for assembly method. Usually, parts must be specifically designed to an assembly method. In fact, certain plastic materials are specifically chosen for an application because of their capability for high-volume assembly. For instance, in the automotive industry, plastics are often chosen because they can be assembled with very fast processes such as ultrasonic welding.

It is important that the designer realize the unique opportunities and problems posed by each method of plastic part assembly. To do this well, he or she must have an understanding of materials science, chemistry, surface science, physics, mechanics, and industrial engineering. All of these disciplines will come into play. Even with this background, final selection of the most desirable assembly method involves some trial and error that can become costly and time consuming.

The joining of plastics is generally more difficult than the joining of other substrates because of their low surface energy, poor wettability, and presence of mold-release agents and other contaminants that can create a weak interface. The relative differences in thermal expansion coefficient and elastic modulus also make joining of plastics to nonplastic materials difficult. They may also cause very high stresses or loose-fitting fasteners in parts assembled with mechanical fasteners. The nature of the polymeric material could also change with the service environment. Parts may swell in solvent, become brittle when exposed to UV, lose plasticizer on aging, gain plasticizer (water) during exposure to humidity, and go through many other changes. All of these will have an affect on the joint whether it be bonded with adhesives or mechanically fastened.

With plastic materials, the designer also has a greater choice of bonding techniques than with many other materials. Thermosets must be adhesively bonded or mechanically joined, but most thermoplastics can also be joined by solvent or heat welding. Plastic parts can also be designed for assembly by means of molded-in, snap-fit, press-fit, pop-on, and threaded fasteners, so that no additional fasteners, adhesives, solvents, or special equipment is required.

Appendix K describes various joining methods for plastics and the advantages and disadvantages of each. The plastic manufacturer is generally the leading source of information on the proper methods of joining a particular plastic.

See also mechanical joining; adhesive bonding; thermal welding; solvent cementing.

joint design (adhesive bonding) Although adhesives have often been used successfully on joints designed for mechanical fastening, the maximum efficiency of bonded joints can be obtained only by designing the joint specifically for adhesive bonding. To avoid concentration of stress (*see* adhesive stress), the joint designer should take into consideration the following rules:

1. Keep the stress on the bond line to a minimum.
2. Design the joint so that the operating loads will stress the adhesive in shear.
3. Peel and cleavage stresses should be minimized.
4. Distribute the stress as uniformly as possible over the entire bonded area.
5. Adhesive strength is directly proportional to bond width. Increasing width will always increase bond strength; increasing depth does not always increase strength.
6. Generally, rigid adhesives are better in shear and flexible adhesives are better in peel.

Brittle adhesives are particularly week in peel because the stress is localized at only a thin line, at the leading edge of fracture. Tough, flexible adhesives distribute the peeling stress over a wider bond area and show greater resistance to peel.

For a given adhesive and adherend, the strength of a joint stressed in shear depends primarily on the width and depth of the overlap and the thickness of the adherend. Adhesive shear strength is directly proportional to the width of the joint. Strength can sometimes be increased by increasing the overlap depth, but the relationship is not linear. Because the ends of the bonded joint carry a higher proportion of the load than the interior area, the most efficient way of increasing joint strength is by increasing the width of the bonded area.

In a shear joint made from thin, relatively flexible adherends, there is a tendency for the bonded area to distort because of eccentricity of the applied load. This distortion causes cleavage stress on the ends of the joint, and the joint strength may be considerably impaired. Thicker adherends are more rigid, and the distortion is not as much a problem as with thin-gauge adherends. Because the stress distribution across the bonded area is not uniform and depends on joint geometry, the failure load of one specimen cannot be used to predict the failure load of another specimen with different joint geometry.

The strength of an adhesive joint also depends on the thickness of the adhesive. Thin adhesive films offer the highest shear strength provided that the bonded area does not have "starved" areas where all of the adhesive material has been forced out. Excessively heavy adhesive film thickness causes greater internal stresses during cure and concentration of stress under load at the ends of a joint. Optimum adhesive thickness for maximum shear strength is generally considered to be between 2 and 8 mil. Strength does not vary significantly with bond thickness in this range.

The ideal adhesive-bonded joint is one in which under all practical loading conditions the adhesive is stressed in the direction in which it most resists failure. A favorable stress can be applied to the bond by using proper joint design. Some joint designs may be impractical, expensive to make, or hard to align. The design engineer will often have to weigh these factors against optimum adhesive performance.

A series of common joint designs and their modifications are shown in Appendix K.

joints for flat adherends The simplest joint to make is the plain *butt joint*. Butt joints cannot withstand bending forces because the adhesive would experience cleavage stress. If the adherends are too thick to design simple overlap-type joints, the butt joint can be improved by redesigning in a number of ways, as shown in Fig. J.1. All the modified butt joints reduce the cleavage effect caused by side loading. *Tongue-and-groove joints* also have an advantage in that they are self-aligning and act as a reservoir for the adhesive. The *scarf joint* keeps the axis of loading in line with the joint and does not require a major machining operation.

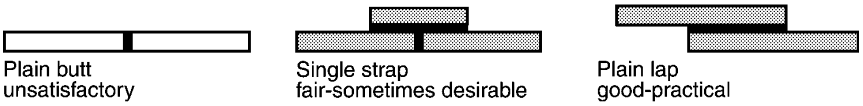

Figure J.1 Common flat adhesive joint designs: butt, plain lap, and single strap. (See Appendix K for joint design improvements on these.)

Lap joints are the most commonly used adhesive joint because they are simple to make, are applicable to thin adherends, and stress the adhesive to be stressed in shear. However, the simple lap joint causes the adhesive to be stressed in shear. In this design the adherends are offset and the shear forces are not in line. This factor results in cleavage stress at the ends of the joint, which seriously impairs its efficiency. Modifications of lap-joint design include:

1. Redesigning the joint to bring the load on the adherends in line
2. Making the adherends more rigid (thicker) near the bond area
3. Making the edges of the bonded area more flexible for better conformance, thus minimizing peel.

The *joggle-lap-joint* design is the easiest method of bringing loads into alignment. The joggle lap can be made by simply bending the adherends. It also provides a surface to which it is easy to apply pressure. The double-lap joint has a balanced construction, which is subjected to bending only if loads on the double side of the lap are not balanced. The beveled-lap joint is also more efficient than the plain lap joint. The beveled edges allow conformance of the adherends during loading, thereby reducing cleavage stress on the ends of the joint.

Strap joints keep the operating loads aligned and are generally used where overlap joints are impractical because of adherend thickness. Like the lap joint, the single strap is subjected to cleavage stress under bending forces. The double-strap joint is more desirable when bending stresses are encountered. The beveled double strap and recessed double strap are the best joint designs to resist bending forces. Unfortunately, they both require expensive machining.

When thin members are bonded to thicker sheets, operating loads generally tend to peel the thin member from its base. The subsequent illustrations show what can be done to decrease peeling tendencies in simple joints. Often thin sheets of a material are made more rigid by bonding stiffening members to the sheet. Resistance to bending forces is also increased by extending the bond area and increasing the stiffness of the base sheet.

cylindrical-joint design Several recommended designs for rod and tube joints are illustrated in Appendix K. These designs should be used instead of the simpler butt joint. Their resistance to bending forces and subsequent cleavage is much better, and the bonded area is larger. Unfortunately, most of these joint designs require a machining operation.

angle-and corner-joint designs Angle and corner joints need special consideration. They are often exposed to peel and cleavage forces, especially when the walls of the joint are made of flexible or semirigid material.

A *butt joint* is the simplest method of bonding two surfaces that meet at an odd angle. Although the butt joint has good resistance to pure tension and compression, its bending strength is very poor. *Dado*, *L*, *and T-angle joints*, offer greatly improved properties. The T design is the preferable angle joint because of its large bonding area and good strength in all directions.

Corner joints for relatively flexible adherends such as sheet metal should be designed with reinforcements for support. With very thin adherends, angle joints offer low strengths because of high peel concentrations. A design consisting of right-angle corner plates or slip joints offers the most satisfactory performance. Thick, rigid members such as rectangular bars and wood may be bonded with an end lap joint, but greater strengths can be obtained with *mortise and tenon*. Hollow members such as extrusions fasten together best with *mitered joints* and inner splines.

flexible plastics and elastomers Thin or flexible polymeric substrates may be joined with a simple or modified lap joint. The double-strap joint is best but also the most time-consuming to fabricate. The strap material should be made out of the same material as the parts to be joined or at least have approximately equivalent strength, flexibility, and thickness. The adhesive should have the same degree of flexibility as the adherends. If the sections to be bonded are relatively thick, a scarf joint is acceptable. The length of the scarf should be at least four times the thickness; sometimes larger scarves may be needed.

When bonding elastic material, forces on the elastomer during cure of the adhesive should be carefully controlled, because excess pressure will cause residual stresses at the bond interface. Stress concentrations may also be minimized in rubber-to-metal joints by elimination of sharp corners and use of metal thick enough to prevent peel stresses that may arise with thinner-gauge metals.

As with all joint designs, polymeric joints should avoid peel stress. Appendix K illustrates methods of bonding flexible substrates so that the adhesive will be stressed in its strongest direction.

rigid plastic composites *Reinforced plastics* are often *anisotropic* materials. This means that their strength properties are directional. Joints made from anisotropic substrates should be designed to stress both the adhesive and the adherend in the direction of greatest strength. Laminates, for example, should be stressed parallel to the laminations. Stresses normal to the laminate may cause the substrate to delaminate. Single- and joggle-lap joints are more likely to cause delamination than scarf or beveled-lap joints. The strap-joint variations are useful when bending loads may be imposed on the joint.

See also adhesive bonding; adhesive stress; adhesion theory; joining (of plastic parts).

jute Jute is a fiber derived from several plants most common in India and Brazil. It is used for making burlap, sacks, cordage, ropes, and upholstery fabrics. The fiber loses its strength when it is damp but is widely used because of its low cost and because of the ease with which it can be spun. Jute fibers, yarn, and fabric have been used for reinforcements in phenolic and polyester resins and in reinforced composites, but these are characterized by low strength compared to other reinforced plastics.

K

K-factor K-factor is a term sometimes used for the thermal insulation value or coefficient of thermal conductivity. It is numerically equivalent to the thermal conductivity expressed in British units (BTU in.)/(ft^2 h°F*),* and its inverse (1/K) is known as the *R-factor.* K-factors and R-factors are commonly used for thermal insulating materials such as plastic foam.

See also thermal conductivity.

kaolin clay The mineral *kaolinite* is the source for clay filler called kaolin, which is a hydrous aluminosilicate mineral commonly used as filler for plastics.

See clay filler.

Kel-F Kel-F is an elastomer that is the copolymer of polyvinylidene fluoride (PVF) and chlorotrifluoroethylene (CTFE). These copolymers range from tough, flexible thermoplastics to elastomers, depending on composition. Their high strengths result from crystalline orientation on stretching.

The elastomers have excellent thermal stability. Prolonged exposure to temperatures greater than 204°C causes no scission or halogen loss. They also have outstanding chemical resistance. The elastomers have high tensile and tear strength with high extensibility. Other properties are comparable to those of other fluorocarbons, including electrical, gas permeability, and water absorption properties. Their low-temperature properties are adequate for many applications with a brittle point of -51°C.

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These copolymers find application as O-rings, chemical-resistant calendered fabrics, and dipped gloves, gaskets, hoses, pump impellers, etc. They come in latex form for such processes as casting and dipping.

ketone Ketones are a class of organic compounds that may be considered as aldehydes in which the distinctive aldehyde hydrogen atom is replaced by a hydrocarbon radical. Thus dimethyl ketone or *acetone* (CH_3COCH_3) is a methyl derivative of acetic aldehyde. Ketones are widely used as solvents for plastics: the chief ones being *acetone*, *methyl ethyl ketone* ($CH_3COC_2H_5$), and *methyl isobutyl ketone* [$CH_2COCH(CH_3)C_2H_5$].

ketone-based peroxide The ketone peroxides are a class of commercially available organic peroxides. They are used in conjunction with promoters or accelerators to initiate room-temperature polymerization of unsaturated polyester resins.

The most widely used room-temperature curing agents of unsaturated polyesters are the peroxy derivatives of methyl ethyl ketone, that is, *methyl ethyl ketone peroxide* (MEK peroxide). These are generally available as 60 percent solutions containing 11 percent active oxygen. The major producers of ketone peroxides offer standard types, which differ in their reactivity. This provides the processor with the ability to select a curing agent for their particular requirements.

See organic peroxide.

ketone-based polymers: polyarylketone (PAEK), polyetherether ketone (PEEK), polyether ketone (PEK) *Polyarylketone* (*PAEK*) polymers represent a family of semicrystalline aromatic polyether ketones. These polymers provide high performance with excellent high-temperature properties. Ketone-based polymers are classified as *engineering resins* and often are found in high-temperature applications requiring a high level of mechanical properties.

Molecularly the polymers in this family vary in the location and number of their ketone and ether linkages. Physical properties are also affected by the ratio and sequence of the ether and ketone groups. The higher the degree of ketone groups (greater the aromaticity), the higher the melt temperature and heat-distortion temperature. PAEK polymers are made from several polymerization processes (e.g., nucleophilic and electrophilic substitution reactions) to form synthetic linkages.

PAEK family of resins represent some of the highest-temperature polymers that can be manufactured by conventional thermoplastic processes. However, high processing temperatures are required because melt temperatures are in the range of 335 to 366°C. PAEK polymers can be injection molded, extruded, compression molded, and transfer molded. However, the resins should be thoroughly dried before processing.

The crystallinity and high molecular weight of this family of polymers provide excellent environmental resistance and mechanical properties including wear resistance, creep, fatigue, and modulus. These excellent properties are also evident at elevated temperatures. Service temperatures of filled formulations can be about 280°C with heat-distortion temperatures to 350°C. The PAEK family exhibits good mechanical properties at high temperature and excellent resistance to creep. The polymers have good chemical resistance at room temperature. They have a high degree of toughness (unusual for a high-temperature-resistant polymer) and high fatigue resistance. Low moisture resistance provides for good hydrolytic stability.

Table K.1 Properties of Polyetherether Ketone (PEEK)

Property	Polyetherether Ketone (PEEK), Unreinforced
Specific gravity	1.32
Tensile strength, psi	1,320
Flexural strength, psi	16,000
Elongation, %	30–150
Glass transition temperature, °C	143–199
Continuous use temperature, °C	315
Dielectric strength, volts/mil	480

Applications include parts in airplane and automobile engines, chemical plants, oil and gas processing equipment, and steam processing equipment. Ketone-based polymers are used in high-temperature electrical and electronic applications and medical applications. Certain resins have been used as electrical coatings and in cables.

The primary members of the PAEK family are *polyetherether ketone (PEEK)* and *polyether ketone (PEK).* PEEK is produced by several manufacturers (Capco Polymer Industries; EGC Corp. tradenamed *Xytrex*; Green, Tweed, & Co. tradenamed *Arlon*; and Victrex). It is available in powder form or as short carbon fiber- or glass fiber-reinforced grades. Special bearing grades are made by incorporating PTFE resin or graphite into the resin. PEK has a slightly higher glass transition temperature and heat-distortion temperature range than PEEK. PEK is manufactured by Victrex.

Kevlar Kevlar is a tradename for an *aramid fiber* (or *aromatic polyamide fiber*) manufactured by Du Pont. When introduced in 1972, Kevlar essentially revolutionized pressure vessel technology because of its great strength in consistency coupled with low density, resulting in much more weight-effective designs for rocket motors. The specific tensile strength of Kevlar was, at its introduction, the highest for any fiber. Carbon/graphite fibers, because of advances in processing, have the highest values now.

Three types of Kevlar aramid fibers are available: a high-tensile-strength, high-modulus type for reinforcement of plastic; a similar fiber for use in ropes, cables, coated fabrics, and protective clothing; and a third type designed to reinforce rubber products such as tires, belts, and hoses.

When Kevlar is used in reinforced composites, the values of tensile modulii may be near to those of the fiber itself, but the tensile strength values for the fibers may be quite different than the composite because of factors such as translation efficiency, possibility of flaws, processing damage, or incorrect fiber orientations.

The tensile strength of Kevlar fiber for reinforcing plastics is better than twice that of nylon or polyester and 15 percent better than that of E-type fiberglass. Elongation is low, and the density of the fiber is 40 percent lower than glass. Aramids are as strong as steel at 1/5 the weight. *Yarns* and *rovings* are available comprised of multiple, continuous, round-cross section filaments with 1/2-mil diameter. Unlike glass, the aramid fiber is relatively insensitive to fiber surface defects.

The thermal stability of aramid fibers is good. Even after exposure for 7 days at temperatures as high as 180°C, the physical property losses are less than half the initial values. Essentially no embitterment or degradation occurs during cryogenic exposure. Aramid fibers also have good chemical resistance except for strong acids and bases. They have high stress rupture life and fracture toughness, good cyclic tensile fatigue resistance, and fair damping characteristics. Environmental stability of composites is generally good except in extremely hostile environments.

Because of its slightly negative coefficient of thermal expansion in the longitudinal directions, composites made with polyaramid fibers exhibit excellent dimensional stability. One special application area is in high-performance electronic circuit boards requiring low *x-y* axis thermal expansion.

The main disadvantages of the aramid fibers include high moisture absorptivity, low compressive strength, and difficulty in cutting and machining of the resulting composites.

See also aramid fiber; aramid composites.

kick over Kick over and *set-up* are shop jargon referring to the curing of a liquid thermoset resin to the solid state.

kirksite Kirksite is a low-melting alloy of aluminum (aluminum, zinc, and copper) used for casting dies for postforming, etc. It has primarily been used in the construction of blow molds. Kirksite imparts a high degree of heat conductivity to the mold.

kiss role coating Kiss role coating is the coating process where the roll arrangement carries a metered film of liquid coating material to the web. At the line of web contact the liquid film is split, with part remaining on the roll and the remainder of the coating adhering to the web.

See also roll coating.

knife coating Knife coating is a method of coating a substrate (usually continuous) in which the substrate in the form of a continuous moving web is coated with a material whose thickness is controlled by an adjustable knife or bar set at a suitable angle to the substrate.

In the plastics industry, polyvinyl chloride (PVC) formulations are widely used in this work, and curing is effected by passing the coated substrate into a special oven, usually heated by infrared lamps or convected air. There are a number of variations of the basic technique, and they vary according to the type of product required.

knife cutting Knife cutting is a method of producing a straight cut in film or thin sheet materials. It is used for cutting a continuous roll into individual sheets of a desired size and for reducing sheets to a smaller or more exact size. The method is suitable for cutting materials from about 1/2 mil to 20 mil thick. Heavier gauges up to a maximum of about 60 mil may also be cut by a guillotine-type knife cutter. For cutting of continuous stock, rotary knives provide an alternative machine.

knit lines Molding compounds are forced to divide as they flow into a mold in order to fill out the part. Where the compound reunites, as in passing a mold pin, a knit line (or *weld mark*) is formed. Failure of the plastic to knit or unite solidly at this point is a common source of production loss.

Knit lines occur in parts made from processes in which the plastic fills out a mold (cold press, compression, injection, reaction injection, resin transfer, structural foam, transfer molding), except when the shape is very simple and there is an unobstructed flow path. Cores, variations in wall thickness, depressions, changes in flow directions, etc., cause the melt to divide as it moves through the mold. Where the melt flows rejoin, knit lines are created.

In some cases there is no weld at all regarding the joining of the separate flow regions. This is a condition known as an open knit line, which is uniformly regarded as an unacceptable part. Knit lines, which are visible but not open, can vary considerably in strength from 10 percent to approximately 75 percent of that of the surrounding material.

Adjustments to molding conditions can improve the quality of the knit line. Depending on the process, relocation of the gate or the charge can alter the location of the knit line. The use of ribs, multiple gates, and so forth will also relocate the knit line. The use of multiple gates will change the flow within the mold as well. Computer simulations are available that can forecast the locations of knit lines with reasonably good accuracy.

knockout A knockout is the mechanism that ejects a part from the mold. The part that directly pushes it out of the cavity or off the force in most cases is known as the *knockout pin*. A number of these may be retained in a *knockout pin plate*, whereas a row of knockout pins may be backed up by a bar or plate, called a *knockout bar*, fixed in a *knockout frame*.

Knockout pins proved an economical form of ejection in a volume run. Because they leave a slight ring, it is desirable that they impinge on some hidden portion of the molded part. Knockout pins are usually located inside the cavity, but they may also be placed on runner, ejection parts, and cold slug wells.

knurl A knurl is a shallow beaded effect on the surface of a metal or plastic part that makes for a good grip and is also decorative. Knurls provide a means of attaching inserts to a molded part.

See also inserts.

kraft paper Kraft paper is a paper made from sulfate wood pulp. It is generally used for electrical insulation, either by itself or when impregnated with resin or an insulating fluid. When impregnated with resin and compression molded, kraft paper is the reinforcement in laminate sheets. The impregnated paper may also be dried or B-staged and then chopped to yield a product that can be compression molded.

L

L/D ratio L/D ratio is a term used to define an extrusion screw that denotes the ratio of the screw length to the screw diameter. The longer the length, the better the plastification. The greater the diameter, the more capacity the screw will have at any given rpm. The higher the L/D, the higher will be the surface available for shearing, mixing, and plasticating the granules. Current practice is to use screws with L/D values of 12:1 to as high as 36:1.

The screw L/D is also the designation used to classify barrels, because the screw fits the barrel with very little clearance.

See also extrusion screw; screw length.

lacquer Lacquer is a term used to refer to a solution of natural or synthetic resins in readily evaporating solvents. It is usually a protective coating. The coating dries primarily by evaporation of the solvent.

At one time the definition of lacquer (as distinguished from other *finishes*) was limited so that the film-forming ingredient in a lacquer formulation was specified as *cellulose nitrate* or other cellulosics, but the definition has now been broadened to include other film formers as well. Typical lacquers include those based on nitrocellulose, other cellulose derivatives, vinyl resins, acrylic resins, and so forth. Although meant to describe only thermoplastic film formers, the term lacquer has been extended to thermosetting coatings as well.

ladder polymer The term ladder polymer refer to polymers that have an aromatic configuration that resembles a ladder (two polymer chains with cross-links

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at frequent intervals). It has been speculated that the ladder configuration represents the upper limit of temperature for a completely organic polymer structure. Chemically, 650°C is the ultimate temperature that can be theoretically expected. The ladder structure provides inherent temperature resistance because bond breakage in the main chain must occur in at least two places to cause scission of the molecular chain and reduction in molecular weight.

Although ladder polymers provide higher molecular order than regular polymers, they create tremendous processing problems. As the molecule becomes more thermally stable, it increases its resistance to melting and flow during fabrication. As a result, ladder polymers are very difficult and expensive to process.

Materials that come close to the ideal ladder structure are thermosetting polyimides and polybenzimidazoles. These are used primarily in high-temperature aerospace applications as composites and adhesives.

lagging Lagging is the process involving the wrapping of resin-impregnated tape around a cylindrical mandrel and applying pressure on the resulting structure by the use of shrink tape. Prestretched polyvinylidene fluoride from Du Pont (*Tedlar*) is the most commonly used shrink tape because it shrinks readily on application of heat.

See also heat-shrinkable tubing and film.

lamella The lamella is the basic morphological unit of a crystalline polymer. Generally, it is a ribbonlike or platelike configuration about 100 Å (10 μm) thick, 1 μm long, and 0.1 μm wide. The lamellar thickness is a characteristic morphological parameter, usually estimated from X-ray studies or electron microscopy.

laminae A laminae (plural of *lamina*) is a set of single plies or layers of a laminate. In reinforced plastics, the laminae may be individually constructed and laid up in the laminate because of requirements to control the fiber direction or because of the method of processing used.

See also laminate; laminate design factors.

laminar flow Laminar flow of thermoplastic resins in a mold is accompanied by solidification of the first layer to contact the mold surface. This layer then acts as an insulating tube through which the material flows to fill the remainder of the cavity. This type of flow is essential to duplication of the mold surface.

laminate Laminates are plastic forms made by stacking and pressing layers of sheets of plastic, which are then pressed together to form a multilayered structure. Most common laminates are pressed and cured layers of resin-soaked sheets of paper, fiber, or fabric, known as reinforcing sheets or, simply, reinforcements. The fibers or fabrics used are most commonly glass or certain polymeric fibers or fabrics.

As an example, a commonly used laminate is glass-epoxy. In this material, epoxy is the resin used and glass fiber or fabric is the reinforcement. In the broad field of laminates, any of a large variety of resins and reinforcements may be used.

There are several industry standards covering laminate materials. One of the primary sets of standards is that established by National Electronic Manufacturers Association (NEMA). Many laminates are clad with copper foil, with the copper later being etched to form printed circuit boards. Epoxy-glass circuit boards are among the most highly used for electronic assemblies. (*See also* printed circuit boards; electrical laminates; NEMA)

Laminates are plastic materials formed by bonding together reinforcing sheets or webs with a polymer or plastic. Heat and pressure are usually required. The reinforcing sheets may be fabric, mats, or paper, and the binder polymer may be either a thermoset or thermoplastic polymer. Table L.1 shows the properties of laminates that are reinforced with different types of fibers.

Although both thermosetting resins and thermoplastic polymers are used as binders in laminates, the thermosetting materials are more common because they generally provide superior stability, thermal resistance, and electrical properties.

Thermosetting resins can be combined with reinforcing fiber directly in a molding press by pouring a liquid resin onto a fiber mat or fabric or by combining the resins and reinforcement in a treater. The molding press process is used to produce *continuous low-pressure laminates* of finite thickness. The treater process is used to produce *high-pressure laminates* in sheet form.

In the treater process, the thermosetting resins are often dissolved in a solvent to aid in the wetting and saturation of the reinforcement web. The reinforcing web is pulled from the delivery roll through a resin impregnating bath or tank, where the viscosity and temperature of the resin are carefully controlled. The saturated web then enters the heating section of the treater. When the product requires a cosmetic appearance, the treater is arranged vertically. When the appearance is not critical, the treater is horizontal (as shown in Fig. L.1 below) and the impregnated web is supported through the horizontal treater on a conveyor. Horizontal treaters can reach speeds of 600 ft/min, and vertical treaters run at speeds from 10 to 100 ft/min.

In the treater, the impregnated web is heated to boil away the solvent and to begin the polymerization of the thermosetting resin. This step is known as *B-staging* or *prepreging*. It is desirable to cure the resin enough so that the web is not tacky or dry and is handleable, but yet sufficiently uncured to permit an additional cure and flow at the lamination press. As the sheets exit the treater, they are sheared, stacked, and stored in temperature- and humidity-controlled rooms.

The prepreg (preimpregnated materials) is then delivered to the lamination press. Here the required number of prepreg sheets is stacked between polished steel plates. The plates are further stacked together to form a pack that is then placed into the laminating press's platens. Each pack can consist of 10 laminations, and the press may have 24 platens, making a press load of up to 240 laminations per cycle. The press is closed, and the laminates are consolidated and polymerized (cured) at temperatures from 121 to 204°C, pressures from 200 to 3000 psi, and times from 3 to 120 min. Molded laminates are then trimmed to final size. Some laminates must be postcured by additional heating in ovens.

Table L.1 Strength of Laminates made with Style 181 Glass Fabric (Ref: Harper, C.A., "Laminates and Reinforced Plastic Materials and Processes", *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

	Tensile Strength, lb/in$^2 \times 10^{-3}$				Flexural Strength, lb/in$^2 \times 10^{-3}$				Compressive Strength, lb/in$^2 \times 10^{-3}$			
Resin	72°F	−110°F	−320°F	−424°F	72°F	−110°F	−320°F	−424°F	72°F	−110°F	−320°F	−424°F
Epoxy	61	98	115	118	94	129	168	172	72	107	138	135
Phenolic	52	66	66	65	77	100	110	110	70	88	100	90
Polyester	41	61	57	55	63	75	70	65	28	42	48	44
Silicone	30	47	70	76	38	46	67	65	21	39	43	46
Phenolic silicone	34	55	63	61	69	102	105	110	46	60	60	56

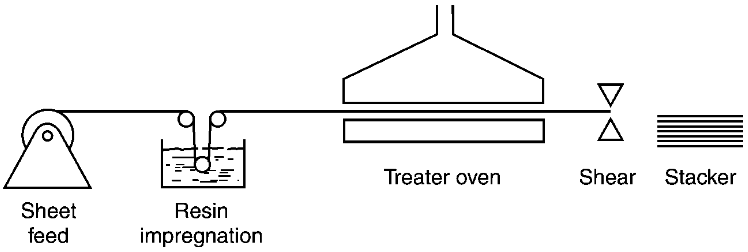

Figure L.1 Horizontal treater for preparing prepreg for laminates. (Ref: Harper, C.A., "Laminates and Reinforced Plastic Materials and Processes", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Many of the thermosetting materials that are laminated into flat sheets can also be made into tubes and rods. Round tubes are made by rolling impregnated prepreg sheets onto mandrels between heated rollers. The resin is then cured or polymerized by oven baking in the case of rolled tubes or by pressing in the heated molds for molded tubing. Molded rods are made of plies of prepreg and are molded into shape in cylindrical molds. Rods can also be machined from flat sheets with properties similar to those of the sheets. Both rods and tubes are highly anisotropic.

The same type of resin-treated material as described above can be shaped into a variety of products by modification of a compression molding technique. Such *molded laminates* have excellent properties similar to high-pressure laminates. Usually a semipositive type of mold is favored with ample clearance for flash around the mold area. Molding pressures range from 250 to 2000 psi with temperatures of about 150–200°C. The cycle depends on the nature of the formulation and its thickness.

Thermoplastic laminates are made by combining polymer solutions or films on either a treater or roll combiners. The thermoplastic material is reinforced with fabric, mat, or paper by impregnation into a solvent solution of the thermoplastic resin followed by drying in a treater or by hot-melt application of the thermoplastic resin, generally in film form, to the reinforcing agent by application through hot rollers. Then, similar to the thermosetting laminates, the treated material is cut into sheets, stacked, and molded in laminating presses under specific conditions of heat, pressure, and time.

See also continuous laminate; decorative laminate; high-pressure laminate; electrical laminate.

laminate design factors The presence of reinforcement lends unusual properties to laminates and reinforced plastics in general. The physical properties of plastic materials are substantially improved by combining them with reinforcing fibers. Tensile strengths, flexural strengths, and compressive strengths are higher in laminates than in the neat polymers. In particular, the strength per unit weight (specific strength) permits reinforced materials to outperform metals in certain applications.

Reinforcements often greatly improve impact strengths, sometimes by a factor of 10. Reinforced plastics, unlike steel, do not demonstrate a clear yield point.

Reinforced plastics can be used very close to their ultimate strength without fear of excessive elongation.

Design factors should be observed for reinforced plastics. Based on the standardized properties of laminates, rods, and tubes, a minimum safety factor of four for mechanical strength and six for electrical strength is recommended. If repeated impact loads are expected, a safety factor of 10 is advisable.

Reinforced plastics, particularly laminates, are anisotropic (i.e., their properties differ depending on the direction of measurement). For example, a laminate made of fabric has physical properties controlled by the weave of the fabric and the number and density of the threads in the *warp* and *fill* directions. Both of these values are different from the values of the *z* or thickness direction. This is clearly evident in the shear properties. Thermal expansion and thermal conductivity properties are also anisotropic. In the *x*, *y*, and *z* planes of the laminate, the thermal expansion values differ. Even the reinforcing fibers themselves may have anisotropic properties.

The electrical properties of laminates and reinforced plastics are also closely related to the nature, direction, and amount of reinforcing fiber present. The dielectric constant follows a “rule of mixtures” that states that the property of mixtures is dependent on the relative volume fractions of the components. The dielectric strength of laminates (as with other dielectrics including neat polymers) is highly dependent on the thickness of the sample. The dielectric strength decreases with increasing thickness. The dielectric strength of laminates is highly dependent on the direction of the electric field stress. Samples tested across the thickness of the laminate have higher dielectric strengths than samples tested end-to-end along the fiber length. The dissipation factor, or tan delta, does not follow the rule of mixtures as closely as the dielectric constant. Instead, the resin component determines the dissipation factor except when the reinforcing fibers are organic.

Other unique properties of laminates are related to the nature of the fiber reinforcement. For example, the ability to punch holes in laminates rather than drill holes is related to the type and amount of fiber. Some laminates, namely, those with fibers of glass, quartz, or Kevlar, do not punch well; others like cellulose, do punch well. Kevlar, because of its tremendous toughness, does not machine well in either laminate or composite form.

laminating resin Laminating resins can consist of both thermoplastic and thermosets. The first industrial laminates were thermoset materials. However, thermoplastic laminates are gaining popularity in certain applications, such as automotive, because of the greater toughness that a thermoplastic resin can provide and faster processing capabilities.

The most common thermosetting laminating resins are phenolics, melamines, epoxies, polyesters, silicones, and polyimides. Thermoplastic resins used in making laminates include polysulfone, polyphenylene sulfide, polyetheretherketone, polyamide-imide, polybutylene terephthalate, nylon 6, and polypropylene.

Phenolics are often used because their cost is lower than those of laminates formed with most other resins. They have excellent water resistance and are frequently chosen for marine applications. They can be used in gears, wheels, and pulleys because of their wear and abrasion resistance and in printed circuits and terminal blocks because of their stability under a variety of environmental conditions.

Melamine-formaldehyde polymers are widely used in the form of high-quality molded dinnerware. The applications take advantage of their heat resistance and water-white color. Melamines retain their properties at low temperatures, and have very good arc- and track resistance. Melamines are also often used where resistance to caustic is required. However, melamine laminates have poor dimensional stability, particularly when the part is exposed to alternating cycles of high and low humidity.

Epoxy laminates consist of a large family with varying polymer, hardening agents, catalyst, fillers, and specialty compounds. They are particularly useful in laminates because they can be B-staged or made into prepreg. Epoxies are resistant to chemicals, are strong, and have superior adhesion and good electrical properties. They are used in electronic applications as circuit boards. Epoxies are also used in cryogenic applications (−253°C). At these low temperatures, the epoxy laminates perform better than other common laminates. (*See* low-temperature properties, Fig. L.3) Laminates can also be made with good retention of physical properties up to 204°C.

Polyester laminating resins usually consist of an unsaturated ester polymer dissolved in a monomer such as styrene. One of the chief virtues of these resins is the excellent chemical resistance of the laminates. Hence, they are used for corrosion resistant tanks, exhaust ducts, scrubbers, and plating equipment. These materials resist acids and bases for long periods at 94°C. They are attacked by most chlorinated solvents. A closely related polymer family, the vinyl esters, has even more superior chemical resistance and some processing advantages.

Silicone laminates are useful from cryogenic temperatures to about 260°C. The dielectric properties of silicones are particularly useful. Both dissipation factor and dielectric constant are low at room temperature and remain relatively constant up to 150°C. Because of the presence of the silicon atom, silicone laminates have good arc- and track resistance. The physical properties of silicones are not greatly influenced by aging, but compared with laminates that are based on other resins, the flexural and tensile strengths of silicones are not unusually high. Silicone laminates are used in electronics, heaters, rocket components, slot wedges, ablation shields, coil forms, and terminal board.

Polyimide resins can be prepared as either thermoplastics or thermoset resins. However, most laminated applications rely on thermosetting polyimides. The thermosetting resins are difficult to process, requiring long, high-temperature cures often at high pressure. Highly boiling solvents often cause blistering problems. The laminates have low creep and can be used continuously from cryogenic temperatures to 232°C and for short times up to 482°C. Polyimide laminates resist burning without chemical modification and have a low dissipation factor and dielectric constant. They are somewhat moisture sensitive, gaining 1 percent in weight after 1000 h at 50 percent RH and 22°C. They are used as printed wiring boards and as structural components in aircraft, copiers, and automobiles.

Bismaleimides (BMI) are formed from methylene dianiline and maleic anhydride. They are laminating resins that prepreg well and can be produced on conventional treating and pressing equipment. They are being used as printed wiring boards and in some aerospace applications. The bismaleimides can also be reacted with triazine to form bismaleimidetriazine resins (BT) and further reacted with epoxies to make BT-epoxy copolymers. These resins have glass transition temperatures of 190°C compared with 120°C for conventional epoxies. Dielectric characteristics are very good.

Thermoplastic polymers offer many advantages to the laminator compared to traditional thermoset materials. Laminates made with thermoplastic resins have better impact strength, improved crack resistance, reuse of scrap, better formability and damping, and simpler part fabrication in that no modification as with catalysts or solvents is needed at the molding facility. However, the thermoplastics have proven very difficult to combine with reinforcements, making the processing of most polymers complex and expensive. The difficulties are caused by two factors: high-melt viscosity and the stiff nature of the prepreg. To overcome these limits, thermoplastic prepregers have derived four methods of preparing prepreg:

1. The polymers that have rather low melt viscosities can be impregnated on a relatively conventional treater where the resin is treated as a hot melt. Other polymers can be dissolved in a solvent and treated similarly. However, these prepregs still have no tack.
2. Films of a polymer are brought into contact with webs of reinforcement like glass fiber or mat. Under heat and pressure, the films are forced to impregnate the fabric to form a prepreg.
3. Combinations of reinforcing fibers and thermoplastic fibers are made where the thermoplastic becomes the binder in finished parts. In some cases slit polymer films are used instead of polymer yarns. These prepregs generally have good drape and handling.
4. Thermoplastic powders are mixed with water to form slurry that is coated onto reinforcing fibers or webs. When the water is evaporated, the powder sticks to the reinforcement. These prepregs are drapable and pliant. However, they are expensive and limited in polymer choice.

See also prepreg.

land The land is the part of a mold on which the plunger rests when a mold is closed. This is the area adjacent to the cavity. It is the horizontal bearing surface of a *semipositive or flash mold* by which excess material escapes. In an extrusion die, the land is the straight section through which the plastic flows just before it emerges.

landed plunger mold The landed plunger mold, sometimes called a *landed positive* mold, provides space above the molded part for the bulk of the molding material before it is formed to shape by closing the mold. It uses a horizontal flash line as in the *flash mold*. The difference lies in the vertical loading.

This class of mold is used only in compression molding and is generally used in all compression molds. The landed plunger mold provides a higher density of molded part and better control of overflow or flashing than the flash mold, and its plunger does not score the cavity walls as a positive mold does. The principal disadvantage of a landed plunger mold is high cost due to the extra cavity depth and fitting of the plunger.

lapping In mold making, lapping is a term referring to rubbing a mold with a very fine abrasive in a fluid cooling agent to achieve high polish and close dimensional tolerance. Such a process may be used to make a mold for optical lenses, for example. More generally, lapping refers to the rubbing of two mating parts together with the same kind of abrasive and cooling agent, to ensure extremely close fit.

laser welding Laser welding is a high-speed, non-contact process for welding thermoplastics. Laser welding is a form of *indirect heat welding* used to weld or seal plastic parts. It uses a focused laser on the plastic part joint area to obtain a molten region. Joining occurs by diffusion of material from one substrate into the other. Once cooled and set, the joint has high strength and is capable of being a barrier to gas or water.

Laser welding of plastic parts has been available for the last 30 years. However, only recently have the technology and cost allowed these joining techniques to be considered broadly. Laser welders produce small beams of photons or electrons. The beams are focused onto the work piece. Power density varies from a few to several thousand W/mm^2, but generally low-power lasers (less than 50 W/mm^2) are used for plastic parts.

Laser welding is expected to find applications in the packaging and medical product industries. Thermal radiation absorbed by the work piece forms the weld. Sold state Nd:YAG and CO_2 lasers are most commonly used for welding. Laser radiation in the normal mode of operation is so intense and focused that it very quickly degrades thermoplastics. However, lasers have been used to butt weld polyethylene by pressing the unwelded parts together and tracking a defocused laser beam along the joint area. High-speed laser welding of polyethylene films has been demonstrated at weld speeds of 164 ft/min with carbon dioxide and Nd:YAG lasers. Weld strengths are very near to the strength of the parent substrate.

Processing parameters that have been studied in laser welding are the power level of the laser, shielding gas flow rate, offset of the laser beam from a focal point on the top surface of the weld interface, travel speed of the beam along the interface, and welding pressure. Butt joint designs can be laser welded; lap joints can be welded by directing the beam at the edges of the joint.

Lasers have been used primarily for welding polyethylene and polypropylene. Usually laser welding is applied only to films or thin-walled components. The least powerful beams, around 50 W, with the widest weld spots are used to avoid the possibility of degrading the polymer substrate. The primary goal in laser welding is to reach a melt temperature at which the parts can be joined quickly before the plastic degrades. To avoid material degradation, accurate temperature measurement of the weld surfaces and temperature control by varying laser strength is essential.

Lasers have been primarily used for joining delicate components that cannot stand the pressure of heated tool or other thermal welding methods. Applications exist in the medical, automotive, and chemical industries. Perhaps the greatest opportunity for this process will be for the high-speed joining of films.

Laser welding has also been used for *filament winding* of fiber-reinforced composite materials with a thermoplastic *prepreg*. A defocused laser beam is directed on areas where the prepreg meets the winding as it is being built up. With suitable control over the winding speed, applied pressure, and the temperature of the laser, excellent reinforced structures of relatively complex shape can be achieved.

Laser welding requires high investment cost in equipment and a ventilation system to remove hazardous gaseous and particulate materials resulting from the vaporization of polymer. Of course, suitable precautions must also be taken to protect the eyesight of anyone in the vicinity of laser welding operations.

See also heat welding (indirect).

latent curing agent A latent curing agent is a curing agent that produces long-time stability at room temperature (i.e., a long *pot life*) but cures rapidly at elevated temperature.

Examples of latent curing agents are *Lewis acids*, such as aluminum trichloride or boron trifluoride (BF_3). These curing agents only become chemically active on exposure to heat. Lewis acids are commonly used in single-part epoxy formulations. Another example of a latent curing agent is in the polymerization of urea formaldehyde resins. These latent catalysts include salts and esters that develop acidity on heating, often in conjunction with the moisture released as a result of condensation polymerization. In fact, in the absence of moisture, the room-temperature effectiveness of the catalyst is nonexistent.

Other ways of producing latency in curing agents are (1) when the curing agent is insoluble and inactive in the resin at room temperature and (2) when the curing agent is chemically blocked at lower temperatures and the blockage is eliminated on exposure to higher temperatures.

latent solvent A latent solvent is a substance that is not a solvent for a particular substance but becomes a solvent in the presence of a relatively small amount of a true solvent. Alcohols, for example, are latent solvents for cellulose nitrate. The term is also used for substances that become effective solvents only when heated.

latex Latex is an aqueous dispersion of a rubber or resin solid. It is a water suspension of microscopic particles of organic polymer material. For most uses, latex-type products are compounded by adding water-dispersible materials (similar to fillers, extenders, and modifiers in conventional plastic formulations) to impart desired properties to the finished articles as well as improvements in processing properties of the latex itself.

Latex and latex compounds are advantageously used in making a variety of articles because of the economy of processing, freedom from fire and toxic hazards, and the quality of the finished products. Common articles that are produced from latex include articles made by dipping forms, coated articles, impregnated fabrics and paper, adhesives, sponge, thread made by extrusion of latex, sheet, and cast or molded articles.

Natural rubber latex is the milklike juice of the rubber tree, widely used as a general-purpose material in making a great variety of articles including adhesives, rubber compounds, and rubber powder. It is particularly suitable for dipping and is generally used where special properties such as resistance to flame or to certain chemicals such as oils are not required. *Latex foam* is a cellular sponge rubber made by whipping air into latex, pouring into molds, and vulcanizing.

Artificial latex is a water dispersion of reclaimed rubber. Water dispersions of crude or reclaimed rubbers are produced by swelling and dissolving the rubber in an organic solvent, treating with an organic acid or with ammonia, and emulsifying. They resemble natural rubber latex but are softer and tackier and are used for adhesives.

Synthetic elastomer latices include styrene butadiene, neoprene, and acrylonitrile butadiene. Neoprene latex is a water dispersion of neoprene rubber, and it has dispersed particles smaller than those of natural latex, giving better penetration in coating paper and textiles. Styrene butadiene latex with 68 percent solids is used for production of *foamed rubber*.

Plastic latices are useful in making articles that do not have to be resilient, but in which tough, somewhat hard deposits are desired. They are particularly suitable for paper and fabric coating. Typical plastic latices are modified polyvinyl chloride and polyvinylidine chloride.

Dispersions are not strictly latices but are water-dispersed systems that have similar appearance and application. They give tough, transparent deposits with good chemical resistance. These include polyvinyl butyral and polyvinyl acetate. Latex water paints are now usually made with synthetic rubber or plastic dispersions.

latex paint Latex paint finishes are versatile finishes that are replacing oil paints and enamels for home use because of their quick drying, low odor, and water-cleanup properties. Basically, they are polymer latices produced by emulsion polymerization to which pigments and rheological control agents have been added.

The film is formed by coalescence of the polymer particles in the latex on evaporation of the water. The polymer itself is not water soluble. In order that the particles coalesce to form a film when the water evaporates, the polymer must be deformable under the action of surface tension forces. Thus polymers for latex paints must be near or above their glass transition temperature at the use temperature.

Modern latex paints are based on acrylic (ethyl and other acrylates) latices because of the acrylic's superior chemical stability and, therefore, resistance to color change and degradation. Most water-cleanable house paints today are based on acrylic latex.

lay-flat film and tubing Lay-flat tubular film or sheeting is produced by extruding a relatively thin-walled tube of a thermoplastic through a *ring die*, closing the end of the tube between nip rollers positioned above the die, expanding the tube radially (by inflating or blowing with air introduced through the die to the extent required for the desired wall thickness), and finally winding up the resulting blown, cooled, and expanded tubular film or sheeting in the flattened (collapsed) form in which it emerges from the nip rollers. (See Fig. L.2.) This is the process used in manufacturing garbage bags and other flat consumer products.

Figure L.2 Lay flat film process. (Ref: Park, W.R.R. ed., *Plastics Film Technology*, van Nostrand Reinhold, New York, 1969 also Schwartz, S.S. and Goodman, S.H., *Plastics Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 507)

layup Layup, as used in reinforced plastics, is the process of placing the reinforcing material in position in the mold or for the final curing process. The term is sometimes also used for the resin-impregnated reinforcement itself. The layup process has traditionally been the largest contributor to labor costs of composite fabrication. As a result, several methods of mechanically assisted, controlled tape laying, and automated integrated manufacturing systems have been developed.

The major types of layup configuration include hand layup, automatic tape laydown, filament winding, resin transfer molding, and pultrusion. The configuration will depend on the type of reinforcement that is used (i.e., tape, tow, fabric, preform, chopped fiber, etc.) and whether or not it is impregnated with resin at the time of laying in the mold.

In addition to any cost savings for long production runs, there are two key quality assurance factors that favor the use of automated lay. These are the greatly reduced chance that release paper or film could be retained, which would destroy shear and compressive strength if undetected, and the reduced probability of the addition or loss of a single ply that could cause warping because of the laminate's lack of symmetry and balance. New automated layup machines have a laser ply mapping accessory that can verify the position of the surface ply.

Automation layup efforts are traditionally directed toward the prepreg tape lay down/autoclave cure processes that are necessary for complex aircraft shapes. Major vendors of such equipment include Cincinnati Machines, Brisard Machine, and Ingersoll.

leaching Leaching is extraction of low-molecular-weight substance from a polymer by a liquid (especially by percolating water). Some of the methods of ASTM C871 (chemical analysis of thermal insulation materials for leachable chloride, fluoride, silicate, and sodium ions) are applicable to plastics used as thermal insulants. Leaching of ions can be degrading to electronic components, and several epoxy resins have a specified maximum leachable ion concentration.

lead trimming and forming Most semiconductor devices encapsulated by transfer molding as well as a host of other high-volume, small, and fragile electronic components use *lead frames* as carriers during assembly and molding. These lead frames need to be trimmed off before testing, marking, and packing the devices. Progressive trimming and forming presses and dies have been developed for removal of the frame and are available both as manually fed and automated systems.

leakage current
See dielectric strength

leno weave
See weave.

let-down ratio Let-down ratio is a term used to indicate the number of pounds of natural resin than can be satisfactorily colored by one pound of colorant. It is used in the process of applying color concentrates in the screw injection machine.

The usual let-down ratio is 10:1 to as high as 30:1. The let-down ratio will depend on the compatibility of the colorant with the polymeric resin, and it will also depend on the L-D ratio of the press or extruder. The higher the L-D ratio, the greater will be the let-down. Other factors that have an influence are the speed of the screw, particularly in an extruder (too fast a screw will lower the let-down ratio), and the temperature profile of the barrel. Increasing the temperature at the feed section slightly is said sometimes to result in a higher let-down ratio.

See also L-D ratio.

lettering Numerous types of lettering are used on plastic parts. Lettering can be molded into the part, or it can be applied as a postmolding application generally by printing, decals, labels, etc. In molded parts, raised letters are often less costly than depressed letters because the raised letters are molded from letters recessed in the mold cavity whereas depressed letters require the mold steel to be cut all around them.

A raised letter is visible only if it is at least 3 mil high. Letters that are over 30 mil high should be tapered and have fillets at the base. Raised letters can be decorated or painted by roll coating. With depressed letters, the surface of the part is spray painted and the excess wiped away, leaving paint in the recess.

See also decorating; printing on plastics; offset printing.

light stabilizer Light stabilizers or *ultraviolet* (*UV*) *stabilizers* are used to protect plastics, particularly polyolefins from discoloration, embrittlement, and eventual degradation by UV light. Protecting plastics from the degradative attack of UV energy is critical for some markets, especially outdoor applications and applications where the plastic parts will be exposed to fluorescent and filtered daylight. (*See* ultraviolet degradation).

The three major classes of light stabilizers are *UV absorbers*, *excited state quenchers*, and *free radical terminators*. Stabilization mechanisms include inhibition of *initiation reactions* by incorporating additives to screen UV energy, to preferentially absorb it, or to quench the excited state; and inhibition of the *propagation reaction* process by incorporating additives that will react chemically with the free radicals and hydroperoxides as soon as they are formed to render them harmless. Each class is named for the mechanism by which it prevents degradation.

The major types of light stabilizers may be categorized by their chemistries as shown in Table L.2. A major trend is toward the use of several additives because combinations can improve performance as well as price. Products have been introduced in concentrate, flake, and liquid forms.

Table L.2 Major Types of Light Stabilizers (Ref: Kattas, L., et. al., "Plastic Additives", *Handbook of Modern Plastics*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

Type	Representative Chemistry
UV light absorbers	
Benzophenone	2-hydroxy-4-methoxybenzophenone
	2-hydroxy-4-*n*-octoxybenzophenone
	2,4-dihydroxy-4-*n*-dodecycloxybenzophenone
Benzotriazole	2,2-(2-hydroxy-5-tert-octylphenyl) benzotriazole
	2-(3′-tert-butyl-2-hydroxy-5-methylphenyl)-5-chlorobenzotriazole
	2-(3′,5′-di-tert-butyl-2′-hydroxyphenyl)-5′-chlorobenzotriazole
	2-(2′hydroxy-3′-5′-di-tert amyl phenyl) benzotriazole
	2-(2-hydroxy-5-methylphenyl) benzotriazole
Phenyl esters	3,5-di-t-butyl-4hydroxybenzoic acid
	N-hexadecyl ester
Diphenylacrylates	Ethyl-2-cyano-3,3-diphenyl acrylate
	2-ethylhexyl-2-cyano-3,3-diphenyl acrylate
Excited state quenchers	
Nickel compounds	Nickel dibutyldithiocarbamate
	2,2′-thiobis (4-octylphenolato)-*n*-butylamine nickel II
Free-radical terminators	
Hindered amine light stabilizers (HALS)	Bis (2,2,6,6-tetramethyl-4-piperidinyl)
	N,N-bis (2,2,6,6-tetramethyl-4-piperidinyl)-1,6-hexane diamine polymer with 2,4,6-trichloro-1,3,5 triazine and 2,4,4-trimethyl-1,2-pentanamine

UV absorbers inhibit initiation of the degradation process. Once they preferentially absorb the UV energy, they convert it into a nondestructive form, infrared energy, which is dissipated harmlessly as heat. Absorbers are more effective in thicker cross sections than in thin ones such as film and sheet, and they may not provide the surface with sufficient protection.

Benzophenone UV absorbers have been used for many years in polyolefins, PVC, and other resins. *Benzotriazole* UV absorbers are highly effective in high-temperature resins such as acrylics and polycarbonates. They also find extensive use in the coatings industry. *Benzoates* and *salicylates*, such as 3,5-di-*t*-butyl-4-hydroxybenzoic acid *n*-hexadecyl ester, function by rearranging in 2-hydroxybenzophenone analogs when exposed to UV light to perform as UV absorbers.

Nickel organic complexes protect against degradation caused by UV light via excited state quenching. These deactivating metal ion quenchers tap the energy before it can break any molecular bonds and generate free radicals. Nickel complexes are primarily used in polyolefin fiber applications. Some examples of nickel complexes are nickel dibutyldithiocarbamate and 2,2′-thiobis (4-octylphenolato)-*n*-butylamine nickel, which are also used in agricultural film because of their resistance to pesticides.

Hindered amine light stabilizers (HALS) are the newest type of UV light stabilizer. Ciba and Sankyo introduced them in 1975. HALS do not screen UV light but stabilize the resin via free radical termination. HALS are used at lower levels than benzophenones and benzotriazoles and are widely used in polyolefins for their cost effectiveness and performance. The successful growth of HALS has been directly related to their substitution for benzophenones and benzotriazoles in many applications as well as their blending with benzophenones.

The choice of UV stabilizer depends on such factors as the application, the polymer's characteristics (particularly its absorption spectrum), the stabilizer's effect on color, and the product's expected life. Another factor that should be considered is toxicity, because most organic UV stabilizers tend to migrate to the surface. Table L.3 shows how the stabilization mechanism can vary from polymer to polymer.

The use of *UV screeners* is another technique for protecting a plastic part from the effects of UV. UV screeners are actually pigments that render the polymer translucent or opaque and absorb or reflect UV light, thus protecting the polymer. *Carbon black* (if the color can be tolerated) is a very effective UV screener. It absorbs over the entire UV and visible range, can be used at low concentrations (1 or 2 percent), and may also act as a free radical scavenger. High loadings of titanium dioxide and other pigments are also effective. *Zinc oxide*, in particular, has been the focus of work with polypropylene.

Other techniques for preventing UV degradation include the alloying or blending of two different polymers (one with better UV stability), surface coating the plastic part with more stable materials (such as an acrylic), or laminating or coextruding an exterior weatherable skin onto parts made from sensitive plastics.

See also ultraviolet stabilizer.

Table L.3 UV Characteristics of Selected Polymers and Conventional Stabilization Methods

Polymer	UV Characteristics of the Unprotected Polymer	Conventional Stabilization Mechanism
ABS	Very susceptible to photo-oxidation	UV stabilizers (particularly the hydroxybenzophenones and the hydroxybenzotriazoles). Also, blend ABS with PVC or cap the ABS part with a stable film like acrylic. Some hindered amines are also being used especially in blends with absorber systems
Acrylic	Have good inherent light stability but will cloud and yellow without stabilizers	Absorbers, quenchers and HALS are used, but only absorbers are recommended for protecting whatever is underneath an acrylic substrate
Cellulosics	Successfully stabilized with a number of different stabilizers	Aryl esters (resorcinol monobenzoate). Also salicylates, hindered amines, then benzophenones, and the benzotriazoles
Epoxies	Stability is not long lasting even with stabilizers	Benzophenones, the benzotriazoles, and the hindered amines
Nylons	Retain properties on weathering, but will yellow with outdoor exposure	Metallic salts (especially copper and manganese)

Polycarbonates	Will discolor fairly rapidly, embrittle, and lose gloss	Absorbers such as benzotriazoles.
Polyethylene	Undergoes photo-oxidation fairly rapidly	Absorbers especially 2-hydroxy-4-alkoxy benzophenones Pigments, such as carbon black, also can serve as UV stabilizers. Pheonlic antioxidants, hindered amines, and metal salts are effective in pigmented polyethylene.
Polypropylene	Similar to polyethylene	Similar to polyethylene
Polystyrene	Have a tendency to yellow rather quickly on exposure to UV (especially impact grades)	Hydroxyphenylbenzotriazoles and the hydroxybenzophenones. Also aryl esters and hindered amines
Polyurethanes	Poor weatherability	Hindered amines (alone or in combinations with a UV absorber)
Polyvinyl Chloride	Poor resistance to UV induced discoloration and degradation	Benzotriazoles and benzophenones
Thermoplastic polyester (PET and PBT)	Good, weatherable materials, but can show yellowing and loss of gloss	Aryl esters, hydroxybenzophenone and hydroxybenzotriazole
Unsaturated polyesters	Loss of gloss and change of color	Hydroxybenzophenone or the application of weatherable gel coats

light transmission and color Light transmission is the percentage of incident light transmitted by the material. It is measured by ASTM D672 and is dependent on the use of a light source and a photoelectric cell.

Plastics range from opaque to transparent. Many have greater transmission than glass. In plastics, the extent of transmission and wave scattering is independent of wavelength, and plastics in their purest form have no color of their own. As impurities are introduced, a plastic becomes more translucent than opaque and begins to acquire a yellowish tinge.

Most plastics transmit at UV wavelengths, and these plastics are often affected by UV-caused degradation. This degradation almost always manifests itself in color deterioration. However, in many plastics deterioration can extend to a significant loss in mechanical and other properties.

See also ultraviolet degradation.

lignin Lignin is a colorless to brown crystalline product recovered from the paper-pulp sulfite liquor. It is generally available in powder form and used as an extender in furfural and phenolic molding compounds. Lignin is also used as a low-cost extender in adhesives and coatings, especially those used in the construction industry. It is also used as a corrosion inhibitor and as a natural binder to make low-pressure laminates from compressed wood products.

limiting oxygen index The limiting oxygen index (LOI) test is a method used to assess the relative flammability of polymeric materials. This index is a measure of the percentage of oxygen in an oxygen-nitrogen mixture, which will just support burning under specific test conditions. The limiting oxygen index apparatus and test procedure are specified under ASTM D2863.

Because the oxygen content of air is 21 percent, materials having LOI values greater than 21 will not burn in air. Test conditions must be duplicated exactly; thus the LOI is not an absolute measure of a polymer's flame retardance. However, it is often used as a relative scale to compare one polymer with another. Table L.4 lists representative LOI values of various polymeric materials.

See also flammability.

linear polymer A linear polymer is a long-chain polymer built up by the repetition of small, simple chemical units much as a chain is built up from its links. If a polymer is built from strictly difunctional monomers, the result is a linear polymer chain. The term is somewhat misleading because the molecules are never stretched out in a truly linear fashion. In general, an isolated linear molecule assumes a more or less random twisted and tangled configuration when not subjected to external stress.

A linear polymer is opposed to a polymer that is *branched* (i.e., having many side chains) or networked in a three-dimensional *crosslinked* configuration. The repeat unit (or *mer*) of the polymer is usually equivalent or nearly equivalent to the *monomer*, or starting material from which the polymer is formed.

See also branched polymer.

Table L.4 Limiting Oxygen Index (LOI) Values of Various Polymeric Materials (Ref: Schwartz, S.S., and Goodman, S.H., *Plastic Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 33)

LOI of Various Plastics	
Plastic	LOI, %O_2
Polyacetal	15.0
Poly(methyl methacrylate)	17.3
Polyethylene	17.4
Polypropylene	17.5
Polystyrene	17.8
Poly(4-methylpentene)	18.0
Filter paper (cellulose)	18.2
ABS resin	18.8
Cellulose acetate	19.0
Styrene-acrylonitrile	19.1
Poly (ethylene terephthalate)	20.0
Birch wood	20.5
Poly(vinyl fluoride)	22.6
Chlorinated polyether (Penton)	23.2
Noryl 731	24.3
Nylon 66	24.3
Polycarbonate	24.9
Nylon 6	26.4
Poly(phenylene oxide)	30.0
Polysulfone, P-1700	30.0
Polyimides	31–45
Polyimide (Kapton film)	36.5
Polysulfone (PES)	38.0
Poly(phenylene sulfide)	>40.0
Poly (vinyl chloride)	40.3
Poly (vinylidene fluoride)	43.7
Chlorinated PVC	45.0
Polysulfone (Astrel)	>50.0
Poly (vinylidene chloride)	60.0
Polytetrafluoroethylene	95.0

LOI of High Performance Fabrics	
Fabric[*]	LOI, %O_2
Untreated cotton	16–17
FR treated cotton	31–32
Natural Nomex	27–28
Dyed Nomex	25–27
Kynol	29–30
Fypro	29–30
Durette	35–38
PBI (polybenzimidazole)	38–43
Nomex HT-4	42–46
PBI-S	42–49

[*] Weight: 4.5–7.0 oz/yd^{2}.

LOI of Spun Fabrics	
Fabric[†]	LOI, %O_2
Acrilan (acrylic)	18.2
Arnel triacetate (cellulose ester)	18.4
Acetate (cellulose ester)	18.6
Polypropylene	18.6
Rayon	19.7
Cotton (greige)	20.1
Nylon	20.1
Polyester	20.6
Wool (dry cleaned)	25.2
Dynel (modacrylic)	26.7
Rhovyl 55 (polyvinyl chloride)	27.1
Nomex N-4272 (aromatic polyamide)	28.2

[†] Weight: 4.8–7.0 oz/yd^{2}.

linters Linters are short cotton fibers that adhere to the cottonseed after ginning. They are used in *rayon* manufacture, as fillers for plastics, and as a base for the manufacture of cellulosic plastics.

liquid crystal polymer (LCP) Liquid crystal polymers are polymers that spontaneously order themselves in the melt, allowing relatively easy processing at relatively high temperatures. They are characterized as long molecules parallel to each other in large clusters. Chemically, they are aromatic copolyesters. The presence of phenyl rings in the backbone of the polymer gives the chain rigidity. These materials are self-reinforcing with high mechanical properties, but as a result of orientation the properties are anisiotropic. The phenyl ring also helps increase the heat distortion temperature.

Liquid crystal polymers include *Victrex* (ICI), *Vectra* (Hoescht Celanese), and *Xydar* (Amoco). These materials are known for their high temperature resistance, particularly heat distortion temperature (170–350°C). They have excellent mechanical properties, especially in the flow direction. For example, in unfilled polymers, the tensile strengths can vary from 165 to 230 MPa, flexural strength from 169 to 256 MPa, and flexural modulus from 9 to 12.5 MPa. LCPs are also known for good solvent resistance and low water absorption compared to other heat-resistant polymers. They have good electrical insulation properties, low flammability with a limiting oxygen index in the range of 35 to 40, but a high specific gravity of about 1.4. LCPs show little dimensional change when exposed to high temperatures, and they have a low coefficient of thermal expansion.

The disadvantages of these materials in addition to their anisotropy are their high price and poor abrasion resistance. Because of the oriented nature of the polymer chains, surface fibrillation can occur quite easily.

Process temperatures are normally below 350°C. LCPs are processable on a variety of conventional equipment. The LCPs generally have low melt viscosity as a result of their ordered melt. They should be dried before use to avoid degradation. LCPs can be injection molded on conventional equipment, and regrind may be used. Mold-release agents are generally not required. Part design for LCPs requires careful consideration of the anisotropic nature of the polymer. Weld lines can be very weak if the melt meets in a “butt” type of weld line. Other types of weld lines show better strengths.

LCPs are used in automotive, electrical, chemical processing, and household applications. One popular application is for oven and microwave cookery.

liquid injection molding

See reaction injection molding.

liquid transfer molding

See resin transfer molding.

litharge Litharge is a yellow lead monoxide, PbO, also called *massicot*. It is used as an inorganic accelerator, as a vulcanizing agent for neoprene, and as an ingredient of paints. With glycerin, litharge is used as a cement (*litharge cement*), which is useful for plumbing applications and as a potting for electronic equipment. A mixture of one part slightly diluted glycerin with two to three parts of lead oxide requires approximately 1 day to form a crystalline compound. Litharge is not used much today because of the toxic effects of lead.

living polymer In *anionic polymerization*, “living” polymers are polymer species resulting from a growing polymer where termination is lacking. Because the termination step usually involves transfer to some species not essential to the reaction, anionic polymerization with carefully purified reagents may lead to systems in which termination is absent. An example of this can be prepared by polymerizing styrene with sodium naphthalene. The resulting polymer can have an extremely narrow distribution of molecular weight and for all practical purpose be essentially monodisperse. The "living" polymer can be "killed" by addition of a terminating agent (e.g., water) at the end of the reaction.

See also anionic polymerization.

loading shoe mold The loading shoe mold is a variation of the *flash mold* and similar to a *landed-plunger mold*. It derives its name from the floating plate, which is mounted between the plunger plate and the cavity plate. This floating plate has the function of providing greater loading space for the bulk of the molding material.

Because the loading shoe's only function is to contain molding material, it is used only in compression molding. It also allows more ready access to the cavity for placing inserts in the mold. High-impact products may be produced in this type of mold; therefore, it is frequently used with impact resistant materials.

loading tray The loading tray or *charging tray* is a device in the form of a specially designed tray that is used to load the charge simultaneously into each cavity of a multicavity mold by the withdrawal of a sliding bottom from the tray.

loading well The loading well is the top area of a mold cavity, the size of which is dictated by the *bulk factor* of the molding compound. High-bulk-factor materials require deeper wells than low-bulk-factor materials.

locating ring The locating ring is a device for making foolproof the setting up of adjacent parts of a mold or fixture. For example, the locating ring affects the alignment of the nozzle of an injection molding cylinder with the entrance of the sprue bushing.

London dispersion forces London dispersion forces are weak intermolecular forces that are based on transient dipole-dipole interaction. These are among the type of forces that hold molecules together for cohesive strength.

loop strength Loop strength or *loop tenacity* is the strength value obtained by pulling two loops, such as two links in a chain, against each other to demonstrate the susceptibility of a fibrous material to cutting or crushing.

loss factor *Electrical loss factor* (ASTM D150) is the product of the dissipation factor and the dielectric constant of a given plastic or other electrical insulation material. It is a measure of the total power loss in an electrically insulated current carrying system. Generally, low-loss-factor plastics are more efficient electrical insulators. (*See also* dielectric properties.)

Mechanical loss factor is a measure of mechanical or acoustical damping in polymer systems. It is the tangent of the loss angle between stress and strain. (*See also* hysteresis.)

loss tangent (loss angle)
See dissipation factor.

low-loss plastic
See electronic plastic.

low-pressure laminate Low-pressure laminate refers generally to laminates than can be molded and cured in the pressure range below 400 psi. Laminates that are processed by the mere contact of plies at atmospheric pressure and laminates that are made by simple contact roll pressure are considered low-pressure laminates. Pressure is usually sufficient for removal of trapped air in the laminate and assurance of a dense part.

See also continuous laminate.

low-profile additive Low profile additives are thermoplastic or elastomeric polymers that are compounded into polyester/glass composites in the formulation step to improve surface appearance. Without low-profile additives, the composite may exhibit several unwanted surface characteristics due to the high volumetric shrinkage that occurs during polymerization of the unsaturated polyester resin. These problems include poor surface appearance; fiber prominence; warpage of molded parts and inability to maintain close tolerances; internal cracks and voids, particularly in thick sections; and notable depression (or sink) on the surface opposite reinforcing ribs and bosses.

During the cross-linking of the unsaturated polyester, the thermoplastic low-profile agent becomes incompatible with the resin matrix. The thermal expansion of the thermoplastic phase, under heat and pressure of the molding operation, offsets the polymerization shrinkage of the thermosetting matrix. The effect of this reduction or elimination of polymerization shrinkage is to eliminate warpage, internal stress, and fiber prominence. Currently, there are five types of thermoplastics commercially used as low-profile additives: polyvinyl acetates, polymethyl methacrylates, nylon, polystyrenes, and polyethylene.

Rubber or elastomeric additives have been found to be effective low-shrink/low-profile additives for sheet and bulk molding compounds (SMC and BMC). These additives include butadiene/styrene and styrene/butadiene/styrene. For maximum surface properties, 15 weight percent of the additive gives good molded appearance even in large, relatively flat, thin panels.

Major suppliers of low-profile thermoplastic additives include Discas Inc. and Union Carbide Chemicals & Plastics Co. Major suppliers of low-profile elastomeric additives include Dexco Polymers, Shell Chemical Co., and Union Carbide Chemicals & Plastics Co.

low-profile resin Low-profile resins are special commercially available polyester resin systems for reinforced plastics that are combinations of thermoset and themoplastic resin. Although the terms *low profile* and *low shrink* are sometimes used interchangeably, there is a difference. Low-shrink resins contain up to

30 weight percent thermoplastic polymers, whereas low-profile resins contain from 30 to 50 weight percent.

Low shrink offers minimum surface waviness in the molded part (as low as 1 mil/in. mold shrinkage); low profile offers no surface waviness from 0.5 to 0 mil/in. of mold shrinkage. Low-profile additives can also be used for improved surface appearance.

See also low-profile additive.

low-temperature properties Low-temperature properties are generally of importance for elastomeric materials. These properties indicate a stiffening range and brittle point for the elastomer. Stiffening range is the more useful of these two but is difficult to measure. Brittle point has little meaning unless the deforming force and rate of strain are known. Time is an important consideration as well as temperature. Some characteristics change as the temperature is lowered and held: hardness, stress-strain rate, and modulus, for example. With many materials, crystallization occurs, at which time the rubber is brittle and will fracture easily.

Plastics generally increase in strength and become more rigid at low temperature. However, many plastics will become brittle. Brittleness results when a material loses its yield. Brittleness can result from crystallization, although many linear polymers become brittle without crystallizing. Rubber-type materials exhibit brittle behavior similar to that of thermoplastics. It also should be noted that some plastics have useful properties below their brittle points (e.g., polystyrene and polymethyl methacrylate).

Cross-linked plastics, such as phenolics and epoxies, are not particularly affected by low temperatures. No crystallization can occur because the polymer chains are held in place by the cross-links (chemical bonds). Highly cross-linked polymers, such as the polyimides and polybenzimidazoles, are usually brittle at room temperature and maintain about the same properties down to the cryogenic temperature range. Polyurethanes and epoxy polyamides are noted for having very high tensile strength and toughness down to the cryogenic temperature range.

The effect of low temperatures on various laminates is shown in Fig. L.3. Tensile properties generally improve as the temperature is reduced. However, impact properties may be degraded. Certain adhesives show a similar trend regarding increase in tensile strength and reduction in impact strength as the test temperature is reduced. However, with adhesives in metal joints, many of the problems that occur at lower temperatures are due to thermal expansion differences between the substrate and the adhesive rather than the cohesive properties of the adhesive itself.

There are many tests to measure cold temperature properties, but for a general comparison of elastomers, it is simplest to bend the specimen manually at the test temperature for a difference in feel or stiffness or actual breakage. Impact testing is often used to determine the brittle point. All tests must be made in the cold box, and precautions must be taken so that the sample does not warm up during the test. The specimens warm very quickly and will produce false results unless extreme care is taken in the testing.

See also cryogenic temperature; brittleness temperature.

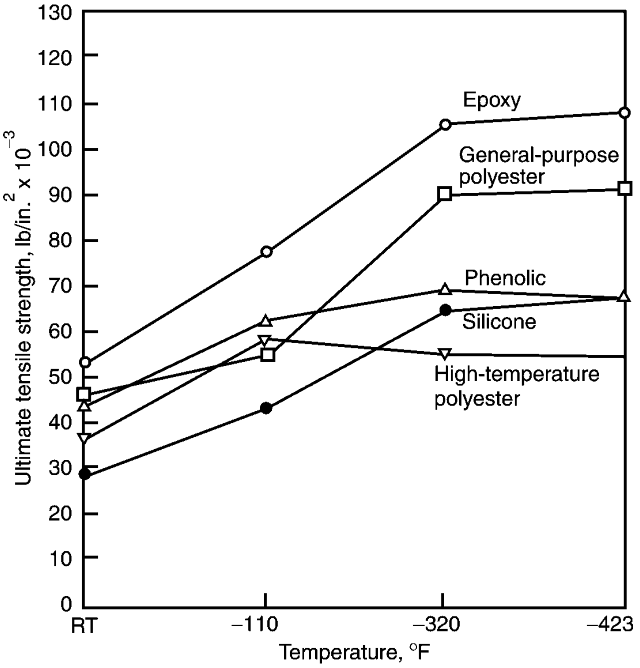

Figure L.3 Cryogenic strength of various laminates. (Landrock, A.H., "Properties of Plastics and Related Materials at Cryogenic Temperatures", Plastics Report No. 20, Picattiny Arsenal, 1975)

lubricant bloom Lubricant bloom is an irregular, cloudy, greasy film on the plastic surface as a result of the lubricant additive within the polymer migrating to the surface. This generally occurs at elevated temperature or with sufficient time at ambient temperatures.

See also haze.

lubricant Lubricants represent a broad class of materials that are used to improve the flow characteristics of plastics during processing. They do this by lowering the melt viscosity or by preventing the polymer from sticking to the metal surfaces of the processing equipment. The benefits are reduced shear and equipment wear, increased rates of production, and decreased energy consumption. Lubricants can also act as melt promoters and antiblock, antitack, and antistatic agents as well as color and impact improvers.

Most lubricants are used in polyvinyl chloride (PVC) processing, where they are critical to the extrusion, calendering, and injection molding processes. They are used generally in packaging film to prevent sticking to the metal processing equipment. In addition to PVC, lubricants have been used in the polyolefins, styrenics (including expandable polystyrene), and some thermosets. Considerable activity has been devoted in developing lubricants (e.g., secondary amides and benzoic acid esters) for engineering thermoplastics. Additives similar to those used as lubricants are also often used as mold-release agents. (*See* mold-release agents.)

Selection of lubricants depends on the type of polymer as well as the process by which it is manufactured. The lubricant's compatibility with the hot resin, the lack of adverse effects on polymer properties, good transparency, regulatory approval, and the balance of other additives in the polymer drive the selection process. The amount of lubricant used can also affect the final polymer properties. Overlubrication can cause excessive slippages, and underlubrication can cause degradation and higher melt viscosities.

The two general classifications of lubricants are internal and external. Several chemicals are used as both internal and external lubricants. *External lubricants* affect the properties between resin particles before fusion and between polymer melt surfaces after fusion. External lubricants are generally incompatible with the polymer itself. These lubricants function by coating the process equipment and reducing the friction at the point of interface. They delay fusion and give melt control and the desired polymer flow to such applications as rigid PVC pipe, siding, and window frames. The influence of lubricants between resin molecules after fusion can be considered internal. *Internal lubricants* are usually chemically compatible with the polymer. They act by reducing friction between polymer molecules by reducing van der Waals forces.

Metallic soaps and salts of stearic acid and other organic acids are used both as lubricants and as auxiliary heat stabilizers. Metallic stearates are the most widely used lubricants. They are predominantly used in PVC, but also find use in polyolefins, ABS, polyesters, and phenolics. The primary disadvantage of metallic stearates is their lack of clarity. *Calcium stearate*, the most common metallic stearate, is primarily used as an internal lubricant, but in PVC applications it provides external lubrication and mold-release characteristics while also acting as a heat stabilizer. In addition to PVC, the calcium sterarates go into polypropylene, polystyrene, and ABS. Zinc stearates are used in crystal and impact polystyrene, ABS, and phenolics.

A general class of lubricants is *alkyl acids* and their derivatives (esters, amides, alcohols, and metallic salts). *Esters*, including fatty esters, polyol esters, and wax esters, are reasonably compatible with PVC. They are also used in polystyrene and acrylic polymers. High-molecular-weight esters are used as external lubricants, and low-molecular-weight esters are used as internal lubricants. Simple *primary fatty amides* possess unique mold-release properties and are used as slip and mold-release agents for polyolefins and other polymers. The more complex bisamides, such as *ethylene bis-stearamide*, offer mold release as well as internal and external lubricity in materials such as PVC and ABS. *Fatty alcohols* are used primarily in rigid PVC. They are used as both internal and external lubricants, and they are useful when clarity is important.

Waxes are often used as multifunctional lubricants. These are generally paraffin hydrocarbon wax (melting point 65–75°C) and polyethylene wax (melting point 100–130°C). Being nonpolar, they are very incompatible with PVC, so they are used as external lubricants. Paraffin lubricants are typically used in rigid PVC pipe and profile extrusion applications at additive levels of 0.5–1.5 phr. Partially oxidized polyethylene wax works well as an external lubricant for PVC by delaying fusion and is almost always combined with calcium stearate for melt flow control. Polyethylene waxes are used in rigid extrusion up to 0.3 phr, in injection molding up to 1 phr, and in semirigid and flexible PVC up to 0.5 phr. They are used in a wide range of thermosets and thermoplastics.

Other lubricants have been developed. *Silicone fluid* and its concentrates have been used with engineering thermoplastics. The *fluoroplastics* (e.g., polytetrafluoroethylene, PTFE) in powder form are also finding use as lubricants. *Molybdenum disulfide* is also finding uses in various resins and blends as a solid lubricant.

Typical suppliers of fatty acid amide lubricants include Ashland Chemical Inc., C. P. Hall Co., and Witco Corp. Typical suppliers of fatty acid esters include Akzo Chemical Inc., Eastman Chemical Products, and ICI Americas Inc. Typical suppliers of metallic stearates include Hammond Lead Products, Inc., Harwick Chemical Corp., and Witco Corp. Typical suppliers of molybdenum disulfide include Acheson Colloids Co., CSA Chemicals, and Specialty Products Co. Typical suppliers of paraffin waxes include Astor Wax Corp. C. P. Hall Co., and Hoechst Celanese Corp. Typical suppliers of polyethylene waxes include Astor Wax Co., Eastman Chemical Products and Exxon Chemical Co. Typical suppliers of silicone lubricants include Ashland Chemical Inc., Dow Corning Corp. and Wacker Silicones Corp. Typical suppliers of fluorocarbon lubricants include Acheson Colloids Co., DuPont, and Harwick Chemical Corp.

luminescent plastic By incorporating luminescent and phosphorescent or fluorescent pigments in a plastic compound, molded or fabricated products are produced that can glow in the dark. The effective life of these pigments is 10–12 h.

M

macerate Macerate is a process to chop or shred fabric for use as a filler for a molding resin. Macerated fabric and cord lead to compounds with 10 or more times the impact strength of corresponding wood flour-filled compositions. As a noun, *macerate* refers to a molding compound containing chopped or shredded fabric.

machine shot capacity In injection molding, the machine shot capacity is the maximum weight of thermoplastic resin that can be displaced or injected by the injection ram in a single stroke.

machining of plastics The major machining operations commonly used in the manufacture of plastic products include the following: sawing and cutting, filing, grinding and sanding, routing, milling and turning, drilling, and taping and threading. Machining of plastic parts is normally used only if there is no other way of designing the functional requirement (hole, rounded edge, etc.) into the primary molded part. Some finishing operations on molded articles can be avoided or reduced by careful design of the part and the mold. For example, placing the flash lines and gates in selected areas could greatly reduce filing needed to remove excess material, and holes molded into the part could eliminate the need for postmold drilling.

Machining requires skilled labor, equipment, and other production resources. However, in certain cases, it can prove to be the least costly production method. If the total number of parts to be produced is small, machining of stock shapes is generally less expensive than investing in expensive and complex molding.

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There are several factors to consider when machining plastics: (1) the material's physical properties, such as toughness or modulus; (2) the material's thermal properties, such as thermal expansion coefficient, thermal conductivity, and glass transition temperature; and (3) stress effects on the plastic, either internal (molded in) stress or external stress from the postprocessing operation.

Brittle plastics tend to break or chip when under a concentrated load such as a drill bit. Softer plastics tend to tear when local load concentrations occur. The modulus of elasticity of plastics is 10–60 times smaller than for metals, and this resilience permits much greater deflection of the work material during cutting. Thermoplastics, especially, must be held and supported firmly to prevent distortion, and sharp tools are essential to keep cutting forces to a minimum.

Plastics have a relatively high coefficient of thermal expansion, and they recover elasticity during and after machining so that drilled or tapped holes often end up tapered or of smaller diameter than the tool. Turned diameters can end up larger than the dimensions measured immediately after the finishing cut. Plastic materials are also very good thermal insulators. Heat is difficult to conduct away from a plastic surface undergoing a machining operation. This results in the plastic expanding because of the heating and, perhaps, even deforming or melting because of the built-up frictional heat. Sufficient clearances must be provided on cutting tools to prevent rubbing contact between the tool and the work. Tool surfaces that meet the plastic part must be polished to reduce frictional drag and resulting temperature increase.

Internal stresses that are molded into the plastic part can be released when in contact with heat or chemicals or during cutting. These stresses, when released on the surface of the part, cause stress cracking or crazing. They are noticeable as microcracks or fractures on the surface of the sections under highest stress. When large internal stresses are released by heating of the part through a finishing operation, it could result in warpage and deformation. Like some metals, plastics may need to be annealed before finishing to avoid warpage or undesirable stress relief during postprocessing. Plastic resin suppliers can provide specific annealing instructions for individual plastics.

Thus there are important guidelines to remember when considering machining of plastics:

- Tools must be extremely sharp (tungsten carbide- or diamond-bit tools are recommended for long production runs).
- Adequate tool clearance is essential.
- Compression, thermal expansion, etc. can result in poor dimensional measurements.
- Heat buildup must be minimized (coolants are usually recommended).
- Fast tool speed and slow material feed are generally recommended.
- Parts may need annealing to relieve internal stress.

Because the many types of plastics have a wide range of elastic modulus and heat resistance, each material will have a certain set of optimal machining parameters. Therefore, it is critical to contact the plastic supplier for specific recommendations as to cutting tool configurations, working speeds, and cooling procedures. Appendix I provides plastic machining guidelines for several common plastics and machining operations.

macromolecule Macromolecules are the large molecules that make up high-molecular-weight polymers. Acceptance of the macromolecular concept came about in the 1920s, largely because of the efforts of H. Staudinger, who received a Nobel prize in 1953 for this viewpoint. Before the macromolecule hypothesis, polymers were thought to be colloids or an association of molecules in coordination complexes.

magnetic fillers Magnetizable ceramic-filled polymer resins can be fabricated by various plastic and rubber processes into magnets. Powders such as ferrites (combinations of iron oxide and oxides or carbonates of barium, lead, strontium, or other metals) are used for this purpose. The filler used most frequently is barium ferrite. Rigid magnets can be compression or injection molded; flexible ones are calendered or extruded. The magnetic properties are directly proportional to the loading level of magnetizable filler.

Flexible permanent magnets are used for signs, electric motors, toys, sealing strips, etc. They are fabricated from compounds with up to 90 percent by weight of magnetizable filler. Binders can be chlorinated and chlorosulfonated polyethylene, various vinyl compounds, nitrile rubber, and ethylene/ethyl acrylate copolymers. Magnetization is typically accomplished, via a magnetic field, after extrusion.

Rigid permanent magnets have a smaller market than flexible magnets. These magnets are formed by injection molding or powder metallurgy methods. Major applications are in fractional-horsepower motors, TV components, toys, and latches. The binder for these molding compounds is often nylon.

Major suppliers of magnetic fillers include Bekaert Corp., Novamet, Reade Advanced Materials, and Stackpole Corp.

magnet wire coating Various coatings are used to insulate magnet wire in electrical and electronic applications. These coatings are generally applied to round or rectangular copper or aluminum conductors in a continuous process. The coatings are generally applied as solvent-based enamels of the following types: polyimide, polyvinyl formal, polyamide, acrylic, epoxy, polyurethane, polyester, polyesterimide, fluorocarbon, and ceramic. NEMA (National Electrical Manufacturers Association) standards, tradenames, and properties for various magnet wire coatings are shown in Appendix D.

maleic acid Several esters of maleic acid are commercially available as plasticizers, including the dimethyl, diethyl, dibutyl, and dioctyl esters. Although they are more volatile than the corresponding phthalates, maleic acid plasticizers are of great interest in polymerizations. They are used as “internal plasticizers” or copolymers in many systems.

Maleic acid is also furnished in the form of its anhydride, which is used in the synthesis of alkyd resins and as a hardening agent in alkyd resin enamels and vinyl resin primers for paints.

mandrel Generally, a mandrel is the core around which paper, fabric, or resin-impregnated fiber is wound to form pipes or tubes. In extrusion, a mandrel is the center finger of a pipe or tubing die. In filament winding the mandrel is the form that the resin-impregnated filaments are wound around, cured on, and finally stripped away from to form the final product.

Tooling of mandrels for filament winding can be any type of body of revolution that can be withdrawn from the cured part. Mandrels are made of steel, aluminum, and plaster. Generally, mandrels are made with a taper and highly polished surfaces to aid in stripping the part from the mandrel after it is cured.

Some mandrels must be made collapsible to facilitate their removal because of geometry of the part or excessive shrinkage of the resin system. Other tools are made of breakaway plasters or of materials that can be dissolved or melted out. Inflatable mandrels have also been used for these purposes.

See also filament winding.

manifold As used in blow molding and sometimes in injection molding, manifold is a term that refers to the distribution or piping system that takes the single-channel flow output of the extruder or injection cylinder and divides it to feed several blow-molding heads or injection nozzles.

mass spectrometer Mass spectrometers measure the molecular weight of gases. Solid or liquid materials can be heated, and the product passes through a mass spectrometer. Analysis of molecular weights of gases can be used to help identify the compounding ingredients. The mass spectrometer is sometimes used in conjunction with thermogravimetric analysis to identify component products as a function of temperature.

See also thermogravimetric analysis.

mat Mat is a term used to describe a reinforcing material composed of randomly distributed, short, chopped fibers that are mechanically held together in sheet or blanket form. Mats are available in blankets of various widths, weights, and lengths. Mats are commonly used as alternatives to woven fabric (especially glass) in fabrication of laminated plastic forms.

See also glass mat.

matched metal molding Matched metal or *matched metal die molding* is a method of molding reinforced plastics between two close-fitting metal molds mounted in a hydraulic press. It is a variation of the conventional compression molding process. The matched metal molding process uses two metal molds having a close-fitting, telescoping area to seal in the plastic compound being molded and to rim the reinforcement. The reinforcement, usually mat or preform, is positioned in the mold, and the mold is closed and heated. Pressures are generally between 150 and 400 psi. Once the part is cured, the mold is opened and the part is removed.

The advantages of matched metal molding are rapid production rates along with good quality and reproducible parts. The disadvantages are high mold and equipment costs. The parts often require extensive surface finishing.

matrix A matrix is essentially homogeneous material in which the filler system of a polymer formulation resides. In *reinforced composite* parts, the resin matrix is the resin that surrounds and embeds the fiber system. The primary function of the matrix system is to keep the fibers in place in the structure, but the matrix system also distributes and transfers load, protects filaments during fabrication and after cure from the effects of moisture absorption, and controls the electrical and chemical properties of the composite.

The elongation of the resin matrix should be greater than that of the fiber. It should have temperature capability, chemical resistance, and strength suited for the application environment. It must be easily processable into the final composite shape. The matrix must also wet and bond well to the fiber and flow to penetrate the fiber bundles and completely eliminate voids to achieve the properties mentioned above.

Many matrix choices are available, and each type has an impact on the processing techniques, physical and mechanical properties, and environmental resistance of the finished part. Thermoplastic and thermoset materials can be resin matrices. Thermoplastic matrices have been developed to increase hot/wet use temperature and the fracture toughness of composites. Thermosetting resins, however, are more common. The common thermoset matrices for composites include polyester and vinyl esters, epoxy, bismaleimide, polyimide, and cyanate ester and phenolic triazine resins.

See also impregnating resin.

mechanical fasteners A large variety of mechanical fasteners can be used for joining plastic parts to themselves and to other materials. These include:

- Machine screws and bolts
- Self-threading screws
- Rivets
- Spring fasteners and clips

In general, when repeated disassembly of the product is anticipated, mechanical fasteners are used. *Metal fasteners* of high strength can overstress plastic parts, so torque-controlled tightening or special design provisions are required. Where torque cannot be controlled various types of washers can be used to spread the compression force over larger areas.

Parts molded of thermoplastic resin are sometimes assembled with *machine screws* or with *bolts*, *nuts*, and *washers*, especially if it is a very strong plastic. Machine screws are generally used with threaded inserts, nuts, and clips. They rarely are used in pretapped holes. Inserts into the plastic part can be used effectively to provide the female part of the fastener. Inserts that are used for plastic assembly consist of molded-in inserts and postmolded inserts.

Molded-in inserts are inserts that are placed in the mold before the plastic resin is injected. The resin then flows around the part geometry and locks the insert into its body as it hardens. Molded-in inserts provide very high strength assemblies and relatively low unit cost. However, molded-in inserts could increase part cycle time while the inserts are manually placed in the mold.

Where the application does not require frequent disassembly, molded-in threads can be used successfully. Coarse threads can also be molded into most materials. Threads of 32 or finer pitch should be avoided, along with tapered threads, because of excessive stress on the part. If the mating connector is metal, overtorque will result in part failure.

Postmolded inserts come in several types: press-in, expansion, self-tapping, thread-forming, and inserts that are installed by some method of heating (e.g., ultrasonic). Metal inserts are available in a wide range of shapes and sizes for permanent installation. Inserts are typically installed in molded bosses, designed with holes to suit the insert to be used. Some inserts are pressed into place, and others are installed by methods designed to limit the stress and increase strength. Generally, the outside of the insert is provided with projections of various configurations that penetrate the plastic and prevent movement under normal forces exerted during assembly.

Whatever mechanical fastener is used, particular attention should be paid to the head of the fastener. Conical heads, called flat heads, produce undesirable tensile stresses and should not be used. Bolt or screw heads with a flat underside, such as pan heads, round heads, and so forth are preferred because the stress produced is more compressive. Flat washers are also suggested and should be used under both the nut and the fastener head. Sufficient diametrical clearance for the body of the fastener should always be provided in the parts to be joined. This clearance can nominally be 0.25 mm (0.010 in.).

Self-threading screws can either be thread cutting or thread forming. To select the correct screw, the designer must know which plastic will be used and its modulus of elasticity. The general advantages of using these types of screws are:

- They are “off-the-shelf” items
- Low cost
- High production rates
- Minimum tooling investment

The principal disadvantage of these screws is limited reuse; after repeated disassembly and assembly these screws will cut or form new threads in the hole, eventually destroying the integrity of the assembly.

Thread-forming screws are used in the softer, more ductile plastics with moduli below 1380 MPa (200,000 psi). There are a number of fasteners especially designed for use with plastics. Thread-forming screws displace plastic material during the threading operation. This type of screw induces high stress levels in the part and is not recommended for parts made of weak resins.

Assembly strengths using thread-forming screws can be increased by reducing hole diameter in the more ductile plastics, by increasing screw thread engagement, or by going to a larger diameter screw when space permits. The most common problem encountered with these types of screws is boss cracking. This can be minimized or eliminated by increasing the size of the boss, increasing the diameter of the hole, decreasing the size of the screw, changing the thread configuration of the screw, or changing the part to a more ductile plastic.

Thread-cutting screws are used in harder, less ductile plastics. Thread cutting screws remove material as they are installed, thereby avoiding high stress. However, these screws should not be installed and removed repeatedly.

Rivets provide permanent assembly at very low cost. Clamp load must be limited to low levels to prevent distortion of the part. To distribute the load, rivets with large heads should be used with washers under the flared end of the rivet. The heads should be three times the shank diameter. Riveted composite joints should be designed to avoid loading the rivet in tension. Generally, a hole 1/64 in. larger than the rivet shank is satisfactory for composite joints. A number of patented rivet designs are commercially available for joining aircraft or aerospace structural composites.

Figure M.1 Standard rivet heads for plastics. (Ref: "Engineering Plastics", *Engineered Materials* handbook, vol. 2, ASM International, Materials Park, OH, 1988)

Push-on spring steel fasteners can be used for holding light loads. Spring steel fasteners are simply pushed on over a molded stud (see Fig. M.2). The stud should have a minimum 0.38-mm (0.015 in.) radius at its base. Too large a radius could create a thick section, resulting in sinks or voids in the plastic molding.

mechanical joining of plastics There are instances when adhesive bonding, thermal welding, or solvent cementing are not practical joining methods for plastic

Figure M.2 Push-on spring fasteners for plastics. (Ref: “Engineering Plastics”, *Engineered Materials Handbook*, vol. 2, ASM International, Materials Park, OH, 1988)

assembly. This usually occurs because the optimum joint design is not possible, the cost and complexity are too great, or the skill and resources are not present to attempt these forms of fastening. Another common reason for foregoing bonding or welding is when repeated disassembly of the product is required. Fortunately, when these situations occur, the designer can still turn to mechanical fastening as a possible solution.

There are basically two methods of mechanical assembly for plastic parts. The first uses fasteners such as screws or bolts; the second uses interference fit such as press fit or snap fit and is generally used in thermoplastic applications. This latter method of fastening is also called design for assembly of self-fastening. If possible, the designer should try to design the entire product as a one-part molding or with the capability of being press fit or snap fit together because it will eliminate the need for a secondary assembly operation. However, mechanical limitations often will make it necessary to join one part to another with a fastening device. Fortunately, there are a number of mechanical fasteners designed for metals that are also generally suitable with plastics and there are many other fasteners specifically designed for plastics. Typical of these are thread-forming screws, rivets, threaded inserts, and spring clips.

As in adhesive bonding or welding, special considerations must be given to mechanical fastening because of the nature of the plastic material. Care must be taken to avoid overstressing the parts. Mechanical creep can result in loss of preload in poorly designed systems. Reliable mechanically fastened plastic joints require:

- A firm, strong connection
- Materials that are stable in the environment
- Stable geometry
- Appropriate stresses in the parts including a correct clamping force.

In addition to joint strength, mechanically fastened joints should prevent slip, separation, vibration, misalignment, and wear of parts. Well-designed joints provide the above without being excessively large or heavy or burdening assemblers with bulky tools. Designing plastic parts for mechanical fastening will depend primarily on the particular plastic being joined and the functional requirements of the application.

See also mechanical fasteners; self-fastening

melamine formaldehyde (MF), melamine phenol formaldehyde (MPF)

See amino resin.

melt The melt is molten plastic during the phase of the molding cycle when the material is in the fluid or semifluid state.

melt extractor The term melt extractor refers generally to a type of injection machine *torpedo*, but the term could refer to any type of device that is placed in a plasticating system for the purpose of separating fully plasticated melt from partially molten pellets and material. The melt extractor, therefore, insures a fully plasticated discharge of melt from the plasticating system.

melt fracture Melt fracture is an instability in the *melt flow* through a die starting at the entry to the die. As the extrusion rate is increased, the extrudate begins to exhibit roughness and, thereafter, an irregular, distorted profile. This phenomenon is known as melt fracture.

Melt fracture can be minimized by increasing the die length, smoothly tapering the entrance to the die, and raising the die temperature. Melt fracture leads to surface irregularities on the finished parts such as a regular helix or irregularly spaced ripples.

melt index (melt flow index) The melt index or melt flow index is the amount of thermoplastic resin, in grams, which can be forced though a 0.0825-in. orifice when subjected to 2160 gms force in 10 min at 190°C. An elementary capillary rheometer (extrusion plastometer) is used to determine the melt index. ASTM D1238 provides a method of measuring the melt flow index.

The melt flow index provides some indication of the molecular weight of a polymer (the higher the molecular weight, the lower the melt flow index) and of the ease of processing (the greater the ease of processing, the higher the melt flow index). However, the melt flow index is also greatly influenced by a number of other factors, including polymer chain branching, polymer stability, and the polymer composition.

melting temperature, T_m Melting temperature (T_m) is a true transition temperature. This means that at T_m, both the liquid and solid phases have the same free energy. Although most semicrystalline polymers show a melting temperature range, pure amorphous polymers do not have a defined T_m at all. Similar to the glass transition temperature (T_g), T_m can be estimated from the molecular structure of the polymer.

Plastics show T_m as low as 2°C for polyisobutylene and as high as 455°C in polyethylene terephthalamide. ASTM methods D2117 and D3418 describe methods for measuring the melt temperature.

melt-processable rubber (MPR) Melt-processable rubbers (MPR) are amorphous polymers with no sharp melt point that can be processed in both resin melt and rubber processing machines, injection molded, extruded, blow molded, calendered, and compression molded. MPR is usually composed of halogenated polyolefins with reactive intermediate-stage ethylene interpolymers that promote hydrogen bonding.

The flow properties are more similar to rubber than to thermoplastics. The polymer does not melt by externally applied heat alone but becomes a high-viscosity, intractable semifluid. It must be subjected to shear to achieve flowable melt viscosities, and shear force applied by the plasticating screw is necessary. Without applied shear, melt viscosity and melt strength increase too rapidly in the mold. Even with shear and a hot mold, as soon as the mold is filled and the plasticating screw stops or retracts, melt viscosity and melt strength increase rapidly.

Proponents of MPR view its rheology as a processing cost benefit by allowing faster demolding and lower processing temperature settings that significantly reduce cycle time. High melt strength can minimize or virtually eliminate distortion and sticking, and cleanup is easier. However, the halogen content of MPRs requires corrosion-resistant equipment and tool steels along with adequate venting.

MPRs have a good degree of weather and chemical resistance. They are also used in applications requiring vibration absorption characteristics. Typical durometer hardnesses are Shore A 60, 76, and 90. MPRs are compounded with various property enhancers, especially stabilizers, plasticizers, and flame retardants.

Applications for MPRs include automotive window seals and fuel filler gaskets, industrial door and window seals and weather stripping, wire/cable covering, and hand-held power tool housing/handles. Nonslip soft-touch tool handles provide weather and chemical resistance and vibration absorption. Translucent grades are extruded into films for face masks and tube/hosing, and they are injection molded into flexible keypads for computers and telephones. Certain grades are paintable without a primer.

Alcryn (Advanced Polymer Alloys Division of Ferro Corporation) is an example of a melt-processable rubber. These are partially cross-linked halogenated polyolefin MPR blends. The specific gravity ranges from 1.08 to 1.35.

melt spinning Melt spinning is one of several processes used in the spinning of polymeric fibers. Melt spinning is basically an extrusion process. The polymer is plasticized by melting and is pumped at a constant rate under high pressure through a plate called a *spinnerette* containing a large number of small holes. The liquid polymer streams emerge downward from the face of the spinneret, usually into air. They solidify and are brought together to form a thread and then wound onto bobbins. A subsequent drawing step is necessary to orient the fibers. The fibers are usually solidified by a cross-current blast of air as they proceed to the drawing rolls.

The denier of the filament is determined not by the diameter of the holes in the spinneret but by the rate at which polymer is pumped through the spinneret and the rate at which the filaments are wound. Speeds of about 2500 ft/min are usually used.

The filaments, as spun, are almost completely unoriented. The drawing step stretches the fibers, orients the molecules in the direction of stretch, and induces high degrees of crystallinity, which is a necessity for good fiber properties. In the drawing step somewhat lower speeds are required than can be achieved in spinning, so the two steps are usually done separately. Nylon fibers are commonly melt spun.

mercaptans Mercaptans are compounds that have an —SH group in their molecular structure. These resins have been investigated primarily as coreactants and curing agents in epoxy resin formulations. Commercial polysulfides, having mercaptan-containing groups, have had the most acceptance. These compounds contain occasional mercaptans randomly distributed along the chain but for the most part are considered bifunctional.

These curing agents generally are used to develop more flexible epoxy systems. In recent years, the polymercaptans have been marketed as extremely fast (seconds to minutes) room-temperature curing agents. They also enable curing to occur at very low temperatures (e.g., −40 to 0°C). There are also BF_3 adducts that will cure in seconds at room temperature, but they are not active at lower temperatures. These polymercaptans are the basis of the so-called “five minute” epoxy repair kits that are generally available in hardware stores and supermarkets.

metal deactivator Metal deactivators are a type of *antioxidation agent*. Metal deactivators combine with metal ions to limit the potential for chain propagation. Metal deactivators are commonly used in polyolefin inner coverings for wire and cable applications where the plastic comes in contact with metal.

In effect, the deactivator acts as a *chelating agent* to form a stable complex at the metal interface, thereby preventing catalytic activity. The most common deactivators contain an oxamide moiety that complexes with and deactivates the metal ions. A typical product is Ciba-Giegy’s *Irganox MD-1024*.

See also chelating agent.

metal inlay Metal inlays provide a means of decorating plastics. A recess is made in the plastic part, and a thin base metal strip is placed in the bottom of it. On this is placed the dome-shaped inlay with the concave side down. As pressure is applied on the top, the greater resistance on the base metal strip causes the inlay to spread and penetrate the sides of the recess and so be permanently locked into place. With transparent material, a reverse inlay can be used that will be visible from both sides. Inlays can also be placed in a recess of a piece of transparent plastic, which is then cemented onto another piece.

See also decorating.

metallic filaments Metal fibers have found use as fillers and reinforcements in various plastics, but because of the cost factor they are used primarily where such specialized factors as electrical and thermal conductivity and magnetic interaction are required. These are used with various plastic resin matrices to make EMI-compatible housing, thermally conductive heat sinks, and electrically conductive heaters.

Nickel, stainless steel, and silver can be made in fiber form. In addition, conventional glass can be aluminized. Carbon and alloy steels fibers are known for their ferromagnetic properties and high strength and modulus. Carbon and carbon alloys and aluminum and aluminum alloys are known for their high electrical and thermal conductivities. Aluminums have the added advantage of low density and the ability to be colored by anodizing. Nickel- and cobalt-based alloys show strength at elevated temperature. Stainless steels exhibit corrosion resistance.

Major suppliers of metallic filaments include American Fillers and Abrasives, Novamet, Reynolds Metals Co., Transmet Corp. and US Bronze Powders Inc.

metallic pigment Metallic pigments are a class of metal-based pigments generally incorporated into a plastic to produce unusual silvery and other metal-like affects. A common metallic pigment consists of thin, opaque aluminum flakes. These are made by ball milling either a disintegrated aluminum foil or a rough metal powder and then polishing to obtain a flat, brilliant surface on each particle. Copper alloy flakes, known as bronze pigments, are also commonly used.

metallization of plastics Metallization of plastics occurs by depositing metallic coatings on nonconductive, resinous material. The advantages of such a coating on molded plastics are:

1. In certain applications, it makes them adequate substitutes for metal parts of the same size or design.
2. It produces attractive decorative items.
3. It offers a means of exploiting the properties of both the molded plastic and the deposited metal.
4. The combination of plastic and metal serves various functional purposes (e.g., electromagnetic shielding).
5. A suitable metal coating of proper thickness eliminates the undesirable properties of the plastic, such as absorption of oils, solvents, and moisture and permeability to gases.

Electroless plating, *electrolytic plating*, and *vacuum metallizing* are processes commonly used to deposit metal surfaces on plastics materials. However, adhesives or hot-stamp methods can also provide metal surfaces. Some finished plastic parts must have shiny metallic surfaces. Besides providing a decorative finish, metal coatings may provide an electrical conducting surface, a wear- and corrosion-resistant surface, or added heat deflection.

Many plated plastics have drastically altered physical properties compared to as-molded parts. This is due partly to the metal plate itself and partly to the plating process. For a part to be electroplated the part should be smooth and blemish-free. There should be no weld lines or sink marks on the part. The metallic coating will magnify any surface irregularity. There should be very little surface stress, as this will affect adhesion of the coating to the part.

Several plastics can be plated on a commercial scale as shown in Table M.1. Some thermoplastics that can be readily etched and plated include ABS, modified PPO, modified polypropylene, and polysulfone. Some grades of foamed plastics can also be plated. The greatest volume of plated plastic is represented by ABS and modified PPO.

Table M.1 Commercial Plastics Used for Plating. (Ref: Krulik, G.A., "Electrolytic Plating", Plastics *Finishing and Decoration,* D. Satas, ed., van Nostrand Reinhold, New York, 1986)

ABS*	Epoxy/glass†	Polyacetal
PEC*	Polyimide†	Polypropylene
ABS/polycarbonate*	Nylon	Polysulfone
Polystyrene	Polyester	Teflon/glass†
Phenolics†	Polycarbonate	

*Highest volume for plating on plastics.
†Typically plated for printed circuits.

Most of the plated plastics market is for automotive parts. However, significant nonautomotive parts that are plated include marine hardware, plumbing fixtures, packaging, and appliance and furniture hardware. One of the most important applications for electroless-plated plastic parts and all forms of metallized plastics is the radio frequency interference (RFI) and electromagnetic interference (EMI) markets.

electroless plating Electroless plating is a surface treatment process that does not require electric current as does electrolytic plating. Electroless plating deposits a dissolved metal, such as copper or nickel, on the surface of a plastic part through the use of a chemical solution. Also, any plastic part to be plated with the electrolytic process must first be electroless plated to create a conductive surface.

Before electroless plating plastic parts, the surfaces have to be treated to ensure good adhesion. The etching process usually involves the use of a chromic acid solution to provide a microscopically roughened surface to the plastic part. The catalytic process is sometimes referred to as seeding. Here very small particles of an inactive noble metal catalyst, normally palladium, are deposited into the micro-cracks created during the etching process. The palladium will act as active catalyst sites for chemical reduction of the electroless copper or electroless nickel. The electroless metal layer formed is usually pure copper or a nickel/phosphorus alloy, depending on the corrosion requirements of the plated part. In an exterior environment electroless copper has been shown to have better corrosion resistance than electroless nickel. Usually the thickness of the electroless metal is approximately 0.5 mil.

Plastics that have been plated with electroless metal can then be given any electrolytic metal coating. This offers to the design engineer more possibilities regarding metal coating type and thicknesses.

electrolytic process Many plastic products require only electroless plating, but electrolytic plating can be added to the process to provide a metallized surface that is thicker and more like typical metal surfaces. The electrolytic plating process starts at the completion of the electroless process. To electrolytically deposit metal onto a plastic, the plastic must be made electrically conductive and then grounded. The metal to be plated is positively charged, thus allowing the positively charged metal atoms to precipitate onto the negatively charged plastic.

In the electrolytic plating process, first the electroless plated plastic is etched once again, this time usually in sulfuric acid. The part then undergoes a semibright nickel deposition. This layer helps limit and control the amount of current that is exposed to the plated surface and thus protect it from burning off. A mild sulfuric acid bath follows. Bright acid copper is electrolytically deposited on the surface followed by bright nickel. The nickel layer is the immediate layer onto which the chrome will be deposited. The final electrolytically deposited layer is usually chrome, but many other finishes are possible, such as bright brass, satin nickel, silver, black chrome, and gold.

Figure M.3 below shows the various layers in an electrolytic coating. Electrolytic-plated parts are nearly indistinguishable from metal parts, and because of the plastic body, the plated plastic parts are lighter and less expensive, and can be used in a wider range of designs than their metal counterparts. To provide a standard rating for plated plastic, the American Society of Electroplated Plastics (ASEP) has developed a service condition code for common applications.

vacuum metallizing Vacuum metallizing is a physical rather than a chemical process for depositing metal coatings on prepared surfaces. In vacuum metallizing, plastics or films are first thoroughly cleaned and/or etched and given a base coat of lacquer to eliminate surface defects. The parts are then placed in a vacuum chamber with small pieces of coating metal (e.g., chromium, gold, silver, zinc, or aluminum) supported on special heating filaments. Once sealed and under about 0.5 μm of vacuum, the heating filaments are energized until the metal melts and vaporizes. The vaporized metal coats everything it contacts in the chamber, condensing on the cooler surfaces.

Vacuum-metallized parts must be rotated for full coverage, because the metal vapor travels in a line of sight from its origin. Once the plating is accomplished, the vacuum is released and the parts are removed and generally coated with lacquer to help protect its surface.

Figure M.3 Layers of construction: (a) electroless plating, (b) electrolytic plating, and (c) vacuum metallizing. (Ref: Muccio, E.A., “Finishing and Decorating Plastic Part”, *Plastic Part Technology*, ASM International, Materials Park, OH, 1991)

The metal thickness on a vacuum metallized plastic part is generally 3–4 Å ($1-4 \times 10^{-6}$ in.), which is significantly less that the 1-mil thickness for conventional electroplating. Vacuum metallizing is a batch-type process and does not have the continuous flow attributes that electrolytic plating has. However, there are several cost savings associated with vacuum metallizing. Because vacuum metallizing inherently has a thinner coating less metal is used, and no toxic chemicals are involved in the process.

metallocene catalysts Metallocene catalysts are a family of organometallic catalysts, occasionally also referred to as single-site catalysts. They are principally used for the production of special versions of polyolefins with a range of tailored properties including increased strength and toughness, transparency, elastomeric properties, reduced permeability, and improved melt strength and hot tack.

These catalysts represent a significant advance in the polymerization technology over the conventional *Ziegler-Natta catalysts* in a number of respects. Appropriate metallocene catalysts are particularly suitable for the production of highly stereoregular α-olefin polymers, notably polypropylene. They are also more effective than conventional catalysts in polymerizing monomers of large molecular size. The general activity of metallocene catalysts is higher than that of Ziegler-Natta catalysts, and they leave fewer residues in the polymer.

metering screw A metering screw is an extrusion screw that has a shallow constant depth and a constant pitch usually over the last three to four flights.

methyl cellulose Methyl cellulose is a cellulose ether analogous to *ethyl cellulose*. It has been developed as a water-soluble coating and film that is tough and flexible. Methyl cellulose is also used as a water-soluble thickening agent and gum. It is prepared by methylating alkali cellulose with monomethyl chloride or dimethyl sulfate.

methyl chloride Methyl chloride is a compound used in the polymerization of silicones and as a methylating agent in organic synthesis.

methyl methacrylate Methyl methacrylate is a colorless, volatile liquid derived from acetone, cyanohydrin, methanol, and dilute sulfuric acid. It is used in the production of acrylic resins.

methyl methacrylate acrylonitrile butadiene styrene (MABS) Methyl methacrylate acrylonitrile butadiene styrene (MABS), or methylacrylonitrile, is a thermoplastic compound somewhat similar to ABS. The four comonomers (methyl methacrylate, acrylonitrile, butadiene, and styrene) are combined in a two-phase graft tetrapolymer. The properties of MABS are generally comparable to those of ABS, except that the presence of methyl methacrylate comonomer in the appropriate proportion brings the refractive indexes of the two phases sufficiently close to impart transparency. It also improves to some extent the resistance to degradation by heat.

methylpentene
See polymethylpentene.

mica Mica, known originally as *Muscovy glass*, is a group of silicate minerals with monoclinic crystals, which break off easily into thin, tough scale. The specific gravity of mica is 2.7–3.1, and the Mohs hardness is 2–3.

Naturally occurring micas have a variety of chemical compositions and morphologies. Three major types are commercially available for use in polymers: *wollastonite, muscovite*, and *phlogopite*. Mica particles are sometimes fiber shaped, but more commonly platelet or flake shaped. Their aspect ratio (width-to-thickness ratio) plays an important part in the reinforcement properties.

The manufacturing process involves delamination of the raw material by wet or dry grinding and possible subsequent separation according to size and shape. High-aspect-ratio grades are claimed to give very good reinforcement at a reasonable cost, particularly when a suitable surface treatment is used.

Mica has excellent electrical properties and is used in many forms as high-temperature insulation in electrical equipment such as motors and capacitors. These materials have low moisture absorption.

Plastics are often heavily filled with mica powder and marketed under tradenames such as *Micabond* and *Lamicoid* in the form of sheets, tubes, and molded parts. Mica ceramics are molded from mica with an inorganic binder and have generally higher physical properties than the polymer composite.

microcellular foam Recently this term has been applied to a group of cellular plastics with very small cell size (typically 1–10 μm) and high cell population density (typically 10^9 to 10^{12} cells/cm^3). This combination of properties results in a very low density of the cellular material, down to 5 percent of that of the solid polymer in some cases. Such microcellular materials are generally produced by blowing with CO_2 or nitrogen. Their main advantage includes a combination of good mechanical and heat insulation properties and a low material cost-to-volume ratio.

microcrack Microcracks are cracks that are formed in composites when thermal stresses locally exceed the strength of the resin matrix. These cracks generally do not penetrate or cross fibers. Therefore, they are generally limited to the thickness of a single ply.

microdispensing
See resin dispensing; underfill compounds

microsphere Microspheres, or microballoons, are spherical particles used in plastics and other materials as fillers and reinforcing agents. They are made of glass or ceramics or plastic resins. *Glass microspheres* may be hollow or solid. Solid spheres have a specific gravity of about 2.5 and diameters of 4–5,000 μm and are generally made of soda-lime glass. Hollow glass microspheres have densities ranging from 5 to 50 lb/cu ft and diameters of from 20 to 200 μm. Glass microspheres withstand very high hydrostatic pressures and are often formulated with a thermosetting resin matrix to form syntactic foam. *Plastic microspheres* are also used in the production of syntactic foams. These can be polyvinylidiene chloride, epoxy, phenolic, or polystyrene.

migration Migration generally refers to loss of plasticizer or other low-molecular-weight compound in a polymeric part by its flow to the surface. Migration may weaken the product as the additive or low-molecular-weight constituent is lost over time. It also may affect objects that are in contact with the part showing migration. For example, notebook binders made of flexible polyvinyl chloride (PVC) may stick to other binders or items because of the migration of plasticizer from one material into the other. Also, some plastics may react with the varnish on a table because of plasticizer migration.

Migration can also refer to the ingress of low-molecular-weight materials into a polymer. For example water, oils, or solvents can migrate into a part from the atmosphere to which it is exposed.

milled fiber Milled fiber is a reinforcement filler manufactured by *hammer milling* continuous glass strands into very short glass fibers. These are generally useful as inexpensive filler or anticrazing reinforcing fillers for adhesives.

milling In formulating plastics, milling refers to the blending of additives, extenders, reinforcements, etc. with counter-rotating rolls. Such rolls are often used for mixing plastic or rubber ingredients, and they may be heated for more efficient mixing.

Milling also refers to the operation of producing a groove or slot in the flat surface of sheet stock, a product or a die, as well as to finish surfaces. *See* milling, turning, and routing.

milling, turning, and routing For all operations such as milling, turning, and routing, carbide-tipped cutters and high speeds are used. A *miller* is a rotary cutting machine that uses a round, multitoothed cutter to cut away small chips as the tool is fed past the work. Many other cutting tools can also perform these processes. Appendix I provides important information regarding the machining of plastic parts.

Adequate support and suitable feed rates are very important. For many plastics a surface speed of 500 ft/min with feeds (depth of cut) of 0.002–0.005 in. per revolution will produce good results. The feeds and speeds should be similar to machining of brass or aluminum. Appendix I gives milling, turning, and routing data for various plastic materials.

Higher cutting speeds improve machined finish but also reduce the life of the cutting tool. To prevent grabbing, tools should have an O-rake, which is similar to the rake of tools for machining brass. For thermoplastics, a diamond-tipped cutter should be used for a mirrorlike finish. Air jets or vacuum attachments can remove the spiral plastic cuttings that leave the cutting edge. In this manner the strips are directed away from the cutter. The machining of thermosets generally produces cutting in powder form.

Reaming may be used to size holes accurately, but diameters produced may also be affected by thermal expansion. Pilot holes may help when the hole is to be reamed or counterbored. Reamer speeds should approximate those used for drilling. Reaming can be done dry, but water-soluble coolants will produce better finishes. For thermoplastics it is recommended to use a reamer 0.001–0.002 in. larger than the desired hole size. Tolerances as close as ± 0.0005 in. can be held in through-holes of 1/4-in. diameter.

mock leno weave

See weave.

modifier A modifier is a chemically inert ingredient that is added to a resin formulation to change its properties. Plasticizers, filler, colorants, and other resins all fall into this category. Although they usually constitute only a small percentage of the formulation, such resin modifiers markedly affect the properties of the plastic.

See also filler; additive.

modulus of elasticity (elastic modulus, stiffness) The modulus of elasticity is the ratio of unidirectional stress to the corresponding strain of an elastic material that is elastically deformed in the linear stress-strain region below the proportional limit. For materials with no linear range, a secant line from the origin to a specified point on the stress-strain curve or a line tangent to the cure at a specified point may be used. Modulus of elasticity can also be referred to generally as the *stiffness* of the polymer.

Several elastic moduli are used depending on the mode of application of stress. These include *tensile modulus* (Young's modulus) measured by ASTM D638 or D882, *shear modulus* (or rigidity) measured by ASTM D1043, and *flexural modulus* measured by ASTM D747 or D790. Lesser-known elastic modulii are *bulk compression modulus* and modulus of *rupture in bending*. The units of modulus are those of stress (psi or MPa) because the strain is dimensionless. Elastic polymers such as rubbers and thermoplastic elastomers have a low modulus of elasticity. Semicrystalline polymers, such as polyethylene and nylon have a moderate modulus of elasticity. Rigid, brittle polymers such as thermosets and polystyrene have a high modulus of elasticity.

Figure M.4 Modulus of elasticity of several thermoplastic materials as a function of temperature. (Ref: Gatten, G.A., "Heat Resistance of Thermoplastics", *Materials Engineering*, July 1962)

moisture in plastic *Moisture absorption* is the amount of water absorbed by a plastic material when it is exposed to water vapor. The weight pickup of water when exposed by immersion in water is generally known as *water absorption*. However, usually such a distinction is not made. Moisture absorption is expressed as percentage of original weight of dry material.

Moisture content is the amount of moisture in a material determined under prescribed conditions and expressed as a percentage of mass of the moist specimen. The method of achieving the moisture content is not distinguished.

Moisture resistance is the ability of a material to resist absorbing moisture, either from the air or when immersed in water. Moisture-resistant materials are less likely to have permanent degradation by the action of water than materials that readily absorb water molecules. (*See also* hydrolytic stability.)

moisture vapor transmission The moisture vapor transmission is the rate at which moisture vapor passes through a material at specified temperature and humidity levels. It is expressed as grams per mil of material thickness per 24 h per 100 in.^{2} of area.

mold As a verb, mold is the shaping of plastic parts or finished articles by heat and pressure. The molding cycle is the period of time occupied by the complete sequence of operations on a molding press required for the production of one set of moldings.

As a noun, a mold is the cavity or matrix into which the plastics composition is placed and from which it takes form. There are many different types of molds, each designed to suit a specific process or application. Table M.2 shows certain mold-making materials as related to the various plastic processes.

Table M.2 Mold Materials for Plastic Processes (Ref: Rotheiser, J.I., "Design of Plastic Products", *Modern Plastics Handbook,* C.A. Harper, ed., McGraw-Hill, New York, 2000)

Process	Mold material
Casting	Epoxy, silicone
Lay-up and spray-up	Epoxy (sometimes plated), aluminum, steel (occasionally)
Cold molding	Epoxy, glass
RTM	Epoxy, glass, aluminum
RIM	Epoxy, glass, aluminum, steel, kirksite
Compression and transfer	Steel (SMC, BMC), aluminum (LPMC)
Rotational molding	Sheet steel, stainless steel, aluminum, cast aluminum, machined metal, electroformed nickel and copper
Structural foam molding	Prehardened steel, aluminum with beryllium copper
Thermoforming	Aluminum (wood, epoxy, or polyester for prototypes)
Blow molding	Aluminum, beryllium copper, zinc alloy, brass, stainless steel
Extrusion	Steel
Pultrusion	Steel
Vacuum and bag molding	Epoxy, glass

A *multicavity mold* is a mold with two or more mold impressions. This type of mold produces more than one molding per molding cycle. A *multiple-gate mold* is a mold that has many small gates into the side of restricted flow areas where fragile mold sections necessitate a minimum and distributed material flow.

See also injection mold parts.

mold cooling Cooling or temperature regulation is required for molds so that uniformly rigidized parts can be removed from the mold. The first parts that are shot may freeze in a short period of time, but as successive injections are made the mold will heat up, increasing cycle times or allowing parts to be ejected that are soft and show distortion or warpage.

Molds are commonly cooled with flowing water, directly from the supply or refrigerated or sent through a mold temperature regulator. If a refrigerated supply is used, it is important that the mold not be cooled below room temperature, because this could cause atmospheric moisture to condense on the mold. The use of a mold at the lowest temperature obtainable is not always the best policy, because, although this will result in the shortest cycle time, it will not always result in the highest gloss on the surface.

Many molds, not connected to a temperature regulator, will have the two main sections of the mold connected in series. The cold water enters the part of the mold that could make the poorest surface; then, through a flexible hose, the warmed water enters the other half of the mold, which is kept at a higher temperature. The second half of the mold, for most resins such as polyethylene or styrene, will then produce a surface with considerably higher gloss. The actual mold temperature differences range from approximately 35°C to 12°C depending on the resin, the mold, the cycle, etc. The important factor is that the mold should be designed with sufficient cooling capacity so that once a temperature has been determined to be satisfactory there will be very little variation during continuous operation.

The design of the cooling systems will vary depending on the cavity shape and depth. In general, multicavity molds should have parallel coolant feed to the cavities rather than series feed, for the reasons noted above. Actual cooling systems include water channeling and a bubbler system, flat plate spirals, and special ring coolers used for one small location. When using water channeling, it is important that the channels be located in relation to the cavity, not in random locations or simply where it is convenient to drill the channels. Random locations can lead to hot and cold regions that can result in nonuniform cooling with consequent warpage, distortion, locked-in thermal stress, and/or sink marks. Areas around gates in particular should be adequately cooled to ensure minimum freezing time. In borderline cases of inadequate cooling, sometimes increasing the coolant velocity or simply increasing the coolant line diameters (in or outside the mold) may result in sufficient cooling.

Partitioned mold cooling occurs when a large-diameter hole is drilled into the mold (usually the core) and partitioned by a metal plate extending to near the bottom end of the channel. Water is introduced near the top of one side of the partition and removed from the other side.

molded edge A molded edge is an edge that is not physically altered after molding for use in final form. The reinforcements at a molded edge are protected from the environment by a coating of the molding resin. A molded edge is not a *cut edge*, where the reinforcing fibers may be exposed along the length of the edge, allowing the wicking of moisture or other liquids into the body of the molded part.

molding compound
See thermosetting molding compounds.

molding compound processing The selection of production equipment and processes for thermosetting molding compounds commences with the compound designer's formulation, which designates the type and quantity of various ingredients that make up the compound. Common molding compounds are in the form of pellets or preforms (sheets, ropes, etc.) or loose, semidry batches. Molding compounds are physical mixtures of resin, reinforcement, or filler, catalyst, lubricant, and color.

The resin is the key component in any thermosetting molding compound because it is the only component that actually goes through the chemical reaction. The next most important component consideration is the reinforcement or filler, because the type and quantity of either will determine the manufacturing process and equipment. Lubricants, which provide a measure of flow promotion, mold release and barrel life during molding, are generally internally supplied but are occasionally provided as an external addition. Coloring does have an effect on the processing equipment if a wide range of colors is to be used.

There are several processing methods for producing molding compound. The dry or nonsolvent process uses low-strength, low-cost, free-flowing granular fillers. It involves the use of ribbon or conical mixers to homogenize the dry ingredients before feeding the mix onto heated roll mills. Here the mix is compounded for a specific time and temperature. Once the mix has been worked to the proper consistency and temperatures, it is then fed onto a three-roll calendering mill, where it is shaped to a specific width and thickness to allow the sheet to pass into a grinder and then onto a screen to obtain the desired granulation and for dust removal. The thickness and temperature of the calendered sheet are controlled for ease of granulation.

The wet process can produce free-flowing pelletized material with water as the carrier and the ingredients thoroughly mixed in a kneader and then auger fed to a heated extruder. The extruder screw densifies the wet mix, forcing it out of the extruder head, which contains many small orifices that determine the diameter of the pellets, and then fly cutters working across the face of the extruder head determine the pellet length. The extruded pellets then require a drying operation before final blending for shipment.

Sheet processes are used to manufacture *sheet molding compound* (*SMC*)*, bulk molding compound* (*BMC*) *or thick molding compound* (*TMC*). These materials are generally produced in sheet form for compression molding with matched metal hardened steel molds.

With *SMC* the doughy material and its reinforcement are covered on both lower and upper surfaces with a thin film of polyethylene release film. This process is illustrated in Fig. M.5. The finished product is then conveyed onto a rotating mandrel and wound-up until it reaches a preset weight and then it is cut off. The sheets ready for shipment generally weigh about 50 lb and are 4 ft wide and approximately 0.075–0.250 in. thick. Formulations generally consist of unsaturated polyester resins (20–30%), chopped glass rovings (40–50%), fine-particle-size calcium carbonate, filler, catalyst, pigment, and modifiers. The resin system can be epoxy, polyester, or vinyl ester to meet the application need.

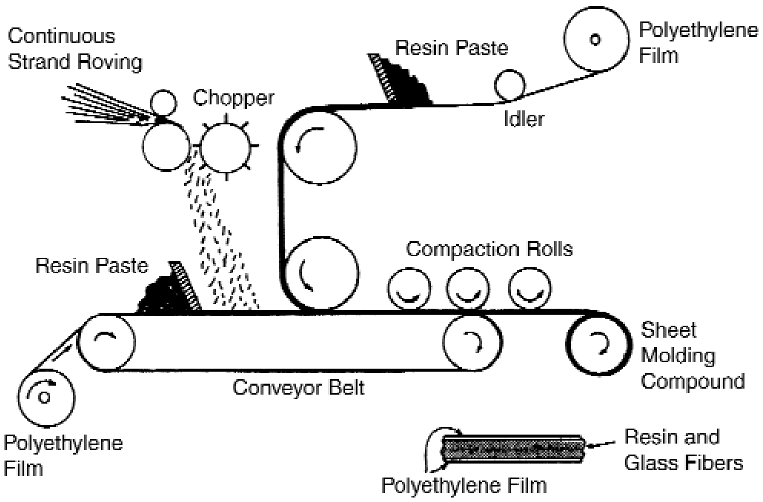


Figure M.5 Sheet molding compound process. (Ref: Harper, C.A., "Thermosets, Reinforced Plastics, and Composites", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

The production of *TMC* differs from the above in that the glass fibers are wetted between the impregnation rollers before being deposited onto the moving film. TMC can be produced in thickness up to 2 in. with glass loading levels of 20–30%.

BMC is different again in that bulky high-strength compounds are batch mixed in low-intensity mixers as a first step in the process. The mixing procedure is carefully monitored to achieve the highest possible mechanical properties with the least amount of fiber degradation. These compounds are also available in a rope form in any length or diameter.

See also sheet molding compound; bulk molding compound; thick molding compound.

molding cycle In injection molding, molding cycle, or *overall cycle time*, is the total time from the instant the dies close during one cycle to the corresponding instant of die closing on the next cycle while the machine is operating on a repetitive production basis.

The term *machine cycle* refers to that portion of the overall cycle time that is controlled by the preset machine cycle element timers. The machine cycle begins when the operator closes the safety gate, which activates the mold-closing stroke.

The machine cycle ends when the machine opens to the limit of the preset mold-opening stroke. The overall cycle time is thus the time required for the operator to open the safety gate, remove the molded shot, and close the safety gate.

mold-release agent When a plastic part tends to stick in the mold, a mold-release agent is applied as an interfacial coating to lower the friction. Improper mold release can lead to long cycle times, distorted parts, and damaged tooling. There are two basic types of mold-release agents: internal and external.

Internal mold-release agents are mixed directly into the polymer. These materials have minimal compatibility with the polymer. The additive either migrates to the surface of the polymer and provides a thin barrier coating between the resin and the mold cavity or it is present in a sufficient quantity on the surface of the polymer to reduce adhesion to the mold cavity.

Traditionally, *external-release agents* are applied by spraying or painting the surface of the mold with an aerosol or liquid or by applying a paste. The solvent or water carrier then evaporates, leaving a layer of release agent on the mold. Release agents should ideally have high tensile strength so abrasive mineral fillers or glass fiber reinforcements do not cause wear of the release film. The agents should also be chemically resistant to decomposition at the molding temperatures and should stick to the mold to prevent interference with the final product.

The major types of materials used as mold-release agents are grouped similar to lubricants. They are metallic stearates, fatty acid esters and amides, fluoropolymers, silicones, and waxes. Mold-release agents are available in several forms: powder, flake, liquid or paste. High-bulk-density powders and pills have been introduced, and nondusting grades are available. They may be added at the reactor stage of the processing or later by the compounder with melt compounding extruders or mills. Powders may also be dusted on pellets.

Metallic stearates, or soaps, are metal salts of organic acids like stearic acid. Calcium and zinc stearates are commonly used, although aluminum, iron, lead, lithium, magnesium, sodium, nickel, and potassium stearates are sometimes found in plastics. Stearates are most commonly used in thermoset polyester molding compounds, but calcium stearate has been used as a lubricant and release agent in polypropylene and ABS. Zinc and sodium stearates are used in polystyrene, SAN, and nylon. Stearates are not recommended for polycarbonate because of discoloration. Recommended loadings are usually 1 percent or less, but up to 5 percent has been used at times.

Paraffins and *hydrocarbon waxes* are most commonly used in polyvinyl chloride (PVC). They are said to be better suited to those polymers that function at higher temperatures. They are not recommended for clear resins, as they tend to yellow or fog. Loadings of less than 0.5 percent are common.

Fatty acid esters are commonly used as internal/external release agents. PVC is the most typical application, but they work well also on acrylic and polycarbonate. They do not reduce clarity. Fatty acid esters and amides do not usually interfere with the secondary finishing operations, and some have high temperature stability, making them well suited for rotational mold resins and engineering plastics. Fatty acid amides, such as ethylene bis-stearamide, erucamide, and oleamide, are probably the most commonly used release agents for polyolefins. They are also used for rigid PVC and thermosets. Loadings tend to be light, such as 0.1–2 phr.

Silicones are the active ingredients in many spray-on mold release agents. Although these are excellent release agents, their use must be carefully controlled. Silicones have a significant tendency to spread throughout the work area. Silicone release agents tend to spread by air flow as well as direct contact with other surfaces. As an external release agent they often can contaminate surfaces that require painting or bonding. They are not generally used as an internal release agent when the part requires painting or bonding.

Fluoropolymers form a monolayer providing easy application, but they are expensive. They are better suited to high-temperature processing of resins like polycarbonate and polysulfone. Some fluoropolymers are used in thermosets, but there are grades that have been developed specifically for thermoplastics. Normal loadings are 0.5–2 phr. Fluoropolymer release agents do not interfere with postmold finishing.

There are numerous suppliers of mold release agents as a result of the variety of chemistries that perform the function of internal and external release. The suppliers are generally large specialty chemical companies that see the particular chemistry to a wide variety of end use applications.

mold shrinkage The mold shrinkage is the difference in dimensions, expressed in inches per inch, between a molding and the mold cavity in which it was molded. Mold shrinkage is caused by difference in thermal expansion coefficients between the molding material and the mold, reduction in volume due to the polymerization process, or volatilization of moisture, solvent, or other low-molecular-weight constituents during the molding process.

ASTM D955 describes a method to measure mold shrinkage. Both the mold and the molding are at room temperature when the mold shrinkage is measured. The values of 0.022 in./in. in the flow direction and 0.018 in./in. in the transverse direction are typical for unfilled crystalline thermoplastics.

Shrinkage is significantly affected by the wall thickness, shape, and size of the part in addition to the molding temperature, cycle, nozzle size, and packing. Mold shrinkage, as defined above, does not account for all of the shrinkage because shrinkage can continue for up to hours and even days after molding for some resins.

When the part shrinks onto a core, it grips the core very tightly and cannot be removed without considerable force. The force can be reduced by placing a slight angle on the walls of the part perpendicular to the parting line. This angle is referred to as *draft* and is common to all molded plastic parts. Drafts of 2° and 3° per side have become commonplace. For deep parts (beyond 6 in.), a 3° draft per side is definitely called for, and a greater draft will speed part removal and the overall molding cycle.

See also shrinkage.

mold steel Mold steel is a term that generally refers to the steels used for making molds for molding plastics. Mold steel should have a uniform texture that will machine readily with die-sinking tools. It must have no microscopic porosity and must be capable of polishing to a mirrorlike surface. When annealed it should be soft enough to take the deep imprint of the hob, and when hardened it must be able to withstand high pressure without sinking and have sufficient tensile strength to prevent breakage of thin mold sections. Mold steels should be dimensionally stable during heat treatment and corrosion resistant to the plastics being formed.

The principal mold steels are the P-type mold steels as specified by the American Iron and Steel Institute, specifically P6, a carburizing steel having moderate hardenability; P20, also with moderate hardenability; and P21, a deep-hardening steel.

molecular weight Molecular weight is the sum of the atomic masses of the elements forming a molecule. In polymers, it is a measure of the length of the polymer chain. Most high polymers that are useful for plastics, rubber, or fibers have molecular weights between 10,000 and 1,000,000.

Polymers are characterized by an average molecular weight because there is a distribution of chain lengths. It is necessary to characterize the entire distribution quantitatively or at least to define and measure average chain length or molecular widths for these materials, because many important properties of the polymer depend on these quantities.

Molecular weights of polymers are usually determined as the *number average molecular weight*. This is defined in a manner analogous to the case of pure, low-molecular-weight compounds. Rather than counting the number of molecules of each size, it is also possible to define an average in terms of the weights of molecules present at each size level. This is the *weight average molecular weight*. These two kinds of molecular weight have the same value only when there is a symmetrical distribution of high- and low-weight molecules on either side of the median value. If there is a large fraction of low-weight molecules, the weight average molecular weight will be smaller than the number average molecular weight.

In general the techniques for the determination of average molecular weights fall into two categories: absolute and relative. In absolute methods, measured quantities are theoretically related to the average molecular weights. Absolute methods of analysis include end-group analysis and colligative property measurements such as vapor pressure and light scattering, For relative methods, a quantity is measured that is in some way related to molecular weight. The most common relative method of determining molecular weight involves measuring the viscosity of several concentrations of the polymer in solution and extrapolating this back to a “zero” concentration (intrinsic viscosity) and applying a standard relationship. The “molecular weight” as determined by different methods may vary significantly. It is always necessary to know by what method it was obtained.

The length of the polymer chain is also specified by the number of repeat units in the chain. This is called the *degree of polymerization*. The molecular width of a polymer is the product of the molecular weight or the repeat unit and the degree of polymerization (DP) of the polymer.

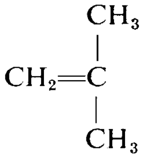
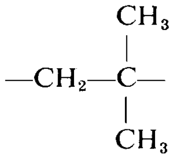
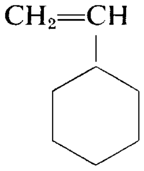
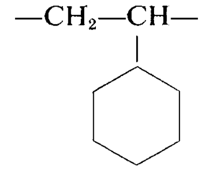
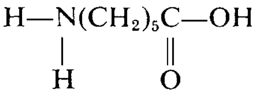
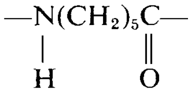
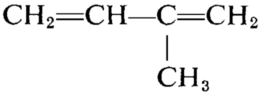
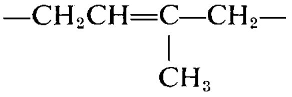
See also average molecular weight; degree of polymerization.

monofilament A monofilament or *monofil* is a single thread or filament produced by extrusion methods. Monofilaments are generally produced by extrusion. Plastic monofils are made from Saran, nylon, polyethylene, polystyrene, polyvinyl chloride, and others. Their applications include the fabrication of bristles, surgical sutures, fishing leaders, tennis racquet strings, screening materials, ropes, and nets. Finer monofilaments are woven and knitted on textile machinery.

A *multifilament* refers to a fiber made up of several single filaments or monofilaments. They often consist of 5–100 individual filaments, usually with some twist in the yarn to facilitate handling. Multifilament yarn sizes are described in denier and range from 5–10 denier up to a few hundred deniers. The larger deniers are usually obtained by plying smaller yarns together.

monomer A monomer is a small molecule that is capable of reacting with similar or other molecules to form large chainlike molecules called *polymers*. It is the starting material from which a polymer is formed. Table M.3 illustrates some common polymers, their monomers, and their repeat units.

Table M.3 Some Linear High Polymers, Their Monomers, and Their Repeat Units (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 4)

Polymer	Monomer	Repeat Unit
Polyethylene	$CH_2{=}CH_2$	$-CH_2CH_2-$
Poly(vinyl chloride)	$CH_2{=}CHCl$	$-CH_2CHCl-$
Polyisobutylene	 $CH_2{=}\overset{CH_3}{\underset{CH_3}{C}}$	 $-CH_2-\overset{CH_3}{\underset{CH_3}{C}}-$
Polystyrene*		
Polycaprolactam (6 nylon)	 $H-\underset{H}{N}(CH_2)_5\underset{\underset{O}{\Vert}}{C}-OH$	 $-\underset{H}{N}(CH_2)_5\underset{\underset{O}{\Vert}}{C}-$
Polyisoprene (natural rubber)	 $CH_2{=}CH-\underset{CH_3}{C}{=}CH_2$	 $-CH_2CH{=}\underset{CH_3}{C}-CH_2-$

* By convention, the symbol  is used throughout to represent the benzene ring, double bonds being omitted.

In an *addition polymerization* reaction, the repeating unit of the polymer is usually equivalent or nearly equivalent to the monomer. A single monomeric constituent unit in a polymer is called a *mer*.

monosil process The monosil process is a process for the manufacture of chemically cross-linkable polyethylene. Siloxane side chains are grafted on the polyethylene for subsequent cross-linking in a single-step extrusion process. The feedstock generally consists of polyethylene, an initiator (e.g., a peroxide), vinyltrimethoxy silane, a cross-linking catalyst, stabilizers, and any required additives. The product is subsequently immersed in hot water or steam to hydrolyze the methoxy groups of the grafted side chains and to effect cross-linking by condensation of the resulting hydroxyls. The resulting compound is used primarily as a cable covering or heat-shrinkable tubing product. This process is also known as the *Siopas process*.

morphology Morphology is the description of the arrangement of polymeric chains and crystalline regions in a semicrystalline polymer. Sometimes morphology is referred to as the “microstructure” of the polymer.

motionless (static) mixer The motionless mixer, or static mixer, is a geometrically designed structure that fits into a barrel. It has no moving parts. The static mixer is made up of many helical elements in a pipe that force the material to converge flow paths many times. This can be used for homogenization of colorants, additives, and polymers as well as leveling out temperature variations if the system is processed at elevated temperatures.

An acceptable static mixer should develop 30,000–40,000 laminar deviations with a pressure drop not to exceed 200 psi, should have low shear, and should be short in overall length. Static mixers are located on extruders, mix-meter-and- dispense equipment, adhesive applicators, and other equipment where two or more components must be quickly blended together. Many major equipment manufacturers supply static mixers with their lines.

mucilage Mucilage is a sticky paste obtained from linseed and other seeds by precipitation from a hot infusion. It is used as a light adhesive for paper and as a thickening agent. It is easily soluble in water. As a more general term, mucilage also refers to water-soluble gums from various parts of many plants that have the same uses.

muffle furnace A muffle furnace is a high-temperature furnace used primarily to burn off cured resin for measurement of the inorganic content (by weight) of laminates having carriers such as fiberglass or other inorganic fillers. The test to determine the organic or inorganic contribution to the sample in this manner is referred to as an *ash test*.

See also ash content.

muller-type mixers Muller-type mixers are grinding, mixing-type blenders for stiff puttylike mixtures. They consist of a horizontal mixing plate with sides over which two heavy abrasive wheels rotate, followed by scraping knives or plows to direct the materials under the wheels. These may be used as preliminary mixers for the Banbury, extruder, or roll-type mixers.

Muller-type mixers have a wide range of application, from dry blends to sticky viscous materials. Extremely fluid mixes cannot be mulled for lack of sufficient friction to rotate the grinding wheels or mullers.

multifilament yarn Multifilament yarn is a yarn with a large number (500–2000) of fine, continuous filaments, usually with some twist in the yarn to facilitate handling.

multiple-head machine In blow molding, a multiple-head machine is a molding machine in which the plastic melt prepared by the extruder is divided into a multiplicity of separate streams (parisons), each ultimately giving a finished item.

multiple-screw extruder A multiple-screw extruder is an extruder machine that has two or four screws, in contrast to conventional single-screw extruders.

See also extrusion.

Mylar Mylar is a tradename for a polyterephthalate film produced by Du Pont. It is manufactured from the polyester of ethylene glycol and terephthalic acid (dimethyl terephathalate). Mylar films are commonly used in the electrical/electronic industries for their excellent electrical properties and also as high-strength film for structural applications.

See polyterephthalate.

N

nadic methyl anhydride Nadic methyl anhydride (NMA) is one of several cyclic anhydrides used as curing agents with epoxy resins. These anhydride groups will not react directly with epoxy groups. For the reaction to occur, it is first necessary that the anhydride ring be opened. The ring may be opened either by active hydrogens present as water or hydroxyls or by a Lewis base.

Anhydride systems generally provide low viscosity and long pot life. They exhibit improved high-temperature stability over the amines and better physical and electrical properties above their heat-deflection temperature. NMA-cured epoxies generally require elevated temperature cures, and postcuring at temperatures above 150°C is often required for maximum properties.

In almost all commercial epoxy resin/anhydride formulations, some form of accelerator is used. Tertiary amines are more conventionally used accelerators. These may be benzyldimethylamine (BDMA) and tris (dimethylaminomethyl)-phenol (DMP-30). Optimum amounts of tertiary amine accelerators in terms of cured properties fall in the 1 to 5 phr range.

See also epoxy resin curing agent.

Nanophase material Nanophase materials or nanomaterials are an emerging group of materials produced in building blocks so small as to be measured in nanos, or 10^{-9} units. They have superior physical or mechanical properties compared with their conventional or bulk counterparts. Nanomaterials are made by controlling the arrangements of matter on atomic or molecular scales so as to create materials

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containing particles or grains 1–100 μm wide or layers or filaments of this thickness. Nanomaterials are often in a multilayered or composite form.

natural resin Natural resins are the exudation of certain species of living trees or fossilized tree products. They have a wide range of viscosities and soften or melt easily when heated. In most cases they are fairly light colored, glasslike with high gloss, and insoluble in water but soluble in certain organic solvents. Natural resins were used in many applications long before the advent of synthetic resins. Even though synthetic resins have many advantages over natural resins, natural resins are still used in many industries.

The natural resins have been used in adhesives and cements, dry colors and pastes, finishing compositions, incense, ink lacquers, linoleum, medicine, oil cloths, oil varnishes, paints, paper sizing, plastics, polishes, rubber compositions, spirit varnishes, textile sizing, and wax compositions. Of particular interest to the plastic field are natural resins in binders and in cold and thermoplastic molding.

natural rubber Natural rubber is a high-molecular-weight polymer of *isoprene*, in which essentially all the isoprenes have the *cis*-1,4 configuration. The polymer has a number average degree of polymerization of about 5000 and a broad distribution of molecular weights.

Natural rubber can be obtained from nearly 500 different species of plants. The outstanding source is the tree *Hevea brasiliensis*, from which comes the name *Hevea rubber*. The tree grows best in damp, warm climates. It was first cultivated in Brazil and then imported to the Malay Peninsula, where the bulk of the world's rubber came before World War II.

Rubber is obtained from latex, which exudes from the bark of the *Hevea* tree when it is cut. The latex is an aqueous dispersion, containing 25–40 percent rubber hydrocarbon, stabilized by a small amount of protein material and fatty acids. As the latex is gathered, a small amount of ammonia is added as a preservative. The latex is later coagulated by the addition of a 5 percent solution of acetic acid. The coagulum is washed and dried.

Vulcanization is the most important natural rubber chemical reaction. Most applications require cross-linking via vulcanization to increase resiliency and strength. Exceptions are crepe rubber shoe soles and rubber cements. There are a number of methods for sulfur vulcanization, with certain methods producing polysulfide crosslinking and other methods producing the more monosulfidic crosslinks.

Natural rubber has good resilience; high tensile strength; low compression set; resistance to wear, tear, cut-through, and cold flow; and good electrical properties. Resilience is the principal property advantage of natural rubber compared with synthetic rubbers. For this reason, natural rubber is used for engine mounts because natural rubber isolates vibrations caused when an engine is running. Natural rubber is an effective decoupler, preventing vibrations such as engine vibration from being transmitted to another location such as the passenger compartment.

Degree of crystallinity can affect natural rubber properties. Milling reduces molecular weight. Molecular weight is reduced by mastication, typically with a Banbury mill, adding a peptizing agent during milling to further reduce molecular weight, which improves natural rubber solubility after milling. Compounding of natural rubber with property enhancers improves resistance to ultraviolet (UV) light, oxygen, and ozone, but formulated elastomeric thermoplastics and synthetic rubber overall have better resistance than compounded natural rubber.

Natural rubber does not have as satisfactory a resistance to fuels and vegetable and animal oils as elastomeric thermoplastics and synthetic rubbers. Natural rubber has good resistance to acids and alkalis. It is soluble in aliphatic, aromatic, and chlorinated solvents, but natural rubber does not dissolve easily because of its high molecular weight. Synthetic rubbers have better aging properties. Synthetic rubbers will harden over time, whereas natural rubbers will soften over time.

Polymers related to natural rubber include ebonite, chlorinated rubber, oxidized rubber, cyclized rubber, and gutta-percha and balata.

near-field welding In ultrasonic welding, near-field welding describes a process by which the joints are made within $^1/_4$ in. or less of the welding horn. Joints that can be made more than $^1/_4$ in. from the horn are termed *far-field joints*.

More rigid materials can be welded with the joints farther away from the welding horn because the rigid polymer will transfer the vibrational energy moderately well. However, tough or elastomeric materials cannot be welded as far-field joints because they absorb the vibrational energy.

neck-in In extrusion coating, neck-in refers to the difference between the width of the extruded web as it leaves the die and the width of the coating on the substrate.

necking Necking is the localized reduction of the cross-sectional area of a tensile specimen that may occur during loading in tension. Necking usually occurs in a test bar during a tensile test.

neck ring process In blow molding, the neck ring process is a process in which the blown ware is formed neck down. The neck portion of the blow mold has a hollow tube to form the inside of the neck and admit blow air. The neck ring starts at the orifice and is filled with the material first and then drops down as a parison forms into its final position. It is clamped as the mold closes and blow starts.

needle blow In blow molding, needle blow is a specific molding technique in which the blowing air is injected into the hollow article through a sharpened hollow needle that pierces the *parison*.

NEMA NEMA stands for National Electrical Manufacturers Association. More particularly in the plastics industry, NEMA develops standards for high-pressure laminates used for electrical applications, which is the first and largest use of these materials.

These standards cover the manufacture, testing, and performance of laminating thermosetting products in the form of sheets, rods, and tubes. The properties of NEMA-type laminates are described in Appendix E.

NEMA standards include many variations for reinforcements, resins, and applications. Reinforcements include paper, fabrics, and glass mats. Resins include phenolic, melamine, silicone, epoxy, and polyester. *Copper-clad laminates* are covered with copper foil for use in printed wiring boards, whereas unclad laminates do not have a foil. Unclad laminates are used in many industrial applications, but NEMA's primary concern is when they are used as electrical insulation.

NEMA also has developed standards and specified test methods for magnet wire insulation coatings. A summary of these materials, properties, and standards may be found in Appendix C.

See also electrical laminate; copper-clad laminate; printed circuit board.

neoprene

See polychloroprene.

nest plate A nest plate is a retainer plate with a depressed area for cavity blocks used in mold construction.

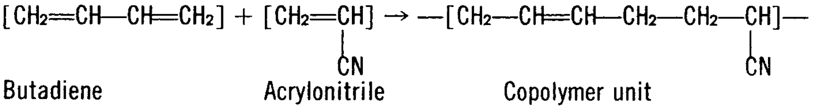
Newtonian behavior Newtonian behavior is a flow characteristic that is evidenced by viscosity that is independent of shear rate (i.e., the shear stress is directly proportional to shear rate). Water and mineral oil are typical Newtonian liquids.

Thixotropic filled resin systems such as sealants and pastes are generally not Newtonian fluids because their viscosity falls as the shear rate increases. These materials show *non-Newtonian* behavior. The flow of molten polymer is generally non-Newtonian because it produces lower viscosities at higher shear rates.

See also thickening agent; thixotropy.

nip The nip is the "V" formed where the *pressure roll* contacts the *chill roll* in a process such as extrusion coating or calendering.

nitrile rubber (NBR) Copolymers of butadiene and acrylonitrile are known by several generic names: *Buna N, nitrile rubber*, and *NBR*. The monomer ratio of butadiene to acrylonitrile may be varied within a wide range. The amount of acrylonitrile present has a major effect on the properties of both the uncured gum and the vulcanizate. The basic polymer reaction is shown in Fig. N.1.



$$\underset{\text{Butadiene}}{[CH_2{=}CH{-}CH{=}CH_2]} + \underset{\text{Acrylonitrile}}{[CH_2{=}\underset{\displaystyle CN}{\underset{|}{CH}}]} \rightarrow \underset{\text{Copolymer unit}}{-[CH_2{-}CH{=}CH{-}CH_2{-}CH_2{-}\underset{\displaystyle CN}{\underset{|}{CH}}]-}$$

Figure N.1 Reaction process of nitrile rubber.

There are five basic levels of acrylonitrile content in commercial polymers: 20, 28, 33, 40, and 50 percent. Nitrile polymers may be polymerized in a variety of ways that will affect the composition of the rubber.

Nitrile polymers are vulcanized in essentially the same manner as styrene butadiene rubber (SBR) and natural rubber. The same ingredients are used, although not necessarily in the same amounts. Sulfur is less soluble in nitrile rubber than in SBR or natural rubber, and smaller amounts are used. A corresponding increase in accelerator is required. Sulfur/accelerator, sulfur donor, and peroxide cures are chosen depending on the ultimate processing methods and applications.

NBR curing, compounding, and processing are similar to those for other synthetic rubbers. However, of wide interest is the use of nitrile rubber compounds for injection molding. This calls for very short cycles and high temperature cures in the range of 30 s to 1 min at 192–218°C. Properties are generally equivalent to conventionally cured nitrile except for compression set. Cure systems for injection molding are commercially available.

Nitrile rubber is a widely used elastomer. With its nitrile group, it is higher than neoprene in polarity and thus poorer in electrical insulation. Its main advantage is that it is considerably more resistant to oils, fuel, and solvents than neoprene. Its other properties fall in line with those of the butadiene group, and nitrile rubber closely matches the physical properties of SBR except that it has much better heat resistance. Considering cost (slightly above that of neoprene), nitrile rubber has overall excellent properties with broader resistance to chemicals than any other polymer. It has a gain in oil resistance over that of neoprene, but at a sacrifice to weathering and ozone resistance.

The oil resistance of the nitrile rubbers varies greatly with their composition. The higher the acrylonitrile content, the greater the oil resistance. Nitrile rubbers are used primarily because of their oil resistance, by which is implied low solubility, low swelling, and good tensile strength and abrasion resistance after immersion in gasoline or oils. Their heat resistance is good; and, if properly protected by antioxidants, they show satisfactory resistance to oxidative degradation as well.

Nitrile rubbers are extensively used for gasoline hoses, fuel tanks, creamery equipment, and the like. Other applications are belting, sheeting, cable jacketing, seals, and shoe soles. In addition, they find wide application in adhesives and in the formulation of lattices for impregnating paper, textiles, and leather. Blends based on nitrile rubbers are used in underground wire/cable covering; automotive weather stripping, spoiler extension, foam integral skin core cover armrests and window frames; footwear; and flexible lay-flat and reinforced rigid spiral hose for oils, water, food, and compressed air.

Hydrogenated versions of nitrile polymers have been produced recently. These new elastomers are seeing considerable use in automotive under-the-hood applications.

nitrobenzene Nitrobenzene ($C_6H_5NO_2$) is a good solvent for cellulose ethers and vinyl resins. Nitrobenzene is produced by nitrating benzene. It is also used in the manufacture of *pyroxylin* insulating compounds and for modifying the esterification of *cellulose acetate.* Nitrobenzene is soluble in alcohol.

NOL ring The NOL ring is a parallel filament-or tape-wound hoop test specimen used in filament winding and developed by the Naval Ordinance Laboratory (NOL), now Naval Surface Weapons Laboratory, for measuring various mechanical strength properties, such as tension and compression, of the reinforced fiber material. The specimen is wound so that the fibers are in the circumferential direction.

The NOL ring specimen is generally wound separately from the filament wound product. If cut from a production piece, the damaged cut glass fibers would considerably degrade the strength of the specimen. Either the entire ring or segments of the ring are tested. This test specimen is also known as the *parallel fiber-reinforced ring*.

nondestructive testing *Nondestructive testing* (NDT), *nondestructive evaluation* (NDE), and *nondestructive inspection* (NDI) are terms used to describe the various processes that determine whether a material will be acceptable for its function.

Plastics are susceptible to flaws that cannot always be seen; thus premature failure can only be prevented if methods are available that will disclose the presence and extent of such flaws without destroying the part. Three of the more common nondestructive testing methods are *ultrasonic*, *γ-radiometric*, and *holographic testing*.

The *through-transmission γ-radiation gauging technique* is the most direct approach to nondestructively determining local volume fractions of reinforcement, resin, and porosity in composite systems.

Ultrasonic testing is sensitive enough to permit the detection of small defects, and it penetrates to a degree that makes the examination of thick sections possible. It can pinpoint flaws, distinguish among them, and measure their extent. The basis of ultrasonics in flaw detection is that any type of wave motion is affected by the interface between areas of dissimilar density. Such interfaces reflect a portion of the energy back to its starting point and reduce the level of that which passes through. Proper interpretation of the defect, reflected pulse, or amplitude reduction of the transmitted pulse through the defect is the key to using this technique.

In *holographic analysis*, a beam splitter divides a narrow laser beam into two controllable beams. One goes through the plastic sample, and the other is used as a reference. Through interferometric recombination, displacements on the level of microinches can be monitored. Low-level stresses can be applied either statically or dynamically. A hologram is taken of the test object and developed before stressing. If the hologram is then viewed so that a reconstructed virtual image is superimposed on the object, stress-induced deformation will appear as a dynamic display of fringe patterns.

nonwoven fabric In the most general sense, a nonwoven fabric is a fibrous sheet material consisting of fibers mechanically bonded together by interlocking or entanglement, by fusion, or by an adhesive. The absence of any patterned interlaping or interlacing of the yarns characterizes the nonwoven fabrics, whereas woven fabrics have interlapping or interlacing yarns.

In the textile trade, the terms *nonwovens* and *bonded fabrics* are applied to nonwoven fabrics composed of a fibrous web held together by a bonding agent, as distinguished from felts, in which the fibers are interlocked mechanically without the use of a bonding agent.

Spin-bonded nonwovens are produced by allowing the filaments emerging from the fiber producing extruder to form into a random web, which is then usually thermally bonded. These nonwovens are limited commercially to the thermoplastic synthetics such as nylons, polyesters, and polyolefins. They have exceptional strength because the filaments are continuous and bonded to each other without an auxiliary bonding agent.

notch sensitivity Notch sensitivity is the extent to which the sensitivity of a material to fracture is increased by the presence of a disrupted surface such as a notch, a sudden change in section, a crack, or a scratch. Low notch sensitivity is usually associated with ductile materials and high notch sensitivity with brittle materials.

A *notched specimen* is a test specimen that has been deliberately cut or notched, usually in a V-shape, to induce and locate the point of failure. The *notch factor* is the ratio of a property, such as impact strength, determined on a plain specimen to the property determined on the notched specimen.

novolacs Novolacs are *phenol formaldehyde* resins obtained when a slightly higher molar ratio of phenol than formaldehyde is used. They are fusible, soluble thermoplastic resins principally used as varnishes. Unless a source of methylene groups is added, novolac resins will remain permanently thermoplastic.

See also epoxy resin (epoxy novolac).

nozzle In injection molding, a nozzle is used between the end of the cylinder and sprue bushing to act as a simple “push to seal” connection. The primary function of the nozzle is to allow injection of the molten resin into the mold with a minimum of leakage. A secondary function, with some nozzles, is to prevent resin leakage from the mold when the pressure is relieved during screw retractions and/or prevent hot-melt “drool” from the cylinder during the open mold portion of the cycle.

General-purpose or standard nozzles are made in varying diameters to accommodate the cylinder bores and sprue diameters and in varying lengths dependent on the heating requirements. Generally, the standard nozzles are made with a drilled straight bore, restricted at the outlet end and tapered as required to match the cylinder bore at the inlet end. Other bore configurations, as required by the resin type, are also used.

Many of the nozzles can be obtained with removable tips. Because the major wear and damage to the nozzle occurs at the tip, savings through the use of replaceable tips can be appreciable. For nozzles without removable tips, radius-refinishing tools are available. Most nozzles are made of steel, heat treated to the proper hardness at the tip and face seal. However, for use with certain corrosive polymers nozzles can be made of stainless steel or Hastelloy. Chrome-plated nozzles have not proved to be satisfactory because of the tendency of the plating to flake off from the crucial corners and surfaces.

In almost all nozzle installations, either external heating bands are used or internal cartridges or heating coils are installed. Along with the heating assemblies, a separate thermocouple and controller are always recommended. Nozzle heaters should not be connected to or be controlled by the barrel heating and control system if consistently uniform production is expected. Other uses for temperature-controlled nozzles are as components in runnerless molding where the nozzle leads directly into the mold cavity, thus eliminating the sprue and runner system altogether.

nuclear magnetic resonance Nuclear magnetic resonance (NMR) is used in the identification of complex organic structures. The infrared spectrophotometer used in *infrared analysis* and NMR complement each other in the organics laboratory.

See also infrared analysis.

nucleating agent Nucleating agents are used in polymer systems to increase the rate of crystallization. These agents are added to partly crystalline polymers and change the polymers' crystallization temperature, crystal spherulite size, density, clarity, impact, and tensile properties. These intentional contaminants achieve these functions by acting as sites for crystalline formation.

Nucleating agents are typically added postreactor and are used primarily in injection molding application. However, they can also be used in other thermoplastic processing applications. They are generally incorporated into materials such as nylon, polypropylene, crystalline polyethylene terephthalate (PET), and other thermoplastic PET molding compounds at use levels typically below 1 percent. Incorporation is done in several ways including powder mixtures, suspensions, solutions, or in the form of a masterbatch.

Several types of nucleating agents are used in specific polymers. The four major categories of chemical nucleating agents are substituted sorbitols, low-molecular-weight polyolefin, sodium benzoate, and ionomer resin. In addition, a variety of mineral fillers, reinforcements, and pigments are used in nylon and other polymers. These nonchemical nucleating agents are easily dispersed, inexpensive, and typically available on-site because they are commonly used for their primary reinforcing and filling functions.

Substituted sorbitols are used in polyolefins, particularly polypropylene (PP), for nucleation and clarification purposes. Use levels range from 0.1 to 0.3 percent of the resin. *Low-molecular-weight polyolefins* are primarily used in crystalline polyethylene terephthalate for rapid crystallization of otherwise amorphous material. Use levels range from 1 to 3 percent. *Sodium benzoate* is predominantly used as a nucleating agent in nylon and PP homopolymer. It has full FDA approval in PP and is used in food applications and pharmaceutical synthesis. Use levels are lower than those of the sorbitols. *Ionomer resins* used as nucleating agents are metal salts of ethylene/methacrylic acid copolymers and have a long-chain semicrystalline structure. Du Pont's *Surlyn* is the representative material. Ionomers are used to control crystallization in PET molding resins. Use levels are below 1 percent.

Suppliers of substituted sorbitol nucleating agents include Milliken (Millad), Ciba, Mitsui Toatsu Chemicals, and New Japan Chemical. For sodium benzoate nucleating agents, suppliers include FBC, Jarchem, Kalama Chemical. For low-molecular-weight polyolefin nucleating agents, suppliers include Allied Signal, Eastman Chemical, ICI, and Shell.

nutshell flour Nutshell flours are ground from walnut and pecan shells and cherry stones. They are traditional fillers for cast polyesters and phenolic molding compounds. However, they are also currently receiving attention in some thermoplastic applications. In products simulating wood, these fillers provide a woodlike color, as well as added strength.

nylon Nylon is the generic name (formerly a Du Pont tradename) for thermoplastic *polyamide* resins. These resins are available as filaments and yarns, molding compounds, and casting materials. Extreme toughness, high softening temperature, and high chemical resistance characterize molded parts. One of the major advantages of nylon resins is that they retain useful mechanical properties over a range of temperatures from −51 to +204°C. Nylons also have good impact, tensile, and flexural strengths, excellent low-friction properties, and good electrical resistivities. Nylon can be molded into thin sections and around delicate inserts. It comes in a wide range of pastel and opaque colors; transparent compositions are still in development.

Because all nylons absorb some moisture from environmental humidity, moisture absorption characteristics must be considered with these materials. They will absorb from 0.5 to nearly 2 percent moisture after 24-h water immersion. However, there are low-moisture-absorption grades, so that moisture absorption effects do not have to limit the use of nylons.

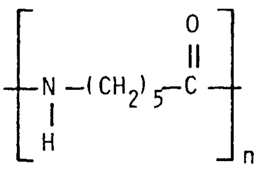
The chief applications are for mechanical parts requiring resistance to wear, such as nuts, gears, and bearings; chemically resistant parts, such as valve seats or jacketing on insulated wire; and heat-resistant parts such as electrical fittings, sterilizable hypodermic needle holders, and hospital utensils.

Nylon may be made from a wide variety of materials, usually from a diamine and a dibasic acid. Certain nylons are identified by the number of carbon atoms in the diamine and dibasic acid used to produce that particular grade. For instance, nylon 6/6 is the reaction product of hexamethylenediamine and adipic acid, both of which have materials containing six carbon atoms in their chemical structure. Some common commercially available nylons are 6/6, 6, 6/10, 8, 11, and 12. The structures of four common nylons are shown in Fig. N.2.

Grades 6 and 6/6 are the strongest structurally. Grades 6/10 and 11 have the lowest moisture absorption, best electrical properties, and best dimensional stability. Grades 6, 6/6, and 6/10 are the most flexible. Grades 6, 6/6, and 8 are heat sealable, with nylon 8 being capable of cross-linking. Another grade, nylon 12, offers advantages similar to those of grades 6/10 and 11, but at a lower cost because it can be more easily and economically processed.

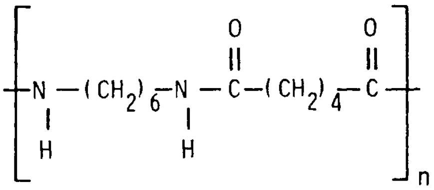
Nylon is usually processed by injection molding or extrusion. Slight modifications are required in standard equipment for handling certain formulations because of their sharp melting point and high fluidity in the molten state.

In situ polymerization of nylon permits massive castings. Cast nylons are readily polymerized directly from the monomer material in the mold at atmospheric pressure. The method finds applications where the size of the part required or the need for low tooling cost precludes injection molding. Cast nylon displays excellent



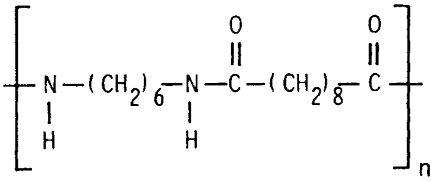
$$\left[-\underset{\underset{H}{|}}{N}-(CH_2)_5-\overset{\overset{O}{\|}}{C}- \right]_n$$

Nylon 6



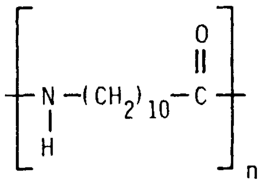
$$\left[-\underset{\underset{H}{|}}{N}-(CH_2)_6-\underset{\underset{H}{|}}{N}-\overset{\overset{O}{\|}}{C}-(CH_2)_4-\overset{\overset{O}{\|}}{C}- \right]_n$$

Nylon 6/6



$$\left[-\underset{\underset{H}{|}}{N}-(CH_2)_6-\underset{\underset{H}{|}}{N}-\overset{\overset{O}{\|}}{C}-(CH_2)_8-\overset{\overset{O}{\|}}{C}- \right]_n$$

Nylon 6/10



$$\left[-\underset{\underset{H}{|}}{N}-(CH_2)_{10}-\overset{\overset{O}{\|}}{C}- \right]_n$$

Nylon 11

Figure N.2 Chemical structures for four types of nylon.

bearing and fatigue properties as well as the other properties characteristic of basic nylon formulations. Cast nylon offers the advantages of size and short-run flexibility in a low-pressure casting process. Castings have a 15 percent increase in tensile strength and a 17 percent increase in flexural modulus over the injection-molded product. Complex castings can also be made having a minimum of internal stress, resulting in better dimensional stability and greater strength.

Nylon parts can also be made by compressing and sintering, thereby creating parts having exceptional wear characteristics and dimensional stability. Various fillers such as molybdenum disulfide and graphite can be incorporated into nylon to give special low-friction properties. Also, nylon can be reinforced with glass fiber, thus giving it considerable additional strength.

Great toughness, strength, and elasticity, high melting point, and a good resistance to water and chemicals characterize the nylon monofilaments and yarns. Nylon fibers will yellow at 149°C, are damaged at 230°C, and will melt at 250°C. They melt before burning. Elastic recovery is 100 percent from 8 percent stretch, and 91 percent from 16 percent stretch. The specific gravity of nylon is 1.14, which is the lowest of commercial synthetic fibers. Although generally inert to alkali and insoluble in most organic solvents, nylon fiber is dissolved by phenol, xylenol, cresylic acid, and concentrated mineral acids.

The material is widely used for bristles in industrial and domestic brushes, and for many textile applications. High tenacity and good elasticity are utilized in nylon rope, thread, and cord. Good resistance to abrasion and chemical attack is utilized in belting and filter cloth applications. Nylon fibers are also widely used as tire cord (nylon 6 and nylon 6/6), apparel, and carpets (nylon 6/6). The ability to give nylon a permanent set by an annealing process at about 100°C has been utilized in the production of permanently pleated garments as well as in preshaped hosiery.

In addition to conventional nylon resins, there are high-temperature nylons called *aramids*. This high-temperature nylon retains about 60 percent of its strength at temperatures of 246–260°C, which would melt conventional nylons. It is available as fibrous paper (*Nomex* from Du Pont) and filament and fabric (*Kevlar* from Du Pont). (*See also* Aramide.)

Major manufacturers of nylon resins include Allied Signal (*Capron*, *Nypel*), BASF Corp. (*Ultramid*), Bayer Corp. (*Durethan*), ComAlloy, DSM, Du Pont Co. (*Zytel*), Elf Atochem (*Rilsan*), RTP Co., and Ticona.

O

odorants Odorants are generally defined as additives that produce a fragrance or odor (in a positive sense) in plastics. Most typical are those additives that produce such fragrances as wood, grass, lemon, flowers, and leather. *Deodorants* are additives that prevent the development of odor. There is a gray area, however, in which odorants mask distasteful odors and, thereby, serve as deodorants.

Odorants are used to duplicate the fragrance of the “contained product” by imparting its scent. They are also used as environmental fixatives, to add fragrance to a product to mask odors when the product is confined in a small area (e.g., plastic garbage cans and garbage can liners).

Several techniques are currently available for adding fragrance to plastics. Some additives are sold as fragrances diluted into solvents and then mixed directly into the plastic. Most thermoplastics have been successfully treated in this way. Another approach is to encapsulate the fragrance into a plastic pellet and concentrate. Basic resins used in this type of approach are polyethylene, polypropylene, and ethylene vinyl acetate (EVA). Encapsulated fragrances function best by being mixed or blended into the resin before processing. They can also be mixed into the resin during molding.

Major suppliers of odorants for plastics include A-Aroma Tech Inc., Harwick Chemical Corp., International Flavors and Fragrances Inc., Keystone Aniline Corp., and Sanitized Inc.

See also deodorant.

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offset molding Offset molding is a form of transfer molding in which the material is moved into the cavity from a step or shelf near to it.

offset printing Offset printing is a subset of *stamp printing*, which is a process to produce code or lettering by a metal or rubber die exposed to an ink. Offset printing is a technique in which the ink is transferred from a bath onto the raised surface of the printing plate by rollers. Subsequently, the printing plates transfer the ink to the object to be printed. There are various types of stamp printing processes including letterpress, letterflex, gravure, pad transfer, and flexographic. Each is a method of applying the ink with various types of dies. All of these except gravure may be considered as offset printing processes. In *gravure* printing the ink is transferred from cells etched in a cylinder rather than from a raised surface.

Letterpress printing is a method in which raised, rigid printing plates are inked and pressed against the plastics part. The raised portion of the plate transfers the image. *Letterflex printing* is similar to letterpress except that flexible printing plates are used. Flexible plates may transfer their designs to irregular surfaces.

Pad transfer printing is a gravurelike process offering versatility for printing on a variety of shapes and surfaces. The image is transferred with a special silicone pad instead of the etched plate used in gravure. Pad printing can reproduce fine line engraving, and it can apply wet ink on wet ink. Pad printing is generally most useful for printing small areas. Pad printers are generally more expensive than hot stamping or screen-printing. The ink costs, however, are much less than the cost of hot-stamping foil.

Flexographic printing is more widely used for short and medium runs. This method prints by transforming images from a flexible raised printing plate directly to the material. A uniform film of ink is applied to the raised portion of the printing plate by bringing it in contact with a foamed roller. The plate continues to rotate until it contacts the substrate and transfers the image to it. Individual colors are applied by a series of separate printing stations.

See also printing on plastics; silk screen printing.

oil resistance (heat and oil resistance) The heat and oil resistance of natural and synthetic rubbers may be characterized for automotive applications by a specification system that has been jointly developed by ASTM and SAE (Society of Automotive Engineers). ASTM D2000, or corresponding SAE Method J200, characterizes the heat and oil resistance by the retention of properties after exposure to a standard time and temperature. The composition of the oil is well characterized and supplied by ASTM. In addition to property retention minimums, the volume change on oil immersion is a key requirement.

The relative heat and oil resistance for rubbers and plastics is shown in Fig. O.1 according to an ASTM/SAE scheme. Both the heat resistance and oil resistance of the polymers shown are not absolute, immutable properties.

During exposure to high temperatures the properties of the vulcanized rubber will continue to change with time. And, within a particular rubber type, the amount

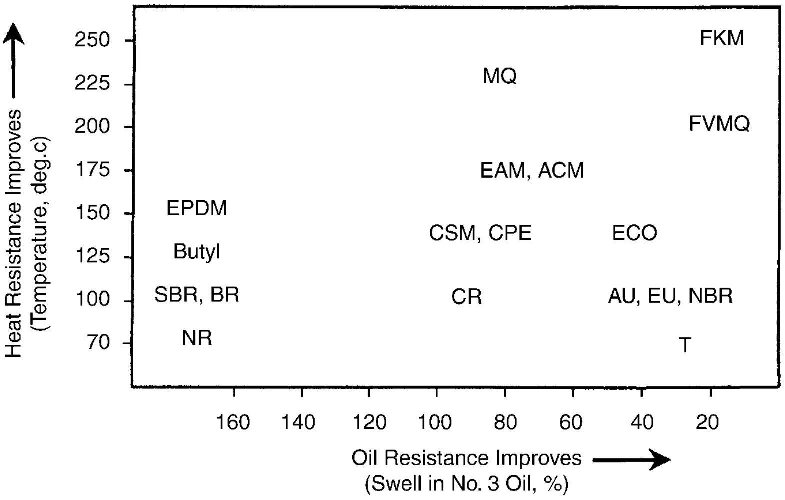

Figure O.1 Heat and oil resistance per ASTM D2000 / SAE J200 schemes. (Ohm, R., and DelVeccio, R.J., "Natural and Synthetic Rubbers", *Handbook of Materials and Plastics Design*, McGraw-Hill, New York, 2001)

of change may vary to some extent depending on the rubber formulation and the use of antidegradants.

olefin and TPO elastomers The olefinic elastomers or thermoplastic polyolefin (TPO) elastomers were introduced in 1972 as mechanical blends of ethylene propylene rubber (EPR) or ethylene propylene diene (EPDM) and polypropylene. Since the introduction of the first materials, several variations have been commercialized.

TPO elastomers are the second most used thermoplastic elastomer on a tonnage basis, accounting for about 25% of the total world consumption. The olefinics are available as pellets or granules that are usually molded in the as-received condition.

EPR and EPDM are used as the elastomeric segment and polypropylene as the thermoplastic segment. LDPE, HDPE, and LLDPE along with copolymers ethylene vinyl acetate (EVA), ethylene ethylacrylate (EEA), ethylene methyl-acrylate (EMA) and polybutene-1 can be used in TPOs. The polymer present in the larger amount will usually be the continuous phase, with the thermoplastic being favored because of its lower viscosity. Each polymer will have its own phase, and the rubber phase will have little or no cross-linking. The discontinuous phase should have a small particle size for the best properties of the TPO.

Olefin copolymers are a group of polyolefin thermoplastics made by copolymerization of olefinic polymers. This family includes polyallomers, ionomers, ethylene vinyl acetate (EVA), ethylene ethyl acrylate (EEA), ethylene *n*-butyl acrylate, ethylene hexane (EH), and ethylene butene (EB).

An EPDM/PP elastomer will have a melt temperature (T_m) near that of the hard polypropylene (PP) phase and a glass transition temperature (T_g) close to that for the soft EPDM phase. These polymers thus melt in the range of 150–165°C and can be processed above these temperatures. They show excellent low-temperature performance with brittle points often below −60°C. The T_m determines the upper theoretical service temperature limit. The medium long-term service temperature is usually 25–50°C below the T_m and is determined primarily by the resistance of the polymers to oxidative attack.

EPDM/PP elastomers compete directly with styreneic thermoplastic elastomers (TPEs) as low-cost, low-specific-gravity materials with fair to good mechanical performance and environmental resistance. They range in hardness from Shore A 60 up to Shore D 65. The harder products are more commonly found in commercial applications. The harder TPOs are essentially impact-modified thermoplastics and not true rubbers. The softer TPOs are rubbery at room temperature, but mechanical properties are radically lower at temperatures above 70–80°C.

The molded and extruded materials have good tensile strengths and elongations and excellent lower-temperature flexibility in most grades. They have the lowest specific gravities (0.9–1.0) of the thermoplastic elastomers. All have good-to-excellent weathering properties and oxygen and ozone resistance. With the addition of ultraviolet (UV) light absorbers, they also have good UV resistance. The olefinics exhibit good chemical resistance to water, dilute acids, and bases. Some aliphatics attack the olefinics, and all aromatics and halogenated solvents attack the materials, causing swelling and loss of strength.

TPOs are one of the lower-performance, lower-cost classes of TPEs. Their performance and properties are generally inferior to those of a thermoset rubber, yet they can be suitable for uses where (1) the maximum service temperature is modest, (2) fluid resistance is not needed, and (3) a high level of creep and set can be tolerated.

Applications include the automotive, wire and cable markets, as well as general mechanical applications. Other automotive uses include exterior trim such as bumpers, fascia, and nonsealing molding, whereas under-the-hood uses are limited because of temperature- and fluid resistance requirements. TPOs are also used in sporting goods because of flexibility, feel, and good colorability.

Major suppliers of TPOs include Advanced Elastomer (*Santoprene*), Advanced Polymer Alloys (*Alcryn*), Du Pont Dow Elastomers LLC (*Engage, Affinity*), Nova Polymers (*Novalast*), Montell (*HiFax*), Solvay Engineering Polymers (*Dexflex*), and Teknor Apex (*Uniprene, Telcar*).

olefinics Olefins are a family of unsaturated hydrocarbons with the formula C_nH_n. This family is known as *polyolefins*. They are formed by polymerizing monomers containing the $C{=}C$ group. Ethylene, containing the olefinic double bond, $CH_2{=}CH_2$, is the simplest monomer that contains this structure. All other polymers having a substituted ethenic base could be called ethenic polymers. However, the term *olefins* is more popular. Olefins are named after the corresponding paraffin by adding “ene” of “ylene” to the stem (e.g., ethylene, propylene). Paraffins are aliphatic hydrocarbons.

Sometimes the broad classification of olefins is broken down into subclasses based on similarities of use, chemical nature of precursor monomers, and properties.

Thus polyethylene, polypropylene, polybutene, and their copolymers are grouped into one subclass. This subclass is generally referred to as polyolefins in commercial trade. Polystyrene, its copolymers, and alloys form a second subclass; with vinyls and copolymers forming a third; and so on. The latter subclasses are generally referred to by a title referencing the base monomer (e.g., vinyls).

There are many similarities among these polymers. The similarities are appearance, general chemical characteristics, and electrical properties. The differences are more notably in physical and thermal stability properties. Basically, polyolefins are all waxlike in appearance and extremely inert chemically. They exhibit a decrease in physical strength at somewhat lower temperatures than the higher-performance engineering thermoplastics.

The two best-known and most massively used polyolefins are polyethylene and polypropylene. Their chemical structure is shown in Fig. O.2.

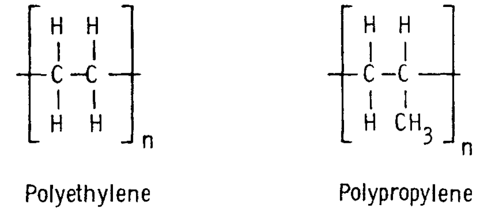

Figure O.2 General chemical structure of polyethylene and polypropylene, two of the main members of the polyolefin family.

Polyethylenes were the first of these materials to be developed and hence for some of the original types, have the weakest mechanical properties. The later-developed polyethylenes, polypropylenes, and polyallomers offer improvements.

The entire class of olefin polymers tends to have a linear structure. Some branching is possible, but highly branched polymers are not usually formed. Crosslinkages between chains may also be formed, but such materials are a small part of the total production. Crosslinked polyolefins, especially polyethylene, have been developed to improve on the standard polymer's tendency to creep or cold flow under the influence of temperature, load, and time. However, these polymers are usually thermoplastics. The general linear structure also indicates suitability for fiber and film applications, which are common.

See also polyethylene; polypropylene; polyallomers; polybutadiene; polybutylene.

oleoresin Oleoresins are semisolid mixtures of resin and essential oils of the plant from which they exude. Sometimes oleoresins are referred to as *balsams*. Oleoresinous materials also consist of products of drying oils with natural or synthetic resins.

oligomer An oligomer is a polymer containing only a few monomer units, such as a *dimer* or *trimer*, or their mixtures.

one-shot molding In urethane foam molding, one-shot molding indicates a system in which the isocyanate, polyol, catalyst, and other additives are mixed together directly and the foam is produced immediately after mixing. This was the original polyurethane foam process.

open-cell foam Open-cell foams are cellular plastics in which there is a predominance of interconnected cells, so the material can readily breathe or act as a sponge to absorb water. Open-cell foams also provide good sound-deadening characteristics, but the thermal insulation characteristics are not as good as those of the closed-cell foams.

A cell may be open because its walls are incomplete or because they are entirely absent. In the latter case the cells take on a filamentary, skeletal outline. Both open and closed cells may coexist to some extent in the same cellular material. Methods of determination of the percentages of open and closed cells in a cellular plastics are given in ASMT D2856.

Two methods are commonly used to form predominantly open-cell foams: (1) a chemical blowing agent technique and (2) a mechanical frothing process in which a gas is used as part of the blowing mechanism. Closed-cell, predominantly rigid foam is also made using chemical blowing agents.

See also cellular plastic; foamed plastic.

optical properties Most polymeric materials are intrinsically capable of transmitting electromagnetic radiation in the wavelength range corresponding to visible light. Light sources (sunlight, incandescent, vapor-arc, and arc lamps) have a characteristic radiation spectrum, and filters can be used to enhance certain wavelengths such as violet, yellow, or red.

The practical characterization of the optical properties of polymeric solids is a complex subject. It involves the definitions and measurement of quantities such as index of refraction, transparency, gloss, haze, and yellowness index.

Transparent polymers and, in some cases, translucent polymer have found many applications where their optical properties match those of glass. They are superior to glass, however, in other respects such as weight, impact resistance, and moldability. Excellent optical quality is required for certain applications such as automotive lenses, prescription and sunglass lenses, and even camera lenses. Lighting fixtures are associated with translucent or transparent diffusers and globes in fixtures. A growing field of application is advanced optical fibers used for light piping or communications.

See also refractive index; transparency; transmittance; gloss; haze; and color.

orange peel Orange peel is a term used to describe an undesirable surface on a molded part. This uneven or rough plastic surface resembles the surface of an orange skin.

organic An organic material is a material that is composed of matter originating from plant or animal life, or composed of chemicals of hydrocarbon origin, either natural or synthetic. The term is often used in referring to chemical structures based on the carbon atom.

organic filler Most organic fillers are derived from process residues that would otherwise be discarded. These sources are renewable, unlike those for inorganics. Common organic fillers are characterized in Table O.1. The plentiful, renewable supply of organic fillers leads to their lower prices. The organics, with lower density, provide an economic benefit of lower volumetric cost. These fillers also help processability, controlling viscosity and improving moldability.

Organic fillers are used more commonly in thermosets than in thermoplastics. Fillers, like wood flour and cotton flock, contribute low cost and an excellent weight-to-bulk ratio, and they are in plentiful supply. Organic fillers will reduce shrinkage and warpage, improving dimensional stability. Further effects on properties will depend to a great extent on the shape of the filler and whether surface modification is used. A common limitation on the use of organic fillers is temperature stability. In thermoplastics, the cutoff point is usually 192–204°C; limiting their use to the low-temperature processing resins such as polypropylene, polyethylene, polystyrene, vinyls, and cellulosics.

Organic fillers are hygroscopic. Their moisture content will vary from 2 to at least 20 percent, depending on type, and many will readily absorb ambient moisture. Filler predrying will often be required for thermoplastics. Many of these fillers will also increase the molded part's tendency to absorb moisture.

Major suppliers for organic fillers include GCA Chemical Corp. and Composition Materials of America (corn cobs); Akrochem Corp., American Fillers & Abrasives, and James River Corp. (flock and fiber); Agrashell Inc. and Composition Materials of America (nutshell and hull flours); Composition Materials of America (rice hulls); and Akrochem, American Wood Fiber, and Smith Chemical & Color (wood flour).

organic peroxide Organic peroxide initiators serve as sources of free radicals in the preparation of a variety of resins for plastics, elastomers, and coatings. Their use in plastics processing can be divided into four functions:

- Polymerization of thermoplastic resins
- Curing for unsaturated polyester thermoset resins
- Cross-linking of polyethylene and various elastomers
- Rheology modification of polypropylene.

The peroxide group ($—O—O—$) contained in all organic peroxides is highly unstable. This instability eventually leads to hemolytic cleavage. When the bond is broken between the two oxygen molecules, the peroxide decomposes and two free radicals are formed.

The general formula for such compounds is $R_1—O—O—R_2$, in which R_1 and R_2 either symbolize organic radicals or an organic radical and hydrogen atom. Organic

Table O.1 Characteristics of Common Organic Fillers

Organic Filler	Size/Shape	Application	Characteristics
Wood flour	40–325 mesh; aspect ratio of 2.5	Extender for thermosets	Moisture content can be up to 8%. Poor bonding to polyolefin matrices
Flock (randomly cut fiber) and fiber	Flock: 30–100 mesh. Fiber: >0.25 in length	Contribute processability and good appearance to thermosets	Include cotton, cellulosic materials, wool and sisal, as well as synthetics
Nutshell flours	To 325 mesh	Extenders for thermoplastics	Moisture content is 2%, but absorb ambient moisture rapidly
Starch		Rendering plastics biodegradable	Used where tensile strength and clarity are not critical Readily absorb moisture
Corncobs	Three grades available: pulpy center, outside chaff, and a combination	Thermosets and thermoplastic fillers to improve processing	Moisture content is 7%, drying is necessary Melt temperatures should not exceed 380°F
Rice hulls	100–125 mesh	Injection molded thermoplastics. Thermosets, especially phenolics. Replacement for chemical blowing agent by employing high water content.	Can be used with surface modified

peroxide initiators can be further classified by functional groups into seven major classes: dialkyl peroxides, diacyl peroxides, hydroperoxides, ketone peroxides, peroxydicarbonates, peroxyesters, and peroxyketals. Table O.2 shows organic peroxides types and functions.

Table O.2 Organic Peroxides–Types and Functions (Ref: Kattas, L., et. al., "Plastic Additives", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

Type	Function
Dialkyl peroxides	Polyethylene cross-linking Initiator for polystyrene polymerization Polypropylene rheology modification
Diacyl peroxides	Initiator for polystyrene polymerization Unsaturated polyester curing
Hydroperoxides	Initiator for ABS polymerization Raw material for other organic peroxides
Ketone peroxides	Unsaturated polyester curing
Peroxydicarbonates	Initiator for PVC polymerization
Peroxyesters	Initiator for ABS polymerization Initiator for polystyrene polymerization Unsaturated polyester curing
Peroxyketals	Polyethylene crosslinking Unsaturated polyester curing

The family of dialkyl peroxides includes dicumyl peroxide, which accounts for one-third of the volume of dialkyls world-wide and is the workhorse of this family of peroxides. Dicumyl peroxide is commonly used as a catalyst in polyester resin systems and for cross-linking polyethylene. Benzoyl peroxide is the most common of the diacyl peroxides. It is also used as a catalyst for curing polyester resins. Hydroperoxides are generally used as a raw material to produce other organic peroxides. The most common peroxides in this family include cumene hydroperoxide and *t*-butyl hydroperoxide. Ketone peroxides are mixtures of peroxides and hydroperoxides that are commonly used for room-temperature curing of polyester resins. Methyl ethyl ketone peroxide (MEKP) is the major product in this family. Peroxydicarbonates are largely used to initiate polymerization of polyvinyl chloride (PVC).

Major suppliers of organic peroxides include Akzo Nobel, Central Chemicals, Concord Chemical Industries, Hercules, Mitsui Petrochemical, Plasti Pigments, and Witco.

organic pigment The major organic pigments used in the plastics industry are classified according to chemical structure. They are identified, compared to inorganic pigments, and listed by applicable color in Table O.3.

Azo pigments are the largest and most widely used group of pigments among the organics. Their colors are in the yellow, orange, and red range. Azo pigments are characterized by an azo chromophore. There are two major groups of azos:

Table O.3 Popular Inorganic and Organic Pigments (Ref: *Plastics Compounding*, 1991/92 Redbook, Edgell Communications, Cleveland, OH)

	Inorganic	Organic
Reds (including maroon and violet)	Cadmium mercury Cadmium sulfoselenide Manganese violet	Carbazole violet Disazo condensate Isoindoline Permanent Red 2B Perylene Quinacridones
Blue	Cobalt aluminate Cobalt blue Iron blue Ultramarine blue	Phthalocyanine
Yellow	Cadmium sulfide Chrome yellow Nickel titanate	Diarylide Disazo condensation FD&C Yellow No.5 Vat anthraquinone Monoazo (Hansa) Isoindolinone Nickel-azo
Green	Chrome green Chrome oxide Hydrated chrome oxide	Phthalocyanine
Orange	Cadmium mercury Cadmium sulfoselenide Chrome orange Molybdate orange	Aniline Disazo condensation Monoazo (Hansa) Isoindolinone
Brown/buff	Iron oxide	

insoluble azo pigments and metallized azo pigments or acid azo pigments. Azo pigments are also classified in terms of the number of chromophores in their structure (*monazo pigments* containing one chromophore and *polyazo pigments* containing more than one). The monazos are characterized by poor heat stability, strong bleeding tendencies, and poor light fastness. They are generally not used in plastics. However, there are more complex structures of monazo pigments that show excellent properties and are used with the engineering thermoplastics. These are benzimidazolones. Polyazos have better heat and bleed resistance and excellent chemical resistance. They are especially suited for elastomeric and thermosetting systems where strong curing and oxidizing agents are used.

Carbon blacks are finely divided forms of amorphous carbons that are produced either by incomplete combustion of natural gas or by incomplete combustion of liquid hydrocarbons. As a pigment, carbon blacks are known for blackness, strength, rheology, and dispersability. Carbon blacks are among the smallest in size and highest in surface area of all pigments. They are available both in loose and pelleted forms.

Dioxazine pigments are available in violet and are unusually strong although expensive. They exhibit excellent stability in light and satisfactory heat stability.

Used in acrylic sheet and extruded low-density polyethylene (LDPE), dioxazine pigments are also widely used for shading greenish phthalocyanine blue and as a toning pigment to blue white.

Isoindolinone pigments are high-performance pigments available in yellow, orange, and red. They can be used in most plastics. However, their high cost has limited them to specialty uses.

Phthalocyanines are widely used in blues and greens. They offer excellent fastness to heat, light, chemicals, and solvents; high tinting strength and transparency; low cost; and intense, pure shades. Most are copper based, although metal-free variations are also commercial. This family is widely used in plastics.

Quinacridone pigments are available in orange, red, and violet. They have good light fastness, excellent bleed and chemical resistance, and adequate heat stability for most plastics. However, they are high in cost. They perform best in polystyrene and acrylic at lower temperatures. They are not recommended for nylon.

Quinophthalone pigments fall in the green shade yellow area and compete with cadmium yellow on a cost/performance basis. These pigments are suitable for rigid and flexible polyvinyl chloride (PVC), polyolefins, styrenics, acrylics, and polyurethane. They possess good resistance to chemicals, solvents, light, and heat (260–282°C). Transparent, semiopaque, and opaque versions are available.

Vat pigments as a group show a wide range of hues and are generally of high strength, transparency, and intense coloration. They include compounds based on thioindigo, anthraquinone, and prerinone and perylene. Each compound has properties that differ significantly from the others.

Major suppliers of organic pigments include Akrochem, BASF Corp., and Hoechst Celanese Corp. (azos); Cabot Corp., Holland Colors Americas Inc., and Mineral Pigments Corp. (carbon black); BASF Corp., Hoechst Celanese and Sandoz Chemicals (dioxazines); BASF Corp., Ciba-Giegy Corp. and Indol Div. Magruder Color (isoindolinones); BASF Corp., Daicolor-Pope Inc., and Harwick Chemical Corp. (phthalocyanines); Hoechst Celanese Corp, Holland Colors Americas Inc., and Keystone Aniline Corp. (quinacridones); BASF Corp, and Compton & Knowles Corp. (quinophthalones); and Fabricolor Inc., Hoechst Celanese Crop, and Summit Chemical Co. (vats).

organosol An organosol is a vinyl or nylon dispersion. The liquid phase contains one or more organic solvents. Plastisols, organosols, and plastigels are termed *paste resins*. They are highly viscous mixtures of finely divided resin dispersed in a liquid medium. When the liquid medium is plasticizer alone, the paste is called a *plastisol*. If volatile organic liquids are added as thinners, the composition is termed an *organosol*. Sometimes it is desirable to thicken the plastisol so that heavy coatings will not run off the coated article. These materials are called *plastigels*.

Other ingredients, such as stabilizers, fillers, colorants, surfactants, and possibly blowing agents or gelling agents are also present. The polymer particles do not dissolve in the liquids but remain dispersed until the mixture is heated. Fusion (plus loss of solvent for the organosols) then yields the final plastic object.

The organosols are a partial dilution of the plastisol with a mixture of solvent and nonsolvent. It is a way of lowering viscosity. Because this does introduce some volatile material, applications are limited to those in which the volatile matter can evaporate conveniently. This is still better, however, than using resin solutions where the solids content is very low (5–30 percent) and toxicity, flammability, cost, and handling of the solvents may be detrimental to efficient use. Organosols typically have a 75–95 percent solids concentration.

See also plastisol.

orientation Orientation is the alignment of crystalline structure (known as crystallites) in a polymeric material so as to produce a highly uniform structure. When a polymer mass is crystallized in the absence of external forces, there is no preferred direction in the specimen along which the polymer chains lie. If such an unoriented crystalline polymer is subjected to an external stress, it undergoes a rearrangement of the crystalline material.

The effects of orientation on the physical properties of the polymer are profound (*see also* crystallinity, Fig. C.8.) They lie in the generally expected direction of increased tensile strength and stiffness with increasing orientation. As orientation is increased, anisotropy of the mechanical properties appears.

Orientation can be accomplished by cold drawing or stretching during fabrication. This is often done to increase the strength of a film or filament. Oriented (drawn) fibers are much stronger along their length than perpendicular to it. Heat treatment during or after the stretching controls the degree of recrystallizaion, lost during the extrusion process.

orientation (stretch) blow molding Orientation or stretch blow molding is a process by which the parison is extruded and while hot it is stretched biaxially: lengthwise by mechanical stressing and diametrically by blowing to result in hoop orientation. The process starts by the continuous extrusion of the parison, which is first clamped in a preform mold. In the preform mold, the parison is blown into a shape, the neck is accurately sized, and most important, the preform is cooled to the optimum temperature for orientation. When the preform has been correctly “conditioned” to the specified temperature, shuttle clamps remove it and place it in a stretch blow mold, where it is mechanically stretched by an internal rod and at the same time blown to the final dimensions.

This process is particularly useful for heat-sensitive materials such as polyvinyl chloride (PVC) and nitriles, because the parison is only subjected to one heat cycle rather than two to obtain the orientation and blowing. In addition to the tensile strength, the process is also claimed to improve impact strength, stiffness, clarity, and gloss and to lower vapor transmission. To obtain all these advantages in material properties, the mold must precisely control the temperature during the conditioning period. To accomplish this, the preform mold is provided with a number of cooling passages divided into as many as four or five zones, with temperatures ranging from 65 to 80°C.

See also blow molding.

orifice The orifice is the opening in the extruder die formed by the orifice bushing (ring) and mandrel. The orifice bushing is the outer part of the die in an extruder head.

orthotropic Orthotropic refers to a material having three mutually perpendicular planes of elastic symmetry.

out-gassing Out-gassing is the devolatilization of plastics or applied coatings during exposure to vacuum processes such as vacuum metallizing. Out-gassing may be caused by moisture content. In this case, drying can be beneficial. However, out-gassing may also be caused by plasticizers or other volatile compounds that migrate to the surface of the part.

In the vacuum metallizing processes, out-gassing results in parts that show voids or thin spots in plating with reduced and spotty brilliance. Out-gassing can also cause fogging of optical components near to the plastic part.

overcoating In extrusion coating, overcoating is the practice of extruding a web beyond the edge of the substrate web.

overflow groove The overflow groove is a narrow groove machined into a mold so that the plastic may flow more freely in it. This prevents the formation of *knit lines* and sections of low density. The small amount of materials that escapes through the overflow groove forms a *fin*, which is easily removed by *tumbling*.

overlay mat (surfacing mat) The overlay or surfacing mat is a nonwoven fibrous mat used as the top layer in a reinforced plastic composite layup. Such mats are usually called surfacing or overlay mats or *veils*. They are usually made from glass, synthetic fiber, etc. and are about 10–30 mil thick.

An extremely smooth surface can be obtained on a reinforced plastic molding by placing a thin overlay sheet on the exposed surface of the composite. This type of mat provides little actual reinforcement. It does, however, facilitates a resin-rich surface layer to be incorporated into the molded part.

Surfacing mats are relatively strong and stiff and are applied when molding flat areas or parts of simple contour. Overlay mats are more drapable and harder to handle but can be used on parts of more complex shape.

oxidation Oxidation refers to the process by which a material is changed by exposure to oxygen. Oxidation of polymeric materials usually results in degradation of physical properties. It may also result in degradation of the surface's appearance.

oxidation induction time Oxidation induction time is a measure of the thermal oxidative stability of a polymer specimen. This test is applicable primarily to polyolefin molding and extrusion materials. In the test, a specimen is held isothermally at an elevated temperature in a differential thermal analysis (DTA) or differential scanning calorimetry (DSC) apparatus. The specimen is exposed to a regulated stream of oxygen, and the time is measured between its first contact with oxygen and the onset of significant degradation as measured by an exotherm or endotherm. This time (usually expressed in minutes) is the oxidation induction time of the material. The test temperature is at least 200°C (compatible with polyolefin processing temperatures) so that the specimen is molten during this test. The oxidation induction time is defined as a test method by ASTM D3895.

oxirane Oxirane is a synonym for ethylene oxide. An oxirane group is one kind of epoxy group. It is a three-membered ring with the following structure: $—CH_2—O—CH_2—$. The oxirane ring and the glycidyl group, $—CH_2—O—CH—CH_2—$, are frequently used in the epoxy resin industry.

oxygen index The oxygen index, sometimes called the *limiting oxygen index,* is the minimum percentage of oxygen in a mixture of oxygen and nitrogen that is just sufficient to maintain flaming combustion of a material. The specimen is in the form of a strip. It is mounted vertically and ignited at the top so that it burns in a candle fashion. This test is specified in ASTM D2863.

See also limiting oxygen index.

P

packaging Plastics are used extensively in packaging because of their outstanding physical, mechanical, and chemical properties. Plastic materials can be applied to do two things: (1) protect the contents of the package either chemically or physically and (2) dress it up for better merchandising.

Plastics are used in packaging in a variety of forms: single films, multilayer flexible structures, sheets, coatings, adhesives, foams, laminations, and rigid or semi-rigid containers. The most widely used plastics in flexible packaging are low-density polyethylene (LDPE), the very fast-growing linear low-density polyethylene (LLDPE), polypropylene (PP), and high-density polyethylene (HDPE). HDPE is widely used for rigid containers. However, the fastest-growing plastic for rigid containers is polyethylene terephthalate (PET) and its copolymers. Other resins such as ethylene vinyl alcohol (EVOH), polyvinyl chloride (PVC) copolymers, and nylons have specialized applications as high-barrier materials. Selected properties of packaging plastics are shown in Table P.1.

New technologies are continuously improving existing resin properties as well as generating entirely new resins like metallocenes and polyethylene naphthalene (PEN). These technologies widen the processing capability of single and composite structures in the production of flexible and rigid containers, while at the same time increasing the number of applications. The interest in package/product interactions has recently increased with the use of recycled plastics, most notably recycled PET for food applications. PET's high recycling rate along with new processes for cleaning the recycled resin and making bottles available have prompted the FDA to clear the use of conventionally recycled PET in direct-contact food packaging.

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Table P.1 Packaging Films–Major Characteristics (Schwartz, S.S., and Goodman, S.H., *Plastic Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 511)

Material	Characteristics
Acrylics	Weather and UV resistance.
Cellulosics: CA, CAB, CAP, CA_3	Good scuff, oil, and grease resistance. High gas permeability, medium MVTR, medium clarity.CAB: good outdoor weathering; major uses: skin and blister packaging.
Fluoroplastics	Excellent electrical, chemical, and thermal properties. $CFCl_3$: lowest MVTR of any transparent film, LOX (liquid oxygen) compatible and flexible at cryogenictemperatures; uses: packaging of hygroscopic pharmaceuticals.
lonomers	Very tough, oil and grease resistant, heat sealable through oil or grease.
Polyamides	Good general-purpose, tough, strong material. Useful from −100°F to +300°F.
Polycarbonates	Strong, flexible material. Attacked by many chemicals. Must be dried thoroughly before processing or bubbles result.
Polyesters	Tensile strengths up to 40,000 psi in tensilized (oriented) condition. Good high-temperature properties (original "boil-in-bag" material). Very good electrical properties. Metallized film used for thermal insulation on spacecraft.
Polyethylenes	Tough, low cost, versatile. Used for all types of packaging: trash bags, bread wraps, shrink film, antistatic film, etc.
Polyimides	Highest temperature resistance of all films. Excellent chemical and electrical properties. Heat sealable using FEP coating.
Polypropylenes	Strong, tough, low gas transmission, good chemical and grease resistance, best when oriented. Poor low-temperature properties.
Polystyrenes	High gas permeability, good for produce packaging, not recommended for outdoor usage. Many grades available. Good thermoforming capabilities for cups, blister packs, etc.
Polyurethanes	Very tough, good tear and abrasion resistance. Can be extruded and calendered onto fabric.
Polyvinyl chlorides	Very versatile, strong, tough. Used for fresh meat and produce packaging.
Polyvinylidene chlorides	Extremely low moisture and gas transmission rates. Good chemical resistance. Good shrink characteristics.
Polyvinyl fluoride	Excellent weather and UV resistance, good chemical resistance.
Polyvinylidene fluoride	Good UV, nuclear, weather, and chemical resistance; good electrical properties.

Plastics, however, have some limitations as packaging materials. These limitations are associated with (1) relatively low-temperature use; (2) mass-transfer characteristics that allow molecular exchange between a plastic container, its product, and the external environment; (3) tendency for environmental stress cracking; and (4) viscoelastic behavior that may produce physical distortion under external forces and heat.

See also specific polymeric materials.

painting plastics Painting is a method of providing a specific color to a plastic part. The most convenient and economical way to color plastics is to blend the color pigments into the base resin. (*See* colorants.) However, often this does not provide the flexibility desired to change colors, to match colors, or to apply multiple colors to a single part. Painting processes used in decorating plastics are similar to those used with other substrates. They include spray painting, electrostatic spraying, dip coating, fill-in marking, screen painting, and roller coating. In all of these painting processes the type of paint, the nature of the solvent, and the temperature of the paint-drying process must be chosen carefully for the specific plastic being coated.

Several categories of paint are generally used for painting on plastic. *Water-based acrylic paints* provide no harmful solvents. They are easy to apply and have many color possibilities. *Lacquers* contain solvents that evaporate, allowing the paint coating to dry without chemical reaction. The lacquer must be carefully chosen to have a solvent that is compatible with the plastic being painted. *Enamels* are based on a chemical reaction that causes the coating film to form and harden. The effect of this reaction on the parent plastic part must be carefully noted. Table P.2 provides recommended paints for specific plastics.

Certain plastics may require a primer to help improve the adhesion of the paint to the plastic. After coating, a topcoat may also be required to improve the environmental or wear resistance of the paint. Two-part paints, such as epoxy or urethane coatings, provide excellent adhesion qualities and do not require a topcoat.

Table P.2 Recommended Paint for Plastics (Ref: Van Har, R.C., "Spray Painting Plastics", *Plastics Finishing and Decorating*, D. Satas, ed., van Nostrand Reinhold, New York, 1986)

Plastic	Urethane	Epoxy	Polyester	Acrylic Lacquer	Acrylic Enamel	Waterborne
ABS	R	R	NR	R	R	R
Acrylic	NR	NR	NR	R	R	R
PVC	NR	NR	NR	R	R	NR
Styrene	R	R	NR	R	R	R
PPO/PPE	R	R	R	R	R	R
Polycarbonate	R	R	R	R	R	R
Nylon	R	R	R	NR	NR	NR
Polypropylene	R	R	R	NR	NR	NR
Polyethylene	R	R	R	NR	NR	NR
Polyester	R	R	R	NR	NR	NR
RIM	R	NR	NR	NR	R	R

Note: R = recommended; NR = not recommended.

Masking is required when areas of the part are not to be painted. Paper-backed masking tape, polyvinyl alcohol coating masks, and electroformed metal masks have been all used with plastic parts. The plastic part can be designed to better accommodate the mask. The part may be designed with some depression or boss that will allow the mask to be properly registered on the part being sprayed so it may do an effective masking job.

In the design of the part for painting, certain features should be avoided. Depressions, which have to be painted, should be relatively wide and shallow. If they are narrow and deep, they are likely to catch too much paint and thus will take much longer to dry. For coating depressions, a technique called wipe-in or fill-in painting can be used. Here the paint is applied to the depressions and surrounding surfaces. The excess paint on the surrounding surfaces is then removed by wiping or a solvent-dampened pad.

Painting on raised surfaces also requires special considerations. Trying to spray paint only on raised surfaces (i.e., letters or numbers) is difficult to mask. However, roller coating may be a method of obtaining good detail on raised sections without masks. Large, flat, smooth areas in which runs or drips would be apparent should also be avoided.

See also colorant; decorating; printing.

paraffin Paraffins (or *alkanes*) are a class of aliphatic hydrocarbons in which the first member is methane (CH_4) and each succeeding member adds CH_2 (e.g., ethane, C_2H_6). They are characterized by straight or branched molecular chains. Paraffins range in form from a gas (methane) to liquids (those with 5–17 carbon atoms) to a colorless solid depending on molecular weight. Most of the paraffins are found in petroleum. *Chlorinated paraffins* are used as plasticizers for rubber, in flame-retardant wire coatings, and for cloth coatings.

paraformaldehyde Paraformaldehyde ($CH_2O_n \cdot H_2O$) is used in the production of synthetic resins. It is used especially in the dry process of manufacturing *phenol formaldehyde*. Paraformaldehyde is obtained by the polymerization of formaldehyde.

parallels In molding, parallels are spacer supports placed under or above bottom to top halves of a mold to support them firmly. They should be placed as close to each other as possible with allowance for the knockout bar, which is generally located between them.

Parallels can be placed between the steam plate and press platen to prevent the middle section of the mold from bending under pressure. Parallels may also be used as pressure pads or spacers between the steam plates of a mold to control height when closed and to prevent crushing the parts of the mold when the land area is inadequate.

parison In blow molding, the parison is the hollow plastic preformed tube from which a part is blown. An extruder is generally used to produce a parison. The hot parison, immediately on emerging from the die, is clamped in a mold, air is introduced, and after a cooling period a formed container is ejected from the mold. A technique has also been developed whereby the parison can be injection molded.

Parison swell is the ratio of the cross-sectional area of the parison to the cross-sectional area of the die opening. Parison swell is caused by the tendency of the parsion to enlarge as it emerges from the die.

When extruding a large parison, the wall thickness will vary as the weight of the material increases and it begins to sag. One method of minimizing the wall thickness variation is by raising the core inside a variable die by means of a programmed timer. Such gradual increase of the die clearance takes place during the parison forming stage. Wall thickness increases gradually and thus compensates for sagging at the upper end of the parison. This is accomplished by an electrical hydraulic assembly, which automatically programs the parison. The process is known as *parison programming*.

See also blow molding.

parting agent

See mold release agent.

parting line The parting line is the line at which the two halves of a mold meet when the press closes. The molded or cast piece often shows a line at this location, which is sometimes considered in the design of the part. Otherwise, it may have to be removed by a finishing operation. Parting lines are at the junction point of all movable molding surface sections.

Parting lines on molded parts require special consideration in part and mold design, especially where two molded parts must come together (for example, on each half of a molded box with a hinged opening).

parylene Parylene is the generic name for members of a thermoplastic polymer series developed by Union Carbide. Parylenes are unique among plastics in that they are produced as thin films by vapor polymerization. The polymers are high-crystalline, high-molecular-weight, straight-chain compounds that are known as tough materials with excellent dielectric characteristics. Parylene films find application in electrical applications such as capacitors and where pore-free coatings with low vapor transmission are required. Parylene polymers are expensive and usually applied as ultra-thin films.

Parylene is extremely resistant to chemical attack, exceptionally low in trace metal contamination, and compatible with all organic solvents used in the cleaning and processing of electronic circuits and systems. Although parylene is insoluble in most materials, it will soften in solvents having boiling points in excess of 150°C.

The basic member of this family is *parylene N* or *para*-xylylene. Its chemical structure is as shown in Fig. P.1.

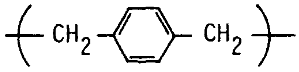


Figure P.1 General chemical structure of Parylene N.

Parylene N exhibits superior dielectric strength, exceptionally high surface and volume resistivities, and electrical properties that vary remarkably little with changes in temperatures. Because its melting point far exceeds that of many other thermoplastics, parylene N can even be used at temperatures exceeding 220°C in the absence of oxygen. Because parylene can be deposited in very thin coatings, heat generated by coated components is easier to control and differences in thermal expansions are less of a problem than with conventional coatings.

The other commercially available members of this group are *Parylene C* and *Parylene D*. Parylene C is poly-mono-chloro-para-xylylene. Parylene C offers significantly lower permeability to moisture and gases, such as nitrogen and oxygen, while retaining excellent electrical properties. Parylene D is poly-dichloro-para-xylene. Properties of Parylene N, C, and D are shown in Table P.3.

Table P.3 Properties of Parylene N, Parylene C, and Parylene D

Property	Parylene N	Parylene C	Parylene D
Melting temperature, °C	405	280	>350
Linear coefficient of expansion, 10^{-5}/°C	6.9	3.5	—
Tensile strength, psi	6500	10000	11000
Yield strength, psi	6100	8000	9000
Elongation to break, %	30	200	10
Density, g/cm^3	1.11	1.289	1.418
Moisture-vapor transmission, g-mil/100 in^2, 24 hr at 37°C, 90% RH	1.6	0.5	0.25

Unlike most plastics, parylene is not produced and sold as a polymer. It is not practical to melt, extrude, mold, or calender as with other thermoplastics. Nor can it be applied from solvent systems, because it is insoluble in conventional solvents. The parylene process starts with a dimer rather than a polymer and polymerizes on the surface of an object. To achieve this, the dimer must first go through a two-step heating process. The solid dimer is converted to a reactive vapor of the monomer. When passed over room temperature objects, the vapor will rapidly coat them with polymer. The coating thickness is very uniform and controlled simply by regulating the amount of dimer that is vaporized.

Although they are expensive, deposition chambers of virtually any size can be constructed. The versatility of the process enables the simultaneous coating of many small parts of varying configurations. However, this is mainly a batch process and difficult to apply in a continuous fashion. Parylenes can also be deposited onto a cold condenser and then stripped off as a free film, or they can be deposited onto the surface of objects as a continuous, adherent coating in thickness ranging from about 0.004 mil to 3 mil or more. The deposition rate is normally about 0.02 mil/min. On cooled substrates, the deposition rate can be as high as 1.0 mil/min.

paste A paste is an adhesive composition having a characteristic plastic-type consistency with a high order or yield value. Paste usually refers to naturally occurring organic adhesive compositions such as those based on starch, casein, or animal glue. The term *paste* is not generally used for synthetic organic-based adhesives such as epoxies, urethanes, etc., where the term *adhesive* is used.

paste resin Paste resin is a term given to a dispersion of certain resins, notably vinyl, in liquid plasticizer. It is used both as a molding compound and as a coating. The paste resin is resistant to solvation by the plasticizer so that the plasticizer surrounds the resin particles but does not penetrate them. The paste like characteristics of this mixture makes possible casting or spreading. Various additives are also usually present as required by product and processing requirements. In the case of polyvinyl chloride (PVC), the term resin is often used synonymously with *plastisol*.

The advantage of pastes in molding is that only very slight pressures are necessary for shaping the product. In coating applications, paste resins do not contain a volatile vehicle to be evaporated. This results in improved environmental characteristics as well as lower material costs. It also permits coating in thicker layers, because formation of bubbles is eliminated. The plasticizer becomes incorporated in the resin during heating of the part.

As the temperature of the paste rises during "cure," the plasticizer penetrates into the polymer particles, which swell and merge. If the temperature is sufficiently high and the time adequate, the process culminates in complete mutual solution of polymer and plasticizer. This is represented by the formation of a homogeneous plasticized PVC melt that on cooling solidifies to a solid plasticized PVC material.

See also plastisol.

PBO fibers A new synthetic polymer fiber, *poly*(*p-phenylene-2-6-benzobisoxazole*) or PBO, was introduced in the 1990s. It was developed by Dow Chemical Co. It has shown great promise in pressure vessels because of its exceptionally high strength and low density. Pressure vessels fabricated with the fiber have demonstrated a performance factor 30 percent better than test vessels fabricated with the highest-performing carbon/graphite fibers.

There are two grades of PBO fiber, with tensile strengths and moduli almost double those of aramid fibers. The fiber also has attractive strain-to-failure ratios and low moisture regain. The fiber is now manufactured in Japan, and it is marketed by Toyobo under the tradename *Zylon*.

pearlescent pigments Pearlescent pigments are a class of specialty pigments consisting of plate like particles that are essentially transparent crystals of a high refractive index. Light is reflected from many parallel surfaces to produce the unique depth effect and silvery luster. Some pearlescents contain the appropriate optical dimensions to produce an iridescent effect as well. Effects range from brilliant highlighting to moderate enhancement of the normal surface gloss.

The original pearlescent colorant was natural pearl essence (natural fish scales). The material is too fragile for most plastics processing, but it has been used in cellulose acetate eyeglass frames. Synthetic pigments include basic lead carbonate, lead hydrogen arsenate, lead hydrogen phosphate, and bismuth oxychloride. The lead compounds are regulated by OSHA. The synthetic pigments are used mostly in PVC films and plastisols.

The newest form of pearlescent pigment is a coated *mica*. The mica provides a transparent platelet shape with its two parallel faces. These faces are coated with a high-refractive-index layer of titanium dioxide or iron oxide. An absorption color layer can be overlaid on the oxide layer, giving additional reflective surfaces. These coated micas have high operating temperatures and are nontoxic. They are supplied in a range of particle sizes, usually from 10 to 50 μm. Loadings of coated mica pearlescents usually run about 1.5–3 percent.

Major suppliers of pearlescent pigments include Daicolor-Pope Inc., EM Industries, Mearl Corp., and Spectrum Color Co.

See also mica.

peel In adhesive bonding, the peel stress is the stress imposed on an adhesive by attempting to remove one substrate from another by applying a tensile stress at an angle to the adhesive bond line. (*See* adhesive stress, Fig. A.5.) Usually the angle of peel is noted (e.g., 180° peel—where the peel is perpendicular to the adhesive bond line). More reproducible peel strengths values occur in tests where the angle of peel is kept constant. The substrate being peeled is generally flexible relative to the other substrate. *Peel strength* is the strength of an adhesive in peel, expressed in pounds per inch of width.

peel ply The peel ply, also called a *tear ply*, is a layer of open-weave material, usually fiberglass or heat-set nylon, applied directly to the surface of a prepreg layup. The surface to which the peel ply is attached is a surface that will undergo adhesive bonding. At the time of bonding, the peel ply is stripped from the cured laminate, leaving a clean, resin-rich surface that needs no further preparation for bonding, other than the application of a primer if one is required.

pellet A pellet is a small thermoplastic resin particle usually in the shape of a small ball. Resin pellets are convenient for filling hoppers in extrusion and injection molding machines. *Pelletizing* is the process of producing pellets.

Molding polymers are usually fed to the molding machine in either pelleted or granular form. Pellets are small, regular shapes, generally cubical or cylindrical, and most often produced by cutting extruded strands to consistent lengths. Granules are irregularly shaped particles produced by crushing polymer chunks or slabs or by grinding sprues and runners; they come in a wide range of particle sizes.

perfluoroalkoxy teflon (PFA)

See fluorocarbon/fluoropolymer/fluroroplastic.

permanent set Permanent set is the increase in length, expressed in percentage of the original length, by which an elastic material fails to return to its original length after being stressed for a standard period of time. For creep tests, permanent set is the residual unrecoverable deformation after the load causing the creep has been removed for a substantial and specified period of time. Permanent set can also be expressed in compression or shear as well as tension.

Compression set refers to permanent set taken under compression stress. It is the permanent deformation that takes place in a gasket, seal, or O-ring after prolonged use. The figure that is given for compression set is the amount of permanent set in the rubber compared to the original deformation. Most rubber materials show compression sets ranging from 25 to 45 percent. In stating the compression set, the data must include the exposure temperature, time, and amount of compression as well as the final set. Compression set is usually performed in accordance with ASTM D395.

permeability Permeability is the passage or diffusion of a gas, vapor, liquid, or solid through a barrier without physically or chemically affecting it. The use of plastic film and rigid plastics for packaging purposes and liners is partly determined by their permeability to the substances they are intended to contain or to water vapor. Sometimes it is desirable for the film to be highly impermeable to water vapor, so that the packaged products will retain their moisture for long periods of time. In other cases, it is to prevent moisture from entering and spoiling the product. In still other cases, a film may be chosen because it will allow water vapor or normal gases to permeate rapidly, as required for certain vegetable packaging applications. No perfect organic barrier for moisture or normal gases is known.

The permeability of a polymer to a gas or vapor is the product of the solubility of the gas or vapor in the polymer and its diffusion coefficient. Permeability is directly measured as the rate of transfer of vapor through unit thickness of the polymer in film form per unit area and pressure difference across the film. There are a number of standard units used for expressing permeability.

Available plastic films vary greatly in their efficiency as a water vapor barrier. Among the more common films, *Saran* (a vinylidine chloride film from Dow Plastics) is usually considered to have about the lowest permeability, with polyethylene and cellophane running a close second. Polystyrene, polyvinyl chloride acetate copolymers, and elastomers transmit much faster, whereas ethyl cellulose is one of the fastest transmitters (3000 times higher than Saran).

Standard test methods have been developed to measure permeability in various polymeric systems. ASTM E96 is a gravimetric test method for water vapor permeabilty. ASTM D3985 is a coulometric determination of oxygen transmission in films, sheeting, laminates, and coated paper or fabrics. ASTM D2684 is a gravimetric determination of permeability to packaged reagents and proprietary products. It is specifically aimed at plastic containers.

permitivity

See dielectric constant.

peroxide

See organic peroxide.

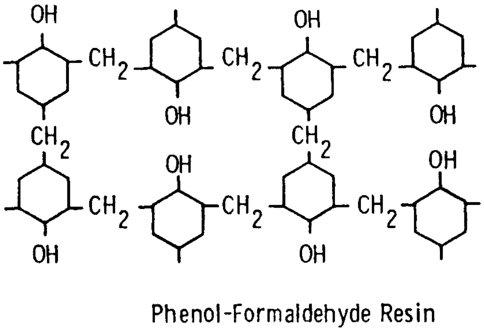


Figure P.2 General chemical structure of phenol formaldehyde.

phenolic (phenol formaldehyde, PF) Phenolic resins are a synthetic thermosetting resin class that is produced by the condensation of an aromatic alcohol with an aldehyde, particularly of *phenol* and *formaldehyde*. As a result phenolic resins are often referred to as phenol formaldehyde (PF) resins. The chemical structure of phenol formaldehyde is shown in Fig. P.2.

Phenolic resins are among the oldest and best-known general purpose molding materials. They were among the very first commercial polymers to be introduced at the turn of the twentieth century under the tradename Bakelite. These polymers are also known as *phenoplasts*.

They provide an excellent combination of high physical strength, high temperature resistance, scratch resistance, and good dimensional stability, electrical properties, and chemical resistance. They are also among the polymers lowest in cost and easiest to mold.

An extremely large number of phenolic materials are available based on the many resin and filler combinations, and they can be classified in many ways. One common way of classifying them is by type of application or grade. The major grades are general purpose, impact resistant, electrical, heat resistant, special purpose, and chemical resistant.

The various grades use different types of fillers. General-purpose grades usually contain wood flour filler. Impact-resistant grades have a range of impact values up to about 30 times that of the general-purpose grade through the use of long-fiber fillers such as cotton flock or cotton cord. Improved heat-resistant grades use mineral fillers. Such formulation may have a maximum operating temperature of days or weeks at 204°C, as compared to 121°C for general-purpose types. Electrical- and chemical-resistant grades also use mineral fillers.

The molding resins compounded with fillers and reinforcement are marketed usually in granular or pellet form. They are partly polymerized for final molding under heat and pressure. The molding step completes the polymerization, making the product infusible and relatively insoluble. Phenolic resins may also come as resinous solutions.

Phenolic resins are generally used as molding materials, laminate sheet, and varnishes. They are also used as impregnating agents and as components of paints, varnishes, lacquers, and adhesives. They serve as binders for wood particleboard used in building panels and core material for furniture. They are the base resin in water-resistant adhesive formulations for exterior-grade plywood and bonding agents for converting both organic and inorganic fibers into acoustical and thermal insulation. They are used to impregnate paper for electrical or decorative laminates and as special additives to tackify, plasticize, reinforce, or harden a variety of elastomers.

Although it is possible to obtain various molding grades of phenolics for various applications, generally the phenolics are not equivalent to diallyl phthalates in resistance to humidity and retention of electrical properties in extreme environments. Phenolics, however, are quite adequate for a large percentage of electrical applications. Grades have been developed that yield considerable improvements in humid environments and at high temperatures. Glass-filled heat-resistant grades are outstanding in thermal stability to 204°C and higher, with some being useful to 260°C. Shrinkage during heat aging varies over a fairly wide range, depending on the filler used. Glass-filled phenolics are more stable than other grades.

Phenolic molding materials are generally molded in compression or transfer molds. The design and proper operation of the mold may be of equal importance to the choice of the molding compound. Preforming and preheating techniques also contribute to successful molding. Often the moisture formed during the remaining condensation polymerization reaction must be accounted for in the molding operation. This is accomplished by venting or partially opening the mold several times during the curing process.

Phenolic resins are available in various grades for compression, transfer, and injection molding. Major suppliers of phenolic resins include Cytec Fiberite (*Enduron*), Occidental (*Durez*), Plastics Engineering (*Plenco*), Lockport (*Valite*), Plaslok, Rogers, and Resinoid.

phenoxy Phenoxy is a high-molecular-weight generally thermoplastic resin based on bisphenol-A and epichlorohydrin. The synthesis of phenoxy resins occurs via the reaction of a dihydric phenol and epichlorohydrin in the presence of an alkali. There are several methods of preparation for both thermoplastic and thermosetting resins.

Phenoxy resins are an outgrowth of epoxy resin technology. They bridge the gap between the thermoplastic and thermosetting polymers. Typical properties of phenoxies include moderately good impact resistance, relatively high strength, good elongation, and creep resistance. Strength retention during thermal exposure is inferior to that obtained with many linear polymers. Phenoxy is resistant to acids and alkalis, has poor solvent resistance (especially in ketones), and has good resistance to aliphatic hydrocarbons. The permeability of phenoxy particularly to oxygen and other gases is the lowest of any melt-processable polymer. The mechanical properties of an non-crosslinked phenoxy will be a function of its molecular weight. Crosslinking will reduce flexibility and thermal and chemical resistance.

The material is available in grades suitable for molding, extrusion, coating, and adhesives. Molding and extrusion grades have molecular weights that range from 25,000 to 40,000. They pick up moisture, so predrying is required.

The largest use for phenoxies is as a vehicle for coating formulations. They are exceptionally useful in primer applications where drying speed, compatibility with various topcoats, and high adhesive strength are required. Molding compounds are limited to applications requiring service temperatures below 80°C. The resin is useful for blow molding of bottles and containers because of its good impact strength, clarity, and impermeability. As an adhesive, the largest use is in wood and plastic sandwich constructions and as production adhesives for wood surfaces. Adhesives have demonstrated room-temperature lap shear strength of over 3,000 psi. The electrical properties of phenoxy resins are equivalent to epoxies, and so they make excellent insulators.

phenylsilane resin Phenylsilane resins are thermosetting copolymers of silicone and phenolic. These high-temperature polymers are generally furnished in solution form.

phosphazene polymer Polyphosphazenes are polymers with a backbone of alternating phosphorus and nitrogen atoms, with two side groups on the phosphorus. The side groups may be of various kinds including perfluoroalkoxy groups. This produces a high-temperature elastomer called *fluorophosphazene rubber.*

phosphorylated polyethylene A modified polyethylene, phosphorylated polyethylenes have higher ozone and heat resistance than ethylene propylene copolymers because of the fire-retardant nature provided by the phosphor.

See also polyethylene.

photoconductivity Photoconductivity in materials occurs when on exposure to light the material exhibits an increase in electrical conductivity. Materials possessing this property are termed *photoconductors.* Photoconductive plastic materials find application in photocopying.

photoelasticity Photoelasticity is an experimental technique for the measurement of stresses and strains in material objects by means of the phenomenon of mechanical birefringence.

photopolymer Photopolymers are polymeric materials that have been formulated to harden or cure in the presence of light of a certain wavelength (generally ultraviolet). There has been a great deal of development and commercialization of photopolymers in the fields of adhesives, decorative coatings, printed wiring board, solder masks, dental restoration, laminates, and pultrusion.

Acrylic comonomers are the most widely used starting materials. Certain urethanes and epoxies have gained popularity, and pure epoxies are being used in applications requiring the highest degree of chemical inertness. Ultraviolet (UV) radiation is used most often to cure these materials, although visible light and electronic beam radiation are used in specific applications.

phthalate ester The esters of phthalic acid are the most versatile and most widely used of all plasticizer types. Those made commercially on a large scale include dimethyl phthalate, diethyl phthalate, dibutyl phthalate, dihexyl phthalate, dioctyl phthalate, dicyclohexyl phthalate, diphenyl phthalate, and dimethoxy ethyl phthalate. The phthalate plasticizers are generally quite economical to use.

The phthalate esters may be used as plasticizers in virtually all applications. Dimethyl and diethyl phthalates are standard plasticizers for cellulose acetate. Dibutyl phthalate, dicyclohexyl phthalate, and diphenyl phthalate are widely used in cellulose nitrate. Dioctyl phthalate is the most widely used plasticizer for polyvinyl chloride (PVC).

As a group, the phthalate esters are characterized by good compatibility, heat and light stability, and generally good electrical properties. The lower members of the series may be somewhat volatile, but the higher members are excellent in this respect. In general, they are colorless liquids with low crystallizing points. Diphenyl phthalate and dicyclohexyl phthalate, however, are crystalline solids.

See also plasticizer.

pick count In woven fabrics, pick count refers to the number of *fill* (across the machine direction) yarns per inch of woven fabric.

See also weave; woven fabric.

piezoelectric polymer Piezoelectric polymers are polymers that spontaneously give an electric charge when mechanically stressed. Conversely, they may develop a mechanical response when an electric field is applied. Piezoelectric polymers are generally manufactured from vinyl polymers as film. They are often used as pressure transducers or as acoustic sensors.

pigment The two basic kinds of colorants used in plastics are pigments and *dyes*. In differentiating between the two, solubility is the most convenient parameter, if not completely accurate. Soluble colorants are dyes; insoluble ones are pigments. Pigments have varied opacifying power; dyes are transparent.

Organic and inorganic pigments are the main types of colorants for plastics. Organic pigments are complex chemical structures that contain one or more benzene structures. They are characterized by small particle size, greater transparency, and color strength. Inorganic pigments are metallic compounds and are larger in size, smaller in surface area, and denser than organic pigments. They function primarily by scattering light. Thus they are more opaque and lower in tinting strength than organic pigments of comparable shade. Table P.4 shows the advantages and disadvantages of both organic and inorganic pigments.

Inorganics produce opaque and somewhat dull shades, and organics are bright and transparent. Inorganics also have better heat stability and light fastness, but their chemical resistance varies. Organics vary widely in fastness to light and migration. They must be carefully selected with regard to inherent properties and their effect on the polymer to be colored. Most organic and inorganic pigments are compatible with most plastics and can be used at the loading needed to effect a given color.

See also organic pigment; colorant.

Table P.4 Pigments Used in Coloring Thermosets (Ref: *Plastics Compounding*, 1991/92 Redbook, Edgell Communications, Cleveland, OH, p. 70)

Type	Pigment and Color	Favorable Properties	Unfavorable Properties
Inorganic	Titanium dioxide: white rutile grade	Easy to disperse, relatively inert, stable, durable, inexpensive	Slightly yellow, expensive as a pacifier
	Titanium dioxide: complexes–yellow, buff, green and blue	Easy to disperse, relatively inert, stable, very good weatherability	Weak in color (poor tint), moderately expensive
	Iron oxides: red, yellow, tan, and black	Easy to disperse, relatively inert, stable, very durable, inexpensive, FDA acceptable	Poor tint strength, dull and slightly dirty in color
	Ultramarine blue and green	Moderately easy to disperse, stable, clean and bright colors, inexpensive, FDA acceptable	Poor tint strength, slightly muddy
	Cobalt complexes–blue and turquoise	Moderately easy to disperse, durable, clean color	Poor tint strength, expensive

	Iron blue and chrome green	Moderately easy to disperse, stable, inexpensive, relatively clean and bright colors	Poor tint strength
	Lead chromates and molybdates: yellow and orange	Moderate tint strength, inexpensive, moderately stable and durable	Toxicity, moderately difficult to disperse
	Cadmium: yellow, orange, and red	Strong and bright colors, moderate durability	Toxicity, moderately difficult to disperse
Organic			
	Carbon black	Excellent tint strength, good stability and durability, inexpensive	Very difficult to disperse
	Phthalocyanines: blue and green	Excellent tint strength, clean colors, good durability, FDA acceptable	Difficult to disperse, low opacity, may affect reactivity
	Quinacridones: red and magenta	Excellent tint strength, clean colors, good durability, FDA acceptable	Expensive, relatively low opacity, may affect reactivity

pinch tube process The pinch tube process is a basic blow molding process in which the extruder drops a tube between mold halves that is pinched off when the mold closes. The *pinch off* is the raised edge around the cavity in the mold, which seals off the part and separates the excess material as the mold closes. The *pinch-off blades* are the parts of the mold that compress the parison to effect sealing of the parison before blowing and to permit easy removal and cooling of flash. *The pinch-off land* is the bottom of the parison that is pinched off when the mold closes.

pitch fiber

See carbon fiber.

plain weave

See weave.

plasma surface preparation A gas plasma-treating process has been developed for surface treatment of many polymeric materials. It is a dry process that is becoming a very common method of treating many different engineering plastics. Low-energy materials, such as polyolefins, polytetrafluoroethylene, polyethylene terephthalate nylon, and silicon rubber are also readily treated with gas plasma without the need for hazardous processes. Relative bond strength improvements of ten to several hundred times are possible depending on the substrate and gas plasma. Plasma treatment has become a very popular treatment for small-to medium-sized parts that can fit into a vacuum container and for production volumes that are amenable to a batch-type process.

Operationally, a plasma differs from corona and flame treatment in that the process is completed at less than atmospheric pressure and with gases other than air. Because of the necessity for partial vacuum, plasma treatment is essentially a batch process. The type of plasma gas can be selected to initiate a wide assortment of chemical reactions, including:

1. Surface crosslinking
2. Surface oxidation or reduction
3. Grafting of active radical to material surfaces
4. Halogenation of surfaces
5. Deposition of inorganic and organic films

Gases or mixtures of gases used for plasma treatment of polymers include nitrogen, argon, oxygen, nitrous oxide, helium, tetrafluoromethane, water, and ammonia. Each gas produces a unique surface treatment process. It should be noted that surface chemistry modification by plasma treatment can make polymer surfaces totally wettable or nonwettable. Nonwettable plasma treatments generally involve the deposition of fluorine-containing chemical groups to produce medical products.

The main difference between plasma surface treatment and corona surface treatments is the nature of the plasma (specialty gas vs. air) and the operating pressure of the plasma (0.1 – 10 torr vs. 760 torr). With the plasma treatment technique, a low-pressure inert gas is activated by an electrodeless radio frequency discharge or microwave excitation to produce metastable excited species that react with the polymeric surface.

The type of plasma gas can be selected to initiate a wide assortment of chemical reactions. Atoms are expelled from the polymeric surface to produce a strong, wettable, cross-linked skin. The plasma treatment produces changes only to the depth of several molecular layers. Generally, only very short treating times (seconds to minutes) are necessary. Commercial instruments are available from several manufacturers to plasma treat parts prior to bonding.

Because of the necessity for very low pressures, a glass or ceramic vacuum container is generally used. Thus plasma treatment is generally thought of as a batch-type process for parts of up to moderate size. Continuous plasma treaters have been developed for processing film and fiber, and large-volume chambers have been built for treating large parts. However, capital expense has limited these applications to specialty markets.

It is generally believed that plasma treating processes provide surfaces with greater stability than chemical etch, corona, flame or other common polymeric treatment processes. Plasma-treated parts can be stored for weeks or longer in a clean, dry storage area, whereas it is normally recommended that corona- or flame-treated polymers be bonded immediately after surface preparation. Exposure to temperatures near the polymer's glass transition temperature will deteriorate any surface treatment. Once bonded, the surfaces of treated polymers are relatively stable, excluding the effects of outside environmental influences.

With plasma treatment, surface wettability can be readily induced on a variety of normally non-wettable materials as shown in Table P. 5. Certain polymeric surfaces, such as the polyolefins, become crosslinked during plasma treatment. The surface skin of polyethylene, for example, will become crosslinked so that if the polymer were placed on a hot plate of sufficient heat, the interior would turn to a molten liquid while the crosslinked outer skin held a solid shape. Other polymers have their critical surface energy affected in different ways. Plasma-treated polymers usually form adhesive bonds that are two to four times the strength of nontreated polymers. Table P.5 presents bond strength of various plastic adherends pretreated with activated gas and bonded with an epoxy or urethane adhesives.

The plasma surface treating process was originally developed by Bell Laboratories in the 1960s. It was then determined that the plasma treatment caused crosslinking of the surface of polyethylene. As a result this process was called *CASING* (crosslinking by species of inert gases) in its earliest days.

Table P.5 Lap Shear Strengths for Several Plasma Treated Polymers

Adherends	Adhesive	Bond Strength, psi Control	After Plasma Treatment	Source
High density polyethylene-aluminum	Epoxy-polyamide	315	3500	1
Low density polyethylene-aluminum	Epoxy-polyamide	372	1466	1
Nylon 6-aluminum	Epoxy-polyamide	846	3956	1
Polystyrene-aluminum	Epoxy-polyamide	566	4015	1
Mylar-aluminum	Epoxy-polyamide	530	1660	1
Polymethylmethacrylate-aluminum	Epoxy-polyamide	410	928	1
Polypropylene-aluminum	Epoxy-polyamide	370	3080	1
Tedlar, PVF-aluminum	Epoxy-polyamide	278	1370	1
Celcon acetal-aluminum	Epoxy-polyamide	118	258	1
Cellulose acetate butyrate-aluminum	Epoxy-polyamide	1090	2516	1
Thermoplastic polyester PBT	Epoxy	520	1640	2
Thermoplastic polyester	Polyurethane	190	960	2
Polyetherimide	Epoxy	190	2060	2
Polycarbonate	Epoxy	1700	2240	2
Polycarbonate	Polyurethane	540	1140	2
Delrin acetal	Epoxy	160	650	2
Polyester PET	Epoxy	683	6067	3
Fluorocarbon, ETFE	Epoxy	10	293	4

SOURCES:

1. Hall J. R., et al., "Activated Gas: Plasma Surface Treatment of Polymers for Adhesive Bonding", *Journal of Applied Polymer Science*, 13, 2085–2096, 1969.
2. Kaplan, S. L., and Rose, P. W., "Plasma Treatment Upgrades Adhesion of Plastic Parts", *Plastics Engineering*, May 1988.
3. Sangiuolo, S., and Hansen, W. L., International Coil Winding Association Technical Conference, Rosemont, IL, 1990.
4. Hansen, G. P., Rushing, R. A., et al., "Achieving Optimum Bond Strength with Plasma Treatment", Technical Paper AD89-537, Society of Manufacturing Engineers, Dearborn, Mich., 1989.

plastication In injection molding, plastication is the process of providing mixing of the resin between melting and injection. Such mixing is advantageous in improving the homogeneity of the melt and of the molded piece and in eliminating the need for prior compounding steps.

Several devices for mixing or plasticating the melt in an injection molding cylinder are used. One is the *rotating spreader*, in which the spreader or *torpedo* is fitted with blades and rotated by means of a shaft passing through the ram to an external drive. A second technique is to replace the ram with a movable screw, much like an extruder screw, which runs during part of the cycle to provide plastication and then moves forward to deliver the molten polymer to the die. In a further variation, an essentially conventional extruder feeds plasticated molten polymer into the chamber of an essentially conventional injection molding machine ahead of the ram. The feed can be from the top or the side.

plastic deformation Plastic deformation is the change in dimensions of an object under load that is not recovered when the load is removed. This is opposed to *elastic deformation*, which is the load that is recovered. Plastic deformation is often referred to in the context of long-term resistance of elastomers, rubbers, and gasketing materials to load.

plasticizer Plasticizers are materials of low volatility added to polymers to enhance flexibility, resiliency, and melt flow. Secondary benefits include greater impact resistance, softness, and a depressed brittle point. Most plasticizers are high-boiling organic liquids. Plasticizers function by reducing the glass transition temperature of the plastic to a point below that at which it will be used in an actual application. This results in a decrease in brittleness at service conditions.

Plasticizers can also function as vehicles for plastisols and organosols (*see* paste resins) and as carriers for pigments and other additives. Some plasticizers offer heat and light stabilization as well as flame retardance.

Most plasticizers are used with polyvinyl chloride (PVC). Some go into such plastics as cellulosics, nylon, polyolefins, and styrenics. Plasticizers are typically di- and tri-esters of aromatic or aliphatic acids and anhydrides. Epoxidized oil, phosphate esters, hydrocarbon oils, and some other materials also function as plasticizers. In some cases, it is difficult to discern whether a particular polymer additive functions as a plasticizer, lubricant, or flame retardant. The most popular plasticizers are the phthalates, followed by the epoxies, adipates, azelates, trimellitates, phosphates, polyesters, and others. There are a number of discrete chemical compounds within each of these categories. As a result, the total number of plasticizers available is substantial.

One of the major criteria in selecting a plasticizer is compatibility with the resin to which it is added. Primary plasticizers have generally good compatibility with their resins, and secondary plasticizers have partial compatibility and must be used in conjunction with a primary plasticizer. The plasticizer and polymer should have similar polarity to produce compatibility. The end use of the plasticized resin must also be a criterion in selecting a plasticizer. The degree of flexibility, heat and light stability, electrical characteristics, flame retardancy, and toxicity must all be taken into account.

Phthalate esters are the most commonly used plasticizers. There are several types within this family, with the most common being the branched type of phthalates with a good balance of price and performance. These include dioctyl phthalate (DOP), diisooctyl phthalate (DIOP), and diisononyl phthalate (DINP). These are commonly used as plasticizers for PVC.

Aliphatic esters are generally diesters of adipic acid. Higher esters of these acids are used in synthetic lubricants and other nonplasticizer materials. Lower esters are used as solvents in coatings and other applications. Adipates and related diesters offer improved low-temperature properties compared with phthalates.

Epoxy ester plasticizers have limited compatibility with PVC, so they are generally used at low levels. Epoxidized soybean oil is the most widely used epoxy plasticizer. It provides excellent resistance to migration. Other epoxy plasticizers include epoxidized linseed oil and epoxidized tall oils. Epoxy plasticizers contribute heat and light stability to the PVC compound but have poor low-temperature properties. In most applications, epoxy plasticizers are used along with other plasticizers for improved stability during and after processing.

Esterification of diols with dibasic acids yields high-molecular-weight *polymeric plasticizers* that can plasticize PVC and other polymers. These polymerics are used in conjunction with phthalates to provide improved permanence and reduced volatility.

Phosphate triesters are considered to be both secondary plasticizers as well as flame retardants. *Trimellitates* are characterized by low volatility. This property increases the service life of a PVC compound subjected to elevated temperatures for long periods of time and reduces fogging. Trimellitates are most commonly used for PVC wire insulation, often in conjunction with phthalates. *Benzoates* are most often used in vinyl floor covering products because of their resistance to staining. *Citrates* are used in food contact and medical applications because of their perceived low toxicity.

Plasticizers are the largest volume additive in the plastics industry. The major suppliers of plasticizers include Eastman Chemical Products, C. P. Hall Co., and Harwick Chemical Co. (adipates); Ashland Chemical Inc., C. P. Hall, and Hatco Corp. (azelates); Ashland Chemical Inc. and Chemco Inc. (benzoates); Akzo Chemicals Inc., Crowley Chemical Co., and Union Carbide Chemicals & Plastics Co. (epoxidized soybean oil); Crowley Chemical Co., C. P. Hall Co., and Harwick Chemical Corp. (hydrocarbon); Ashland Chemical Inc., Eastman Chemical Products, FMC Corp., Great Lakes Chemical Corp. C. P. Hall Co., and Harwick Chemical Corp. (phosphates); Eastman Chemical Co., Great Lakes Chemical Corp., C. P. Hall Co., and Harwick Chemical Corp. (phthalates); C. P. Hall Co., Harwick Chemical Corp., and Witco Corp. (polymeric); and Ashland Chemical Inc., BASF Corp. Chemicals Div., and Harwick Chemical Corp. (trimellitates).

plastic memory Plastic memory is the tendency of a thermoplastic material that has been stretched while hot and then cooled to return to its original unstretched shape.

See also heat shrinkable film; tubing.

plastisol Plastisols are mixtures of vinyl resins and plasticizers that can be molded, cast, or converted to continuous films by the application of heat. If the mixtures contain volatile thinners as well as plasticizers, they are known as *organosols*. A *rigidsol* is a plastisol having a high elastic modulus, usually produced with a crosslinking plasticizer.

Plastisols and organosols are the most important of the fluid types of vinyls. A plastisol is a dispersion of a PVC resin with plasticizer as the dispersing medium.

The principal distinguishing characteristic of the resin used is its particle size, which is small enough (approximately 1 μm) to permit it to stay in suspension without settling. Another key characteristic is that the resin particle resists solvation at room temperature. Thus it is possible to suspend the resin particles in liquid plasticizer and have the mixture remain in a stable fluid condition indefinitely. The paste can then be shaped and converted to a solid state by heating. This conversion takes place in two steps. The first is gelation at approximately 66°C and the second to a solid where the plasticizer is dispersed in a homogeneous resin matrix (127–177°C).

Plastisols have a variety of uses. They are ideally suited for spread coatings on continuous webs of fabric or paper by conventional knife or roller coating equipment. They may also be molded or cast into flexible shapes.

See also paste resin; organosol.

plastometer A plastometer is an instrument for determining the flow properties of a thermoplastic resin by forcing the molten resin through a die or orifice of specific size at a specified temperature and pressure. Usually the time required to extrude a certain weight of resin material is used as an indication of the flow property or viscosity.

plate dispersion plug A plate dispersion plug helps in the dispensing of colorant in the injection molding process. It is a design consisting of two perforated plates held together with a connecting rod. These are placed in the nozzle of an injection molding machine to aid in dispersing a colorant in a resin as it flows through the orifices in the plates.

platen Platens are generally referred to as the top and bottom contact surfaces of a press. Molding press platens have facilities for mounting molds and are cored for heating and cooling. Heating is supplied mostly by steam or electrical resistance heaters, and cold water is used for cooling. Generally, one platen is movable and one is stationary.

plate-out Plate-out is a term given to the persistent sticky deposit that sometimes appears on the working surfaces of polyvinyl chloride (PVC) processing equipment. It can occur in extrusion, calendering, and molding as well in finishing operations. Plate-out deposits are a nuisance necessitating cleaning operations. They are also detrimental to product quality when present in extrusion dies, embossing rolls, etc.

Plate-out deposits are formed by material exuding from the hot PVC stock as a result of incompatibility of some constituents with the PVC composition. The formulation components that should be primary suspects when plate-out occurs are lubricants and stabilizers.

platform blowing Platform blowing is a special technique for blow-molding large parts. To prevent excessive sag of the heavy parison the molding machine uses a movable table. After rising to meet the parison the die descends with the parison but at a slightly lower rate than the parison extrusion speed.

plating The advantages of metallized plastics in many industries, coupled with major advances in both platable plastic materials and plating technology, have resulted in a continuing and rapid growth of metallized plastic parts. Some of the major problems have been adhesion of plating to plastic, differential expansion between the plastics and metals, failure of the plated part in thermal cycling, heat distortion and warpage of plastic parts during plating and in systems use, and improper design for plating.

The major plastics that are plated and their characteristics for plating are identified in Table P.6. Improvements are being made continuously, especially in ABS and polypropylene, which yield generally lower product costs. Aside from the commercial plastics described in Table P.6, excellent plated products can be obtained with other plastics. Notable is the plating of TFE fluorocarbon, where otherwise unachievable electrical products of high quality are reproducibly made. Examples of applications are printed circuit boards, corona-free capacitors, and low-loss, high frequency electronic components.

Because most plated plastic parts are decorative rather than functional, appearance is extremely critical. For a smooth, even finish on a piece, the design of the part and molding process must be carefully considered. Mechanical welds are difficult to plate. If they are necessary, they should be hidden on a noncritical surface. Gates should be hidden on noncritical surfaces or should be disguised in a prominent feature. Gate design should minimize flow and stress lines, which may impair adhesion.

See also electroless and electrolytic-plated plastic; metallization of plastic.

Table P.6 Commercially Platable Plastics (Ref: Kruilik, G.A., “Electrolytic Plating”, *Plastics Finishing and Decorating*, D. Satas, ed., van Nostrand Reinhold, New York, 1986)

	ABS	Poly-propylene	Poly-sulfone	Poly-arylether	Modified PPO
Flow	AA	AA	BA	BA	A
Heat distortion under load	A	BA	AA	AA	A
Plateability	AA	A	BA	AA	BA
Thermal cycling	BA	A	AA	AA	AA
Warpage	A	BA	A	A	A
Mold definition	AA	BA	A	A	A
Coefficient of expansion	A	A	A	A	A
Water absorption	BA	AA	A	BA	AA
Material cost	A	AA	BA	BA	BA
Finishing cost	AA	BA	BA	AA	BA
Peel strength	A	AA	AA	BA	BA

Polymers are rated according to relative desirability of various characteristics: AA = above average; A = average; BA = below average.

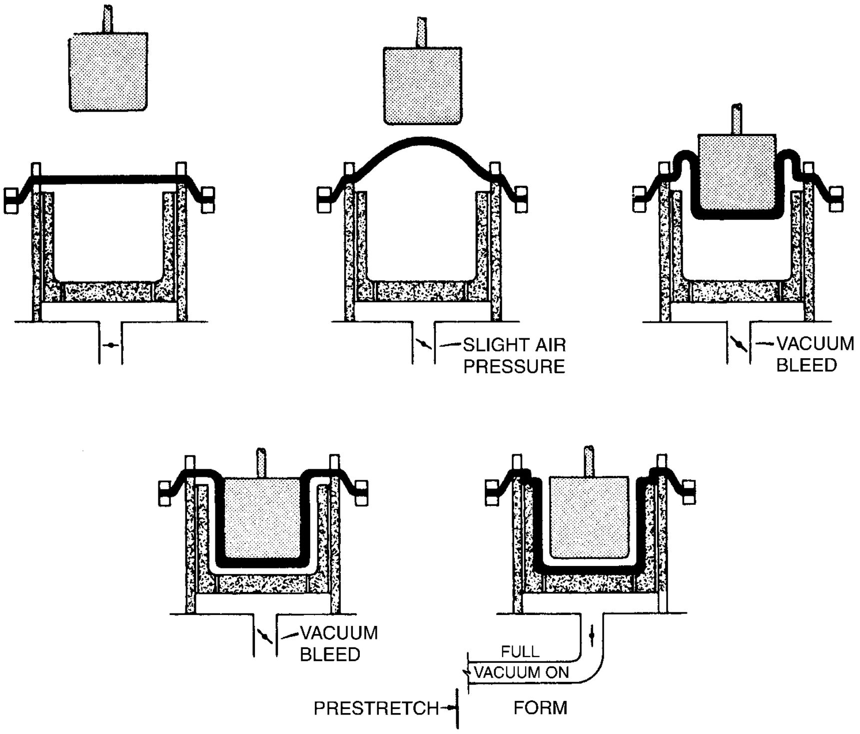


Figure P.3 Plug-assist reverse draw forming process. (Dow Chemical Company also Schwartz, S.S. and Goodwin, S.H., *Plastics Materials and Process*, van Nostrand Reinhold, New York, 1982, p. 637)

plug forming Plug forming is a *thermoforming* process in which a plug or male mold is used to partially preform the part before forming is completed with vacuum or pressure. The *plug and ring process* is a method of sheet forming in which a plug, functioning as a male mold, is forced into a heated plastic sheet held in place by a clamping ring. *See* Fig. P.3.

plunger molding
See transfer molding.

ply A ply is one layer of a product (impregnated glass fabric, film, adhesive, etc.) that is ultimately bonded to adjacent layers. A ply is a single layer in a laminate containing many plies.

ply orientation One of the advantages of using a modern reinforced composite is the potential to orient the fibers to respond to load requirements. This means that the composite designer must determine the material, the orientation of each ply, and how the plies are arranged (ply orientation).

A shorthand code for ply orientations has been adapted for use in layouts and studies. Appendix F summarizes the format conventionally used for the ply layup of reinforced composites.

poise The poise is a unit of *viscosity* expressed as one dyne per second per square centimeter. A *centipoise* is 0.01 poise.

See also viscosity.

Poisson's ratio Poisson's ratio is the absolute value of the ratio of transverse strain to axial strain resulting from a uniformly applied axial stress below the proportional limit of the material. It is one of the characteristic, basic properties of a material.

When a solid body is being stretched (or compressed) by a uniaxially applied force, it will undergo extension (or compression) in the direction in which the force is acting. This deformation will also be accompanied by a lateral one: a contraction if the axial deformation is in extension, or an expansion if the axial force is in compression. For a body, that is homogeneous and isotropic, the ratio of lateral strain to the corresponding axial strain is a constant known as Poisson's ratio.

Poisson's ratio is approximately 0.5 for rubbers. For a number of noncrystalline polymers, a fairly representative value of Poisson's ratio would be about 0.3.

A relatively simple standard method is available for the determination of Poisson's ratio. This is a tensile test in which a tensile stress that is rapidly applied produces substantial strain with relatively negligible creep (ASTM E132).

polyacrylate acrylic rubber (ACM) Acrylic rubber can be emulsion- and suspension-polymerized from acrylic esters such as ethyl, butyl, and/or methoxyethyl acetate to produce polymers of ethyl acetate and copolymers of ethyl, butyl, and methoxyl acetate. Polyacrylates can be vulcanized with sulfur or metal carboxylate, with a reactive chlorine-containing monomer to create a crosslinking site.

Polyacrylate rubber, such as *Acron* (Cancarb, Ltd.), possesses heat resistance and oil resistance between nitrile and silicone rubbers. Acrylic rubbers retain properties in the presence of hot oils and other automotive fluids. They resist softening or cracking when exposed to air up to 200°C. The copolymer retains flexibility down to −40°C. These properties and inherent ozone resistance are largely due to the polymer's saturated backbone. Acrylic rubber has better oil, heat, and ozone resistance than nitrile rubber; however, it is not as good as nitrile for low-temperature applications. Acrylic rubber has good sunlight resistance.

Acrylic rubber has found an advantage over nitrile rubber in hot oil applications where the oil is often fortified with sulfur-bearing chemicals. The sulfur in such systems, such as automobile transmissions, will continue to react and harden a nitrile-based rubber to a point of excessive hardening. Acrylic rubber is not affected by hot sulfur-modified oils. Where transmission oil test temperatures are normally run at 121°C for nitrile, 150°C is used for the acrylic rubber.

Automotive seals and gaskets in hot oil applications comprise a major market for these materials. Acrylic rubbers can be compounded in a Banbury mixer and fabricated by injection molding, compression molding, resin transfer molding, extrusion, and calendering.

polyacrylonitrile Polyacrylonitrile is a thermoplastic prepared by the polymerization of acrylonitrile monomer with either free radical or anionic initiators. Bulk, emulsion, suspension, solution, or slurry methods may be used for the polymerization.

Polyacrylonitrile will decompose before reaching its melting point, making the material difficult to form. The decomposition temperature is near 300°C. The pure polymer is difficult to dissolve. Suitable solvents, such as dimethylformamide and tetramethylenesulfone, have been found for polyacrylonitrile, allowing the polymer to be formed into fibers by dry and wet spinning techniques.

Being a polar material, polyacrylonitrile has good resistance to solvents, high rigidity, and low gas permeability. Polyacrylonitrile exhibits exceptional barrier properties to oxygen and carbon dioxide.

Copolymers of acrylonitrile with other monomers are widely used. Copolymers of vinylidene chloride and acrylonitrile find application as low-gas-permeability films. Styrene-acrylonitrile (SAN polymers) copolymers have also been used in packaging applications. A number of acrylonitrile copolymers were developed for beverage containers, but the requirement of very low levels of residual acrylonitrile monomer in this application led to many of these products being removed from the market. One copolymer currently available is *Barex* (BP Chemicals). Acrylonitrile is also used with butadiene and styrene to form ABS polymers. Unlike the homopolymer, copolymers of acrylonitrile can be processed by many methods including extrusion, blow molding, and injection molding. BP Chemicals is a major supplier of these copolymers.

Acrylonitrile is also often copolymerized with other monomers to form fibers. These acrylic fibers have good abrasion resistance, flex life, toughness, and high strength. They have good resistance to stains and moisture. Modacrylic fibers contain between 35 and 85 percent acrylonitrile. Polyacrylonitrile polymers are also used as precursors to carbon fibers.

See elastomer.

polyallomers Polyallomers are thermoplastic *polyolefin copolymers* produced from two or more different monomers, such as propylene and ethylene, that would produce a propylene-ethylene polyallomer. Hence many properties of polyallomers are similar to those of polyethylene and polypropylenes. They have a density of about 0.9 g/cm^3 and thus are among the lightest of plastics.

Polyallomers have a brittleness temperature as low as -40°C and a heat-distortion temperature as high as 210°F at 66 psi. The excellent impact strength plus exceptional flow properties of polyallomer provide a wide latitude in product design. Notched Izod impact strengths run as high as 12 ft lb/in. notch.

Although the surface hardness of polyallomers is slightly less than that of the polypropylenes, resistance to abrasion is greater. Polyallomers are superior to linear polyethylene in flow characteristics, moldability, softening point, hardness, stress crack resistance, and mold shrinkage. The flexural fatigue-resistance properties of polyallomers are as good as or better than those of polypropylenes

Polyallomer can be injection molded, extruded, and thermoformed. Some of the physical properties of these materials change significantly during the 1 to 2-day period of polymer crystallization that occurs immediately after processing.

Polyallomer is used for blow-molded bottles, wire coating, film, sheet and pipe extrusion, and thermoforming applications. Applications also include automotive body components, closures, and a variety of cases such as tackle boxes, office machine cases, and bowling ball bags.

polyamide

See nylon.

polyamide themoplastic elastomer Polyamide thermoplastic elastomers (TPEs) are usually polyester-amides, polyetherester amide block copolymers, or polyether block amides (PEBA). The polyamide is the hard (thermoplastic) segment, whereas the polyester, polyetherester, and polyether segments are the soft (elastomeric) segment.

Polyamide thermoplastic elastomers are characterized by their high service temperature under load, good heat aging, and solvent resistance. They retain serviceable properties for longer than 120 h at 150°C without adding heat stabilizers. Addition of a heat stabilizer increases service temperature. Polyesteramides retain tensile strength, elongation, and modulus to 175°C. The advantages of polyether block amide copolymers are their elastic memory, which allows repeated strain without significant loss of properties; lower hysteresis; good cold weather properties; hydrocarbon solvent resistance; UV stabilization without discoloration; and lot-to-lot consistency.

Polyamide TPEs have a specific gravity of about 1.0 and a hardness range of about Shore 73 A to 72 D. Water absorption is 1.2%. They have abrasion resistance; long wear life; elastic memory; flexibility at −40 to 80°C; good adhesion to metals; small variation in electrical properties over service temperature range and frequency range; printability and colorability; and tactile properties such as good hand, feel, and nonallergenicity. Polyamide/ethylene-propylene, with higher crystallinity than other elastomeric polyamides, has improved fatigue resistance and improved oil and weather resistance.

The copolymers are used for waterproof/breathable outerwear, air conditioning hose, under-hood wire covering, automotive bellow, flexible keypads, decorative watch faces, rotationally molded sport balls, and athletic footwear soles. They are also insert molded over metal cores for nonslip handle covers.

An example of a polyamide TPE is *Pebax* (Elf Atochem). This is a polyether block amide copolymer consisting of regular linear chains of rigid polyamide blocks and flexible polymer blocks. They are injection molded, extruded, blow molded, thermoformed, and rotationally molded. Elf Atochem is a major supplier of polyamide TPE compounds.

polyamide-imide

See polyimide.

polyaniline Polyaniline is a polymer of aniline. It possesses high inherent electrical conductivity. This material has been known for many years, but its intractability in conventional processing methods has hindered commercial applications. Polyaniline has been suggested for use in coating formulations for conductive or antistatic surface coatings.

Polyarylate (PAR) Polyarylates (PAR) are amorphous, aromatic polyesters. They are prepared from dicarboxylic acids and bisphenols. The presence of an aromatic ring gives the polymer a high glass transition temperature and good temperature resistance. The resulting polymer is a high-temperature, transparent resin. Other key characteristics are high heat-deflection temperature, excellent ultraviolet (UV) light resistance, toughness, transparency, excellent flexural recovery, high elastic limits, and good electrical and mechanical properties including outstanding creep resistance.

The temperature resistance of the polyarylates lies between polysulfone and polycarbonate. The polymer is flame retardant and shows good toughness and UV resistance. Polyarylates are transparent and have good electrical properties. The abrasion resistance of polyarylates is superior to polycarbonate. In addition, the polymer shows a very high recovery from deformation. However, the material is subject to environmental stress cracking, particularly in the presence of aromatic and aliphatic hydrocarbons.

Polyarylates are processed by most conventional thermoplastic methods. Injection molding should be performed with a melt temperature of 260–382°C and with mold temperatures of 65–150°C. Extrusion and blow molding grades are available. Polyarylates must be dried before being used because they can react with water at processing temperatures.

Polyarylates are used in automotive applications such as door handles, brackets, and headlamp and mirror housings. Polyarylates are also used in electrical applications for connectors and fuses. The polymers can be used in circuit board applications because of their high temperature resistance. The excellent UV resistance allows them to be used as a coating for other thermoplastics for improved outdoor weathering. The good heat resistance of polyarylates allows them to be used in applications such as fire helmets and shields.

Suppliers of polyarylate resins include Union Carbide Corporation (*Ardel*), Ticona (*Durel*), and RTP (glass reinforced grades).

polyaryl ether (PAE) Polyaryl ether is an engineering thermoplastic from Uniroyal, Inc. as *Acrylon*. Modified polyaryl ether has a high heat-deflection temperature only exceeded by polyphenylene oxide (PPO) and polysulfone. This, combined with excellent processablity, is one of the most important and unusual characteristics of the material.

The material has a high heat-deflection temperature of 149°C measured at 264 psi. Polyaryl ether has high impact strength with an Izod notch impact of 8 ft lb/in. at 22°C and 2.5 ft lb/in. at −29°C. It also has excellent chemical resistance, resisting organic solvents except chlorinated aromatics, esters, and ketones. The resin also appears to resist hydrolysis, withstanding prolonged immersion in boiling water.

Fabricating advantages include a low shrinkage factor, precision molding of void-free parts, and insensitivity to moisture requiring only nominal drying before molding. Polyaryl resins also have excellent flow characteristics that permit easy filling of intricate sections within thin walls.

Markets for polyaryl ether include the automotive, appliance, and electrical industries. It is used in automotive components, business machine parts, recreation helmets, snowmobile parts, plumbing valves and fixtures, and special machinery such as power tool housings and fluidic controls.

polyaryl sulfone (PAS) Polyaryl sulfone (PAS) is an engineering thermoplastic of the *polysulfone* family. It offers a unique combination of thermoplasticitiy and retention of structurally useful properties at 260°C. The material is supplied in both pellet and powder form. It is available in filled and reinforced grades as well as both opaque and transparent versions. Commercial material is available as *Astrel* resin from 3M Co.

Polyaryl sulfone consists mainly of phenyl and biphenyl groups linked by thermally stable ether and sulfone groups. It is distinguished from polysulfone polymers by the absence of aliphatic groups, which are subject to oxidative attack. This aromatic structure gives it excellent resistance to oxidative degradation and accounts for its retention of mechanical properties at high temperatures.

The presence of ether-oxygen linkages gives the polymer chain flexibility to permit fabrication by conventional melt-processing techniques. The polymer can be injection molded, provided the cylinder and nozzle are capable of reaching 425°C. It also may be extruded. The polymer must be dried before processing. Injection molding barrel temperatures should be 270–360°C at the rear, 295–390°C in the middle, and 300–395°C at the front.

Polyaryl sulfone polymers are stiff, strong, and tough polymers with very good chemical resistance. Most fuels, lubricants, cleaning agents, and hydraulic fluids will not affect the polymers. However, methylene chloride, dimethyl acetamide, and dimethyl formamide will dissolve the PAS. The glass transition temperature is about 210°C, with a heat-deflection temperature of 205°C at 1.82 MPa. PAS also has good hydrolytic stability. The polymer finds application in electrical parts for motors, connectors, and lamp housings.

polybenzimidazole (PBI) Polybenzimidazoles (PBI) are high-temperature-resistant polymers. They have an aromatic, ladderlike backbone, which provides for great temperature resistance even though they are thermoplastic materials. They are prepared from aromatic tetramines and aromatic dicarboxylic acids. The reactants are heated to form a soluble prepolymer that is converted to the insoluble polymer by heating at temperatures above 330°C. The general structure of PBI is shown in Fig. P.4.

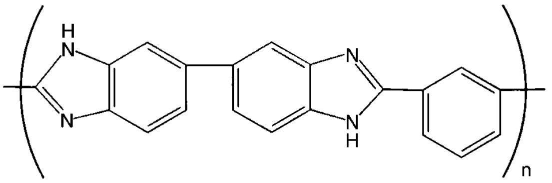


Figure P.4 General chemical structure of polybenzimidazole.

The polymer has high temperature stability, good chemical resistance, and nonflammability. The polymer releases very little toxic gas and does not melt when exposed to pyrolysis conditions. For this reason it is finding use in flame-resistant clothing, aircraft fabric, etc.

PBI is usually amorphous with a glass transition temperature near 430°C. In addition to high temperature resistance, the polymer exhibits good low-temperature toughness. PBI polymers show good wear and frictional properties with excellent compressive strength and high surface hardness. The properties of PBI at elevated temperatures are among the highest of the thermoplastics or thermosets. PBI can withstand temperatures up to 760°C for short durations and exposure to 425°C for longer durations.

The polymer is not available as a molding resin and is generally not processed by conventional thermoplastic processing techniques, but rather by a high-temperature and pressure-sintering process. The polymer is available in fiber form, certain shaped forms and finished parts, and solutions for composite impregnation.

The polymer can be formed into fibers by dry spinning processes. PBI is often used in fiber form for a variety of applications such as protective clothing and aircraft furnishing. Parts made for PBI are used as thermal insulators, electrical connectors, and seals.

polybutadiene (PBD) Polybutadiene (PBD) polymers are essentially pure hydrocarbon resins that vary in the 1,2 microstructure from 60 to 90 percent. Typical chemical structure is as shown in Fig. P.5. Polybutadienes may be considered very much like polyethylene resins with a crosslink at every other carbon in the molecular chain. They have many of the same properties as the thermoplastic polyolefin resins except with crosslinking and resultant high temperature stability.

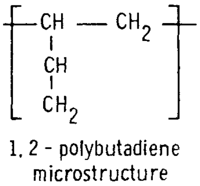


Figure P.5 General chemical structure of polybutadiene.

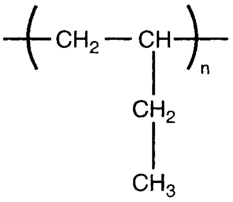
Three types of polybutadiene are available: high-*cis* (97%), medium-*cis* (92%), and low-*cis* (40%). The high-*cis* rubber is made by polymerization with a cobalt or nickel catalyst to keep the detrimental vinyl content below 1 percent. The medium-*cis* rubber, the most popular grade, uses a titanium catalyst, and the low-*cis* product uses an alkyl-lithium initiator. The rubbers have less resilience and a higher heat buildup than natural rubber, but they also give much greater wear life, low-temperature flexibility, and increased groove-cracking resistance in automotive tire treads and sidewalls.

Polybutadiene is almost always used in blends with other rubbers. Polybutadiene is also used as a raw material for making hexamethylenediamine, the precursor for nylon 6,6, and acrylonitrile butadiene styrene plastics.

Polybutadiene resins are cured to a thermosetting structure by peroxide catalysts. These catalysts produce carbon-to-carbon bonds at the double bond sites in the vinyl groups. The final product is 100 percent hydrocarbon except where the starting polymer is the —OH- or —COOH-terminated variety. Use of high-temperature peroxides maximizes the opportunity for thermoplastic-like processing, because even the higher-molecular-weight forms become quite fluid at temperatures well below the cure temperature. Compounds can be injection molded in an in-line machine with a thermoplastic screw.

Conventional polybutadiene resins offer potential as moldings, laminating resins, coatings, and cast liquid and formed sheet products. They have outstanding electrical and thermal stability properties. Originally developed by Firestone, thermosetting polybutadiene resins have not gained widespread commercial success except for niche markets where the combination of high temperature properties, low electrical losses, and processing characteristics are highly valued. Polybutadiene laminates have been evaluated for radomes and electrical grade laminates.

polybutylene (BP) Polybutylene (PB) polymers are linear, crystalline, thermoplastic resins prepared by the polymerizaton of 1-butene with Ziegler-Natta catalysts. They belong to the polyolefin family of polymers, with the entire polymer consisting of carbon and hydrogen. Copolymers with ethylene are often prepared as well. The general structure for polybutylene is shown in Fig. P.6.



$$-\!\left(CH_2-\underset{\underset{CH_3}{|}}{\underset{CH_2}{|}}{CH}\right)_n\!-$$

Figure P.6 General chemical structure of polybutylene.

The glass transition temperature for this polymer ranges from −17 to −25°C, indicating that it is elastic at room temperature. Polybutylene resins are linear polymers exhibiting good resistance to creep at elevated temperatures and good resistance to environmental stress cracking. They also show high impact strength, tear resistance, and puncture resistance. As with other polyolefins, polybutylene shows good resistance to chemicals, good moisture barrier properties and good electrical insulation properties. The chemical resistance is quite good below 90°C, but at elevated temperatures the polymer may dissolve in solvents such as toluene, decalin, chloroform, and strong oxidizing acids.

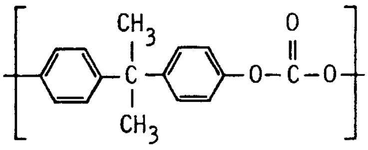
Polybutylene can be processed on equipment similar to that used for low-density polyethylene. Polybutylene can be extruded and injection molded. Film samples can be blown or cast. The slow transformation from one crystalline form to another allows polybutylene to undergo postforming techniques such as cold forming of molded parts or sheeting. A temperature range of 160–240°C is typically used to process polybutylene. The die swell and shrinkage are generally greater for polybutylene than for polyethylene.

An important application of polybutylene is plumbing pipe for both commercial and residential use. The excellent creep resistance of polybutylene allows for manufacture of thinner wall pipes compared to pipes made from polyethylene or polypropylene. However, recently this application has come under review because of aging degradation of polybutylene plumbing. Several building codes now prohibit the use of polybutylene pipe. Polybutylene pipe can also be used for the transport of abrasive fluids.

Other applications include hot-melt adhesives and additives for other plastics. The addition of polybutylene improves the environmental stress cracking resistance of polyethylene and the impact and weld line strength of polypropylene. Polybutylene is also used in packaging applications.

Polybutylene molding compounds are made in blow molding, extrusion, and injection molding grades. Major suppliers of these resins include Shell Chemical (*Duraflex*) and DSM Engineering.

polycarbonate (PC) Polycarbonate resins belong to a group of plastics that were among the first to be classified as engineering thermoplastics because of their high-performance characteristics. The general chemical structure is as shown in Fig. P. 7.



Polycarbonate

Figure P.7 General chemical structure of polycarbonate.

Two current synthesis processes are commercialized, with the economically most successful one said to be the "interface" process, which involves the dissolution of bisphenol A in aqueous caustic soda and the introduction of phosgene in the presence of an inert solvent such as pyridine. An alternative method involves transesterification of bisphenol A with diphenyl carbonate at elevated temperatures.

Polycarbonates are outstanding in impact strength, having strengths several times higher than other engineering thermoplastics. Polycarbonates are tough, rigid, and dimensionally stable and are available as transparent or colored parts. As with most other plastics containing aromatic groups, radiation stability is high. The most commonly useful properties of polycarbonates are creep resistance, high heat resistance, dimensional stability, good electrical properties, self-extinguishing properties, product transparency, and the exceptional impact strength, which compares favorably with that of some metals and exceeds that of many competitive plastics. In fact, polycarbonate is sometimes considered to be competitive with zinc and aluminum castings.

Oxidation stability on heating in air is good, and immersion in water and exposure to high humidity at temperatures up to 100°C has little effect on part dimensions. Steam sterilization is another advantage that is attributable to the resin's high heat stability. However, if the application requires continuous exposure in water, the temperature should be limited to 60°C. Polycarbonates are among the most stable plastics in a wet environment.

They are easily fabricated with reproducible results, by using standard molding or machining techniques. An important molding characteristic is the low and predictable mold shrinkage, which sometimes gives polycarbonates an advantage over nylons and acetals for close-tolerance parts. A disadvantage of polycarbonates is the need for drying and elevated temperature processing. PC has limited chemical resistance to numerous aromatic solvents, including benzene, toluene, and xylene and has a weakness to notches. Design engineers take care not to design with tight radii, where PC's tendencies to stress crack could be a hindrance.

In addition to their performance as engineering materials, polycarbonates are also alloyed with other plastics to increase the strength and rigidity of these plastics. Notable among the plastics with which polycarbonates have been alloyed are the acrylonitrile butadiene styrene (ABS) plastics. The favorable ease of processing and improved economics makes PC/ABS blends well suited for thin-walled electronic housing applications such as laptop computers. Blends with polybutylene terephthalate are useful for improving the chemical resistance of PC to petroleum products and for improving its low-temperature impact strength.

PC alone is widely used as vacuum cleaner housings, household appliance housings, and power tools. It is also used in safety helmets, riot shields, aircraft canopies, traffic light lens housings and automotive battery cases. In addition to standard grades of polycarbonates, a special film grade exists for high-performance capacitors.

Polycarbonate is available in blow molding, extrusion, and injection molding grades. Major suppliers include GE Plastics (*Lexan*), Bayer (*Apec, Makrolon*), Ashley Polymers (*Ashiene*), Mitusbishi Gas (*Iupilon*), Dow Chemical (*Calibre*), Bay Resins, ComAlloy, DSM Engineering, LNP (*Lubricomp*), Nova Polymers, Federal Plastics, Ferro (*Karlex*), and Compound Technologies.

Polycarbonate alloy suppliers include Kotec, MRC Polymers, Eastman Chemicals, GE Plastics, Bayer, Dow Chemical, LNP, MRC Polymers, Polymerland, and Spartech.

polychloroprene (CR) Polychloroprene (CR), or *neoprene* as it is more commonly called, was actually the first commercial synthetic rubber. Chloroprene, 2-chloro-1, 3-butadiene, the monomer from which all neoprenes are made, is produced from acetylene and hydrochloric acid. The chloroprene is emulsified in water, catalysts and modifier are added, and the system is allowed to polymerize under carefully controlled conditions of time and temperature.

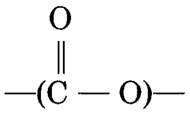
Neoprenes are the workhorse of the elastomer industry. They are classified as a moderately oil-resisting rubber with very good weather- and ozone-resisting properties. Other properties are closer to those of natural rubber than to styrene butadiene rubber (SBR).

Because of its crystallizing nature, neoprene has inherent high tensile strength, elongation, and wear properties at pure gum (not extended or hardened) levels. In this respect, it compares with natural rubber. SBR needs reinforcing materials for good tensile strength and thus has low pure gum properties. Electrically, neoprene ranks below natural rubber or SBR because of its polar chlorine group.

Neoprene can be compounded for temperatures as low as −55°C, but the rubber will crystallize rapidly, and it is not as good in low-temperature properties as either natural rubber or SBR. Neoprene has excellent flame resistance and is, in fact, self-extinguishing. Because of this property, it is a must in coal mining operations and other areas where fire is a potential hazard. Also, neoprene has good resistance to oxidative chemicals.

polyester-glass
See laminate.

polyester (thermoplastic) The broad class of thermoplastic polyesters is characterized by the fact that they contain an ester linkage and may be either aliphatic or aromatic hydrocarbon units. The ester linkage is shown in Fig. P.8.



$$—(\overset{\overset{\displaystyle O}{\|}}{C} — O)—$$

Figure P.8 General chemical structure of polyester linkage.

Thermoplastic polyesters include polybutylene terephthalate (PBT), polycyclohexylene dimethylene terephthalate (PCT), polyethylene terephthalate (PET), and liquid crystal polymers (LCP).

Thermoplastic polyester polymers are used extensively in the production of film and fibers. They are high crystalline, with a melting point of over 204°C. They are fairly translucent in thin molded sections and opaque in thick sections but can be extruded into transparent thin film. Both reinforced and unreinforced formulations are extremely easy to process and can be molded in very fast cycles.

The unreinforced resins offer the following characteristics: (1) hard, strong, and extremely tough; (2) high abrasion resistance, low coefficient of friction; (3) good chemical resistance, very low moisture absorption and resistance to cold flow; (4) good stress crack and fatigue resistance; (5) good electrical properties; and (6) good surface appearance. Electrical properties are stable up to the rated temperature limits.

The glass-reinforced thermoplastic polyester resins are unusual in that they are the first thermoplastic that can compare with, or are better than, thermosets in electrical, mechanical, dimensional, and creep properties at elevated temperatures (approximately 150°C), while having superior impact properties. The glass fiber concentration usually ranges from 10 to 30 percent in commercially available grades. In molded parts, the glass fibers remain slightly below the surface so that finished items have a very smooth surface finish as well as an excellent appearance.

Unreinforced resins are primarily used in housings requiring excellent impact and in moving parts such as gears, bearings, pulleys, packaging applications, and writing instruments. The flame-retardant grades are primarily aimed at television, radio, and electrical/electronic parts as well as business machine and pump components. Reinforced resins are being used in automotive, electrical and electronic, and general industrial areas, replacing thermosets, other thermoplastics, and metals. Electrical and mechanical properties coupled with low finished part cost are enabling reinforced thermoplastic polyester to replace phenolics, alkyds, diallyl phthalate (DAP), and glass-reinforced thermoplastics in many applications.

Polyethylene terephthalate (*PET*) resins are used as injection molding grade material for blow-molded bottles, and for oriented films. PET can be synthesized from dimethyl terephthalate and ethylene glycol by a two-step ester interchange process. Other commercial manufacturing methods have evolved to a direct esterification of acid and glycol in place of the ester exchange process. Methods of producing oriented PET films have been well developed. The well known film *Mylar* from Du Pont is an oriented polyethylene terephthalate film. Because of the chemically inert nature of PET, films used in coating applications are often treated with a variety of surface modifiers. Organic and inorganic fillers are often incorporated in relatively thick films to improve handling characteristics by roughening the surface. (*See also* Mylor.)

Major suppliers of PET resins include Goodyear (*Cleantuf*), Eastman Chemical (*Eastapak*), Adell, Albis (*Pelton*), Allied Signal (*Petra*), ComAlloy (*Hiloy, Voloy*), GE Plastics (*Valox*), RTP, Plastics Engineering, Ticoma (*Impet*), and Du Pont (*Rynite*). PET alloys are available from B.F. Goodrich, DSM Engineering, Eastman Chemical, Spartech, and MRC Polymers.

Polybutylene terephthalate (*PBT*) is different from PET with the substitution of four ethylene repeat units rather than the two in PET. This feature imparts additional flexibility to the backbone and reduces the polarity of the molecule, resulting in mechanical properties similar to those of PET. PBT blends such as PBT/ASA (acrylonitrile/styrene/acrylic ester) are popular in automotive exterior and under-hood applications.

PBT is also blended with PMMA, PET/PC, and polybutadiene. Another development involving the use of PBT is coextrusion of PBT and copolyester thermoplastic elastomer. This can then be blow molded into under-hood automotive applications, which minimize noise vibration. PBT is suitable for applications requiring dimensional stability. It is particularly good in water, and it is also resistant to hydrocarbons oils without stress cracking. To improve PBT's poor notch impact strength, copolymerization with ethylene and vinyl acetate will improve toughness.

Major suppliers of PBT molding compounds include Albis (*Pocan*), Adell, Ashley Polymers, BASF (*Ultradur*), Bay Resins, ComAlloy, DSM Engineering, Du Pont (*Crastin*), Ferro, GE Plastics (*Valox*), LNP, and Ticona (*Celanex*). PBT alloys are supplied by Ticona, GE Plastics, BASF, and Du Pont.

Polyethylene naphthalene (*PEN*) is a relatively new polyester. It has a great potential as a resin for bottles and films. PEN is a clear material, although less clear than PET, with enhanced barrier values to oxygen, carbon dioxide, and other chemicals. It has a higher glass transition temperature and is stronger and stiffer than PET. This makes it more suitable for hot filling and an excellent material for carbonated beverages. Bottles made with PEN provide the product with additional UV protection. PEN resins can be processed by blow molding, injection molding, and extrusion thermoforming.

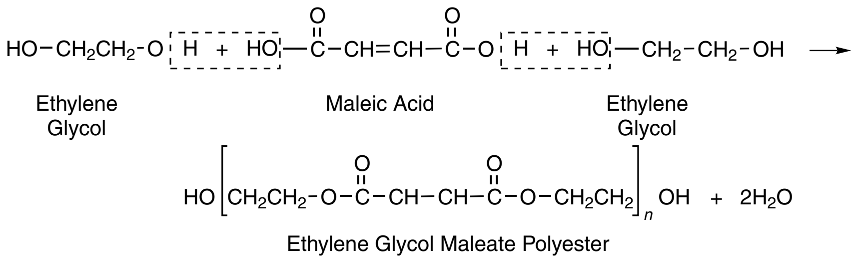
Polycyclohexylenedimethylene terephthalate (*PCT*) is a condensation product of the reaction between dimethyl terephthalate and 1,4-cyclohexylene glycol. This material is biaxially oriented into films, and although it is mechanically weaker than PET, it offers superior water and weather resistance. PCT also differentiates itself from PET and PBT by its higher heat-distortion temperature. Copolymers of PCT include an acid-modified polyester and a glycol-modified polyester. Major suppliers of PCT are Eastman Chemical (*Thermix, Eastar*) and GE Plastics (*Valox*).

Liquid crystal polymers (*LCP*) are aromatic copolyesters. The presence of phenyl rings in the backbone of the polymer gives the chain rigidity, forming a rodlike chain structure. The materials are self-reinforcing with high mechanical properties, but as a result of the oriented liquid crystal behavior, the properties will be anisotropic. The phenyl ring also helps to increase the heat-distortion temperature. These materials are difficult to process because of their very high melting points. Thus the formulation of copolymers is popular. Liquid crystal polymers based on these techniques include *Victrex* (ICI), *Vectra* (Hoescht Celanese), and *Xydar* (Amoco).

LCP materials are known for their high temperature resistance, particularly heat-distortion temperature (170–350°C). They also have excellent mechanical properties, especially in the flow direction. However, they have poor abrasion resistance, because of the oriented nature of the polymer chains. Liquid crystal polymers are used in automotive, electrical, chemical processing, and household applications. One application is for oven and microwave cookware.

polyester (thermosetting) Polyester resins are a broad family of clear, liquid, thermosetting resins of adjustable viscosity that, when catalyzed and subjected to heat or the action of accelerators, cure to extremely hard, stable solids. The chemical linkages shown in Fig. P.9 will form a rigid, crosslinked, thermosetting molecular structure.

The free radical addition process is used to polymerize the resin. The catalyst (organic peroxides) becomes the source for the free radicals, and with elevated temperature the heat decomposes the peroxide, producing the free radicals. Peroxyester and benzoyl peroxide are the organic peroxides primarily used at elevated temperatures. (*See* peroxide.) Promoters used singularly or in combination and retarders complete the cure system.

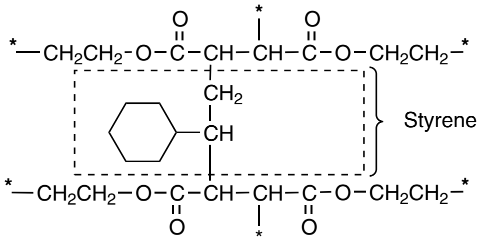


$$\mathrm{HO{-}CH_2CH_2{-}O\boxed{H + HO}{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}CH{=}CH{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O\boxed{H + HO}{-}CH_2{-}CH_2{-}OH} \longrightarrow$$

$$\mathrm{HO\left[CH_2CH_2{-}O{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}CH{-}CH{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}CH_2CH_2\right]_n OH + 2H_2O}$$

Reaction B

Polyester polymer units react (copolymerize) with styrene monomer in presence of catalyst and/or heat to yield styrene-polyester copolymer resin or, more simply, a cured polyester. (Asterisk indicates points capable of further cross-linking.)



Styrene-Polyester Copolymer

Figure P.9 Simplified diagrams showing how crosslinking reaction produce polyester resins (styrene-polyester copolymer) from basic compounds (Ref: Harper, C.A., ed., "Fundamentals of Plastics and Elastomers", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

The curing system does not greatly change the properties of the final polyester product, but the storage life, mold or press time, postcure conditions, and maximum temperature developed are controlled by the choice of curing system. The reactivity of the polyester chosen as well as the size and shape of the final product affect the choice of systems. This versatility of the cure schedule, from very rapid room-temperature cure to extended-temperature cure, is one of polyester's most attractive attributes.

Unsaturated, thermosetting polyesters are produced by addition polymerization reactions. Polyester resins can be formulated to have a range of physical properties from brittle and hard to tough and resistant to soft and flexible. Viscosities at room temperature may range from 50 to more than 25,000 cP. The polyester resin formulation usually consists of resin, monomer, inhibitors, catalyst or promoters, and appropriate fillers, additives, etc.

Polyester can be used to fabricate a variety of products by many techniques such as open-mold casting, hand layup, spray-up, vacuum-bag molding, matched metal die molding, filament winding, pultrusion, encapsulation, centrifugal casting, and injection molding.

Monomers are added to polyester formulation to copolymerize with the resin. Most vinyl monomers are strong solvents, so that acrylates and styrene are generally used. Because the monomer added as a resin diluent becomes a component part of the final polymerized mass, its properties will influence those of the final polymers.

Styrene is the most widely used monomer because of its low cost, high solvency, low viscosity, reactivity, and desirable cured properties, which it imparts to the polyester. Abrasion and wear properties increase in most polyester laminates when the styrene content is raised from 21 to 31 percent. α-Methyl styrene, when used at a concentration of 2–4 percent, reduces exotherm without affecting the cure time excessively. Larger concentrations decrease hardness and tensile strength. It is used in large castings. Methyl methacrylate used in combination with styrene increases durability, color retention, and resistance to fiber erosion and improves weathering resistance. Proper concentrations will change the index of refraction of the polyester to match that of glass and thus produce a nearly transparent laminate. However, methyl methacrylate will also provide lower boiling point, higher cost, and greater cure shrinkage than polystyrene.

Other monomers with their characteristic effect on the polyester resin are:

- Vinyl toluene—shorter cure time, higher boiling point, lower cure shrinkage, and higher viscosity than styrene.
- Diallyl phthalate—low volatility gives prepregs long shelf life, lower cure shrinkage, lower exotherms, reduced odor, increased flexural strength and Izod impact resistance, but at a higher cost.
- Triallyl cyanurate—provides greatly improved high temperature stability, but with greater cure shrinkage and more brittleness.
- Divinyl benzene—this monomer is used with styrene to produce harder (but more brittle) castings that are more heat resistant.
- Chlorostyrene—used to provide increased chemical resistance.

Most of the monomers that are added are somewhat unstable at room temperature. Consequently, to control shelf life and viscosity, inhibitors are incorporated into the polyester system. The most widely used inhibitors are hydroquinone and *p*-tert-butylcatechol.

The control of gelation and cure is the most critical part of polyester resin technology. Gelation is followed immediately by a self-propagated cure with considerable evolution of heat, which in thick sections and with a highly reactive resin can cause a temperature rise to over 204°C. Molded or laminated structures can be made with low or zero pressure. In closed systems, there is no loss of volatiles during cure.

Polyester resins can be cured from room temperatures up to 149–163°C. The addition of nothing but an organic peroxide is satisfactory for cure above 82°C, but cure at lower temperatures requires the use of both a peroxide catalyst and a promoter. Most of the chemical catalysts or initiators used for curing unsaturated polyester are peroxides. Ninety percent of the peroxides used consist of benzoyl peroxide, cumene hydroperoxide, di-tert-butyl peroxide, or methyl ethyl ketone peroxide (MEKP). Of these MEKP is most used, and it is often used for room-temperature curing. The promoters most often used are organic cobalt salts and dimethyl- or diethylaniline.

Excellent resistance to heat, chemicals, abrasion, and moisture characterizes polyesters in the cured state generally. As laminates reinforced with proper fillers, they provide exceptional strength and fatigue and impact resistance.

By the appropriate choice of ingredients, particularly to form the linear polyester resin, special properties can be imparted. Fire retardance can be achieved through the use of one or more of the following: chlorendic anhydride, tetrabromophthalic anhydride, tetrachlorophthalic anhydride dibromoneopentyl glycol, and chlorostyrene. Chemical resistance is obtained by using neopentyl glycol, isophthalic acid, hydrogenated bisphenol A, and trimethyl pentanediol. Weathering resistance can be enhanced by the use of neopentyl glycol and methyl methacrylate. Appropriate thermoplastic polymers can be added to reduce or eliminate shrinkage during curing and thereby minimize one of the disadvantages historically inherent in polyester systems.

Thermosetting polyesters are widely used for moldings, laminated or reinforced structures, surface gel coatings, and liquid castings. Cast products include furniture, bowling balls, simulated marble, gaskets for vitrified clay sewer pipe, pistol grips, pearlescent shirt buttons, and implosion barriers for television tubes.

By layup and spray-up techniques, large- and short-run reinforced items are fabricated. Examples include boats of all kinds, dune buggies, all-terrain vehicles, custom auto bodies, truck cabs, horse trailers, motor homes, housing modules, concrete forms, and playground equipment.

Molding is also performed with premix compounds, which are doughlike materials generally prepared by the molder shortly before they are to be molded by combining the premix constituents in a sigma blade mixer or similar equipment. Premix using conventional polyester resins is used to mold automotive heater housings and air conditioner components. Low-shrinkage resin systems permit the fabrication of exterior automotive components such as fender extensions, lamp housings, hood scoops, and trim rails.

Wet molding of glass mats or preforms is used to fabricate such items as stackable tabletops, food trays, tote boxes, and stackable chairs. Corrugated and flat paneling for room dividers, roofing and siding, awnings, skylights, fences, and the like are a very important outlet for polyesters. Pultrusion techniques are used to make fishing rod stock and profiles from which slatted benches and ladders can be fabricated. Chemical storage tanks are made by filament winding processes.

polyether Polyethers consist of a family of several polymers containing ether linkages in their chain. Polyglycols are the major class in this group and include chlorinated polyether and polyaryl ether. Polyglycols are not considered to be engineering polymers, but chlorinated polyether and polyaryl ether are.

See also polyglycol; chlorinated polyether; polyaryl ether.

polyetherimide (PEI) Polyetherimide (PEI) is an amorphous thermoplastic with high temperature resistance, impact strength, creep resistance, and rigidity. The glass transition temperature is 215°C. It is transparent with an amber color. The polymer has a structure as shown in Fig. P. 10.

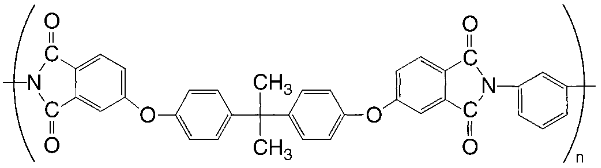


Figure P.10 General chemical structure of polyetherimide.

This material can be melt processed because of the ether linkages present in the backbone of the polymer. However, it still maintains high-temperature properties similar to the polyimides. The high-temperature resistance of PEI competes with polyketones, polysulfones, and polyphenylene sulfides.

The polymer has very high tensile strength, an Underwriter's Laboratories (UL) temperature index of 170°C, flame resistance, and low smoke emission. The polymer is resistant to alcohols, acids, and hydrocarbon solvent but will dissolve in partially halogenated solvents. Both glass- and carbon fiber-reinforced grades are available.

The polymer should be dried before processing, and typical melt temperatures are 340–425°C. PEI resins can be processed by injection molding and extrusion. The polymer can also be thermoformed and blow molded.

PEI is used in electrical applications including printed circuit substrates and burn-in sockets. In the auto industry, PEI is used for under-hood temperature sensors and lamp sockets. The dimensional stability of the polymer allows for large, flat parts such as in hard disks for computers.

Polyetherimide molding compounds are commercially available in extrusion and injection molding grades. The major suppliers of this material include GE Plastics (*Ultem*), Compound Technologies, DSM Engineering, LNP, and RTP. A polyetherimide-polycarbonate alloy and a polyetherimide-silicone alloy are also available from GE Plastics.

Polyether Sulfone (PES) Polyether sulfone is a relatively new high-temperature engineering thermoplastic belonging to the *polysulfone* family. The polyether sulfone chemical structure shown in Fig. P. 11 produces an amorphous polymer, which possess bonds of high thermal and oxidative stability. Whereas the sulfone group provides high temperature performance, the ether linkage contributes toward practical processing by allowing mobility of the polymer chain when in the melt phase.

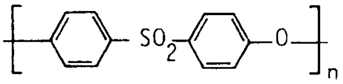


Figure P.11 General chemical structure of polyether sulfone.

Polyether sulfone is a transparent polymer with high temperature resistance and self-extinguishing properties. It gives off little smoke when burned. Polyether sulfone has a glass transition temperature near 225°C and is dimensionally stable over a wide temperature range. Polyether sulfone has a heat-deflection temperature of 203°C at 264 psi. Certain grades are capable of operating at temperatures above 200°C.

It has outstanding long-term resistance to creep at temperatures up to 150°C. In this respect it is superior to polysulfone, phenylene oxide-based resins, or polycarbonate. It is also capable of being used continuously under load at temperatures of up to about 180°C and in some low-stress applications to 200°C. A constant stress of 3000 psi at 20°C for 3 years produces a strain of 1 percent, whereas a stress of 6500 psi results in only 2.6 percent over the same time period.

Polyether sulfone is especially resistant to acids, alkalis, oils, greases, and aliphatic hydrocarbons and alcohols. It is attacked by ketones, ester, and some halogenated and aromatic hydrocarbons.

Polyether sulfone can be processed by injection molding, extrusion, blow molding or thermoforming. It exhibits low mold shrinkage. For injection molding, barrel temperatures of 340–380°C with melt temperature of 360°C are recommended. Mold temperatures should be in the range of 140–180°C. For thin-walled molding higher temperatures may be required. Unfilled PES can be extruded into sheets, rods, film, and profiles.

PES finds application in aircraft interior parts because of its low smoke emission. Electrical applications include switches, integrated circuit carriers, and battery parts. The high-temperature oil and gas resistance allow PES to be used in automotive applications. The ability of PES to endure repeated sterilization allows it to be used in a variety of medical applications. Consumer uses include cooking equipment and lighting fittings. PES can also be vacuum metallized for a high-gloss mirror finish. They are also used for specialized adhesive and lacquer applications.

Polyether sulfone is commercially available in blow molding, extrusion, and injection molding grades. Glass fiber-reinforced grades are available for increased physical properties. The major suppliers of this molding compound are BASF (*Ultrason*), LNP, DSM Engineering, RTP, Compound Technologies, Gharda Chemicals, and Amoco (*Radel*).

polyethylene (PE) Polyethylene belongs to the family of *polyolefin* resins. Polyethylene is among the best-known thermoplastic. It is a simple polymer with repeating $—CH_2CH_2—$ structure. It is an incredibly versatile polymer with almost limitless variety due to copolymerization potential, a wide density range, and a molecular weight that ranges from low to very high.

Four established production methods are used for producing polyethylene: a gas-phase method known as the *Unipol process* practiced by Union Carbide, a solution method used by Dow and Dupont, a slurry emulsion method practiced by Phillips, and a high-pressure method.

Polyethylene has high toughness, ductility, excellent chemical resistance, low water vapor permeability, and very low water absorption. These properties combined with the ease with which it can be processed make PE one of the highest-volume polymers in the world. PE is limited by its relatively low modulus, yield stress, and melting point. PE is used to make containers, bottles, film, and pipes among other things.

Polyethylene comes in three main classifications based on density: low, medium, and high. These density ranges are generally 0.910–0.925, 0.925–0.940, and 0.940–0.965, respectively. Commercially available grades are broken down further by density into:

- Very low-density PE (VLDPE)
- Low-density PE (LDPE)
- Linear-low density PE (LLDPE)
- High-density PE (HDPE)
- Ultra-high-molecular-weight PE (UHMWPE)

Chain configurations for HDPE, LLDPE, and LDPE are shown in Fig. P. 12. All polyethylenes are relatively soft, and hardness increases as density increases. Generally, the higher the density the better the dimensional stability and physical properties, particularly as a function of temperature. The thermal stability of polyethylenes ranges from 88°C for the low-density material up to 121°C for the high-density material. Toughness of the parts is maintained to low negative temperatures. Generally, yield strength and the melt temperature increase with density, whereas elongation decreases with increased density.

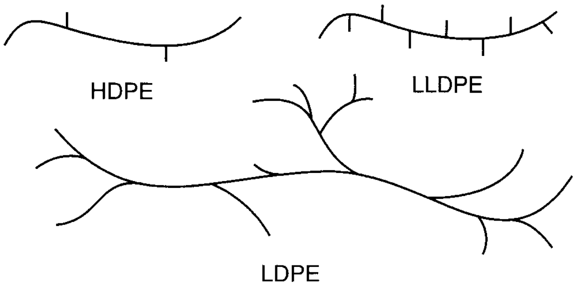


Figure P.12 Chain configurations of polyethylene.

Very low-density polyethylene (*VLDPE*) is principally used in film applications. It varies in density from 0.880 to 0.912 g/cm^3. Its properties are marked by high elongation, good environmental stress cracking resistance, and excellent low-temperature properties. It competes most frequently as an alternative to plasticized PVC or ethylene-vinyl acetate (EVA). The inherent flexibility in the backbone of VLDPE circumvents plasticizer stability problems often associated with polyvinyl chloride (PVC), and it avoids odor and stability problems that are related to molding of ethylene vinyl acetate (EVA).

Blow molding, extrusion, and injection molding grades of VLDPE are commercially available. The major suppliers of these materials include Union Carbide (*Flexomer*) and Dow Chemical (*Attane*).

Low-density polyethylene (*LDPE*) is formed via free radical polymerization, with alkyl branch groups of two- to eight-carbon atom lengths. LDPE combines high impact strength, toughness, and ductility. It is the material of choice for packaging films. Films include shrink film, thin film for automatic packaging, heavy sacking, and multilayer films (both laminated and coextruded), in which LDPE acts as a seal layer or a water vapor barrier. It competes with LLDPE in these film applications because of LLDPE's higher melt strength.

There are very many suppliers of LDPE, and many grades are available. Several of the major suppliers of LDPE include Dow Chemical, Exxon Polymers, Nova Chemical, DuPont, Westlake Polymer, Mobil, Eastman Chemical, General Polymers, and Union Carbide.

Linear low-density polyethylene (*LLDPE*) has enhanced tensile strength for the same density as LDPE. Its density ranges from 0.915 to 0.940 g/cm^3. Film accounts for most of the consumption of this polymer. It is a long linear chain without long side chains or branches. The short chains disrupt the polymer chain uniformity enough to prevent crystalline formation and, hence, prevent the polymer from achieving high densities. LLDPE has production economies compared to LDPE because of lower polymerization pressures and temperatures.

Extrusion, blow molding, injection molding, and rotational molding grades of LDPE are commercially available. Major suppliers of LDPE molding compounds include Union Carbide, Dow Chemical (*Elite*), Exxon Polymers (*Exceed*), Nova Chemicals (*Novapol*), Mobil, and ICI Chemical (*Faralloy*). There are many suppliers of unfilled material and several suppliers of filled grades.

High-density polyethylene (*HDPE*) is one of the highest-volume commodity plastics produced. The most common method of processing HDPE is by blow molding. Two commercial polymerization methods are most commonly practiced: one involves Phillips catalyst (chromium oxide), and the other involves the Ziegler-Natta catalyst systems. HDPE blow molding is used to produce bottles, housewares, toys, pails, drums, and automotive gas tanks. It is also commonly injection molded into housewares, toys, food containers, garbage pails, and milk crates and cases. HDPE films are commonly found as bags in supermarkets and department stores and as garbage bags.

There are very many suppliers of HDPE, and many grades are available. The major suppliers of HDPE also are the major suppliers of LDPE.

Ultra high-molecular-weight polyethylene (*UHMWPE*) is identical to HDPE but with a higher molecular weight. The high molecular weight imparts outstanding abrasion resistance, high toughness, even at cryogenic temperatures, and excellent stress cracking resistance. However, the high molecular weight does not allow the polymer to be processed by conventional means. UHMWPE is often molded from fine powder that can either be ram extruded or compression molded. It is used as liners for chemical processing equipment, lubrication coatings in railcar applications to protect metal surfaces, recreation equipment such as ski bases, and medical devices.

A product has been developed by Allied Signal (*Spectra*), that involves gel-spinning UHMWPE into lightweight, very strong fibers that compete with Kevlar in applications for protective clothing. A series of molding compounds, primarily for extrusion and compression molding, are available from Montell, N.A. and Ticona (*Hostalen*).

Crosslinked polyethylene offers thermal performance improvements of up to 25°C or more over the standard non-crosslinked polymers. Cross-linking has been achieved primarily by chemical means and by ionizing radiation. Products of both processes are available. *Chemically crosslinked polyethylene* is generally achieved by incorporating peroxides into the formulation. Crosslinking occurs via the free radical polymerization route. *Radiation-crosslinked polyolefins* have gained particular prominence in a heat-shrinkable form. This is achieved by crosslinking the extruded or molded polyolefin with high-energy electron beam radiation, heating the irradiated material above its crystalline melting point to a rubber state, mechanically stretching to an expanded form, and cooling the stretched material. The material is stable and is sold in this state. On further heating, the material will then return to its original size, tightly shrinking onto the object around which it has been placed. Heat-shrinkable boots, jackets, and tubing are widely used. Also, irradiated polyolefins, sometimes known as *irradiated polyalkenes*, are important materials for certain wire and cable jacketing applications.

The properties of PE can be tailored to meet the needs of a particular application by a variety of different methods. Chemical modification, copolymerization, and compounding can all dramatically alter specific properties. The homopolymer itself has a range of properties depending on the molecular weight, number, and length of side branches, the degree of crystallinity, and the presence of additives such as fillers or reinforcing agents.

Further modification of polyethylene is possible by chemical substitution of hydrogen atoms; this occurs preferentially at the tertiary carbons of a branching point and primarily involves chlorination, sulfonation, phosphorylination, and intermediate combinations. (*See* chlorinated polyethylene; chlorosulfonated polyethylene; phosphorylated polyethylene; ionomer.)

polyethylene copolymer Ethylene is copolymerized with many nonolefinic monomers, particularly acrylic acid variants and vinyl acetate, with EVA polymers being the most commercially significant. All of the copolymers involve disruption of the regular, crystallizable polyethylene (PE) homopolymer, and as such they feature reduced yield stresses and moduli with improved low temperature flexibility.

See also ethylene acrylic acid copolymer; ethylene ethyl acrylate copolymer; ethylene methyl acrylate copolymer; ethylene *n*-butyl acrylate copolymer; ethylene vinyl acetate copolymer; ethylene vinyl alcohol.

polyethylene fiber Allied Signal produces polyethylene fibers under the tradename *Spectra*. The polyethylene fibers have the same shear and compression property drawbacks as the aramids, but they also suffer from a low melting temperature that limits their use to composites that cure or operate below 150°C and a susceptibility to degradation by ultraviolet (UV) light exposure.

Both the aramids and the polyethylenes have wide use in personal protective armor, and the polyethylene fibers have found wide use as ropes and lines for mountain climbing as well as boating and sailing because of their high strength and low density. They float on water and have a pleasant feel or hand as a rope or line.

See also polyethylene.

polyglycol Polyglycols are a family of polyether resins that are produced from the polymerization of several oxides. Materials can range from liquids to resinous plastics, resembling polyethylene in appearance and bulk properties.

One type of polyglycol is *polyethylene glycol*, produced from polyethylene oxide. These polyethers have many uses because of their water solubility, lubricating properties, and waxy feel. They are used in cosmetics and pharmaceuticals as well as in water-based paints, paper coatings, adhesives, inks, and mold-release agents. The highest-molecular-weight materials have interesting plastic properties. They are highly crystalline and yet have very good ductility. Films are heat sealable and water soluble, suggesting use in water-soluble packages and capsules.

Polypropylene glycols are produced from propylene oxide and are produced commercially in a range of molecular weights. Up to a molecular weight of 750, the materials are also water soluble, but only slightly so at higher molecular weights. However, they are very soluble in various solvents. Polypropylene glycols have the same uses as the polyethylene glycols, and they are important intermediates for polyurethanes via reaction with diisocyanates.

polyimide-glass

See laminates.

polyimide (PI) and polyamide-imide (PAI) Among the commercially available plastics generally considered as having high heat resistance, polyimides can be used at the highest temperatures and they are the strongest and most rigid.

Polyimides are heterocyclic polymers having a noncarbon atom of nitrogen in one of the rings in the molecular chain. The repeating unit of polyimide structure is shown in Fig. P. 13. The fused rings provide chain stiffness essential to high-temperature strength retention. The low concentration of hydrogen provides oxidative resistance by preventing thermal degradative fracture of the chains.

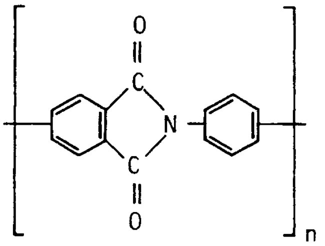


Figure P.13 General chemical structure of polyimide.

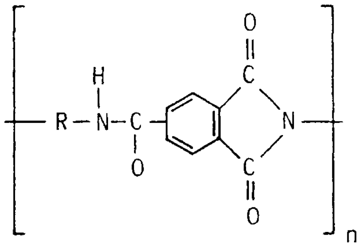


Figure P.14 General chemical structure of polyamide-imide.

The other resins considered as members of this family of polymers are the polyamide-imides. These compositions contain aromatic rings and the characteristic nitrogen linkages as shown in Fig. P. 14.

There are two basic types of polyimides: condensation and addition resins. The *condensation polyimides* are based on a reaction of an aromatic diamine with an aromatic dianhydride. A tractable (fusible) polyamic acid intermediate produced by their reaction is converted by heat to an insoluble and infusible polyimide, with water being given off during the cure. Generally, the condensation polyimides result in products having high void contents that detract from optimal mechanical properties and result in some loss of long-term heat resistance.

The *addition polyimides* are based on short, preimidized polymer chain segments similar to those composing condensation polyimides. These prepoylmer chains, which have unsaturated aliphatic end groups, are capped by components that polymerize thermally without the loss of volatiles. The addition polyimides yield products that have slightly lower heat resistance than the condensation polyimides.

The condensation polyimides are available as either thermosets or thermoplastics, and the addition polyimides are available only as thermosets. Although some of the condensation polyimides technically are thermoplastics, which would indicate that they could be melted, this is not the case, because they have melting temperatures that are above the temperature at which the materials begin to decompose thermally.

Polyimides have a useful operating range to about 482°C for short durations and 260–316°C for continuous service in air. Prolonged exposure at 260°C results in moderate (25–30%) loss of original strength and rigidity. In addition to heat resistance, polyimides possess excellent electrical and mechanical properties that are also relatively stable from low negative temperatures to high positive temperatures, dimensional stability in most environments, low cold flow, excellent resistance to ionizing radiation, and very low out-gassing in high vacuum. Polyimides have a very low coefficient of friction that can be further improved by the use of graphite or other fillers.

Polyamide-imides and polyimides have very good electrical properties although not as good as those of the fluorocarbons. However, they are much better than fluorocarbons in mechanical and dimensional stability properties.

These materials can be used in various forms including moldings, laminates, films, coatings, and adhesives. They have high mechanical properties, wear resistance, chemical and radiation inertness, and excellent dielectric properties over a broad temperature range. They provide advantages in many high-temperature electronic applications. Their properties also make polyamide-imides and polyimides excellent material choices in extreme environments of space and temperature. Films are quite similar to Mylar, except for greatly improved high-temperature properties. The best known polyimide film is *Kapton* (Du Pont). It is used in many high-temperature applications.

Thermoplastic polyamide-imide molding compounds are commercially available in extrusion and injection molding grades from Amoco (*Torlon*) and Chem Polymer (*Beetle*). Thermoplastic polyimide molding compounds are available in the same grades from Mitsui Toatsu (*Aurum*) and RTP. Thermosetting polyimide molding compounds for compression and transfer molding are available from Ciba Specialty (*Kinel*) and Quantum Compositions. Injection molding grades are available from Ciba Specialty and Furon (*Meldin*). A high-temperature polyimide film (*Kapton*) is available from Du Pont.

polyisoprene rubber (IR) Polyisoprene (IR) rubber is a synthetic rubber equivalent of natural rubber. It was introduced in the 1950s as a replacement for natural rubber. Isoprene rubber products and processing properties are better than natural rubber in a number of characteristics. Molecular weight and its distribution can be controlled for consistent performance and processing properties.

Polymerization of isoprene can yield high purity *cis*-1,2-polyisoprene and *trans*-1,4-polyisoprene. Depolymerized polyisoprene liquid is used as a reactive plasticizer for adhesive tapes, hot melts, brake linings, and wire and cable sealants.

Isoprene rubber products are exemplified by *Natsyn* (Goodyear Tire and Rubber Co.), which is used to make tires and tire tread. Tires are the major *cis*-polyisoprene product. *Trans*-polyisoprene can be used to make golf ball covers, hot-melt adhesives, and automotive and industrial products.

polyketone: polyether ketone (PEK), polyether ether ketone (PEEK), polyether ether ketone ketone (PEEKK) The polyketone family of resins includes structures that vary in location and number of ketonic and ether linkages on their repeat units as shown in Fig. P.15. The members of this high-temperature thermoplastic family include polyether ketone (PEK), polyether ether ketone (PEEK), polyether ether ketone ketone (PEEKK), polyarylether ketone (PAEK), as well as other combinations. The chemical structures of PEK, PEEK, and PEEKK are shown in Fig. P.15.

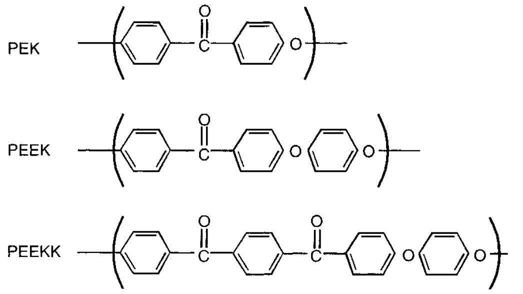


Figure P.15 General chemical structure of PEK, PEEK, and PEEKK.

Because of their high temperature and chemical resistance they are considered to be in the class of high-performance engineering plastics. PEK has a higher melting point and heat distortion temperature than PEEK, but PEEK is somewhat more flexible. PEK has relatively high ultimate tensile properties.

All of these resins have very high thermal properties because of the aromaticity of their backbones. However, they are readily processed via injection molding and extrusion although their melt temperatures are very high (370°C for unfilled PEEK and 390°C for filled PEEK as well as both filled and unfilled PEK). Mold temperatures as high as 165°C are also used.

Their toughness is surprisingly high for such heat-resistant materials. They have high dynamic fatigue capability, low moisture absorption, and good hydrolytic stability. As a result they are often found in parts for nuclear plants, oil wells, high-pressure steam valves, chemical plants, and airplane and automobile engines.

Glass and carbon fiber reinforcements are the most important fillers for the polyketone family. Although elastic extensibility is sacrificed, the additional heat resistance and moduli improvements allow the glass and carbon fiber formulations entry into many applications.

The most common of the polyketones are PEK, PEEK, and PAEK. All are available as thermoplastic molding compounds. PAEK is available as a compression molding compound from Amoco (*Kadel*). PEEK is available as a compression molding, extrusion and injection molding compound from Victrex, Compound Technologies, DSM Engineering, LNP and RTP. PEK is available as an injection molding compound from RTP.

polyliner In injection molding, a polyliner is a perforated, longitudinally ribbed sleeve that fits inside the cylinder of an injection molding machine. It is used as a replacement for conventional injection cylinder torpedoes.

polymer A polymer is a high-molecular-weight organic compound whose structure can be represented by a repeated small unit, the *mer*. A polymer is prepared by stringing together a series of low-molecular-weight species (such as ethylene) into an extremely long chain (such as polyethylene), much as one would string together a series of beads to make a necklace.

The chemical characteristics of the starting low-molecular-weight species will determine the properties of the final polymer. The properties of different polymers can vary widely. Properties can be varied for each individual plastic material as well, simply by varying the microstructure of the material. In its solid form a polymer can take up different structures depending on the structure of the polymer chain as well as the processing conditions.

A polymer can be either natural or synthetic. Synthetic polymers are formed by addition or condensation polymerization reactions of monomer. If two or more different monomers are involved, a *copolymer* (such as ethylene vinylacetate) is obtained.

Polymers can be of various hardnesses and strengths and of vastly different properties and processing characteristics. Polymers can either be thermosetting where the molecular chains are crosslinked into a structure that will not flow on the application of heat or thermoplastic where the chains are not cross-linked and the polymer can flow on application of heat and pressure; crystalline

Polymers come in many forms including plastics, elastomers, and fibers. Plastics are stiffer than elastomers yet have reduced low-temperature properties. Generally, a plastic differs from an elastic material because the location of its *glass transition temperature* (T_g). A plastic has a T_g above room temperature, whereas rubber will have a T_g below room temperature.

See also amorphous polymer; copolymer; crystalline.

polymer blend Polymer blends are simply mixtures of two or more polymers where there is no chemical interaction between the polymers. Considerable interest in polymer blends has been due to the difficulty in developing new polymeric materials from monomers. In many cases it can be more cost effective to tailor the properties of a material through the blending of existing materials.

One of the most basic questions regarding blends is whether the two polymers are miscible or exist as a single phase. In many circumstances, the polymers will exist as two separate phases. In this case the morphology of the phases is of great importance. In the case of a miscible single-phase blend, there is a single T_g, which is dependent on the composition of the blend. When two phases exist, the blend will exhibit two separate T_g values, one for each of the phases present. In the case where the polymers can crystallize, the crystalline portions will exhibit a melting point even in the case where the two polymers are a miscible blend. Miscible blends of commercial importance include PPO-PS, PVC-nitrile rubber, and PET-PBT.

Immiscible blends include toughened polymers in which an elastomer is added, existing as a second phase. The addition of the elastomer phase dramatically improves the toughness of the resulting blend. Examples of toughened polymers include high-impact polystyrene, modified PP, ABS, PVC, nylon, and others. In addition to toughened polymers, a variety of other two-phase blends are commercially available. These include PC-PBT, PVC-ABS, PC-PE, PP-EPDM, and PC-ABS.

Polymer blends are often used in adhesive formulations where properties associated with rigid polymers (high temperature resistance, chemical resistance, etc.) must be obtained along with properties associated with tough, elastic polymers (impact strength, high peel strength, etc.). Examples of these adhesive systems are nylon-epoxy, phenolic-nitrile, epoxy-polysulfide, epoxy-nitrile, and epoxy-urethane.

polymer fiber There are many naturally occurring polymeric fibers, which can be subdivided into fibers of animal origin (wool, mohair, angora, camel, fur, silk, cashmere, alpaca, etc.) and fibers of vegetable origin (cotton, flax or linen, sisal, etc.). These fibers are either protein- or cellulose based. Polymeric fibers that are the result of chemical reactions or transformation are referred to as man-made, synthetic, or artificial fibers.

Fiber-forming polymers are normally of the crystallizing, non-crosslinked type, but besides crystallization, strong orientation of molecules and crystalline units is an essential feature. Polymeric fibers are used in a variety of applications, including filters, cords, cables, and fabrics.

The long-established textile industry has developed specific methods for characterization of fibers and associated units. (*See* denier; tenacity.)

The formation of monofilaments is completed in two basic steps, which are often conducted in rapid sequence. The first step is filament spinning. This can be achieved in several ways. It sometimes involves a chemical reaction during the fiber forming stage, but in the majority of cases, the transformation or changes are only physical, involving heat or mass transfer. One process is referred to as “wet” spinning and another as “dry” spinning. (*See* spinning.)

The second step to forming a monofilament is referred to as *cold drawing* or simply *drawing*. This step confers most of the orientation through a stretching, yielding, and drawing process that takes place in the solid state but above the glass transition temperature of the crystallizing polymer.

There are six major types of conventional synthetic fibers: rayon, acetates, olefinics, vinylics, acrylic, nylons, and polyester. Rayon or viscose rayon fibers are marketed as regular, cross-linked, or high wet modulus types. Acetate or triacetate fibers are based on cellulose acetate. Olefinic fibers include polyethylene and polypropylene. Vinylics are based on polyvinyl chloride but often involve copolymerization with vinyl acetate or vinylidene chloride. Acrylics or modarylics are based on polyacrylonitrile but generally involve copolymerization with polyvinyl chloride. Polyamides or nylons involve aliphatic polyamides, and polyester involves polyethylene terephthalate. In addition, a number of special-purpose or high-performance fibers have been commercialized, including polyurethanes, aramides, extended-chain polyethylene, polybenzimidazole, and polyetherether ketone.

polymerization Polymerization is the chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more monomers are involved, the process is called *copolymerization* or *heteropolymerization*.

See also addition polymerization; condensation polymerization.

polymerization system Several types of polymerization systems are used for conversion of monomer to polymer: bulk polymerization, solution polymerization, suspension polymerization, and emulsion polymerization. Table P.7 offers a comparison of these polymerization systems.

The simplest and most direct method of converting monomer to polymer is known as *bulk* or *mass polymerization*. A typical charge might consist of monomer, a monomer-soluble initiator, and perhaps a charge-transfer agent. Simple rate and heat transfer problems due to reaction kinetics generally create problems with bulk polymerization. However, some polymers such as polystyrene are sometimes made in bulk.

Table P.7 Comparison of Polymerization Systems (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 339)

Type	Advantages	Disadvantages
Homogeneous		
Bulk (batch type)	Minimum contamination. Simple equipment for making castings.	Strongly exothermic. Broadened molecular weight distribution at high conversion. Complex if small particles required.
Bulk (continuous)	Lower conversion per pass leads to better heat control and narrower molecular weight distribution.	Requires agitation, material transfer, separation, and recycling.
Solution	Ready control of heat of polymerization. Solution may be directly usable.	Not useful for dry polymer because of difficulty of complete solvent removal.
Heterogeneous		
Suspension	Ready control of heat of polymerization. Suspension or resulting granular polymer may be directly usable.	Continuous agitation required. Contamination by stabilizer possible. Washing, drying, possibly compacting required.
Emulsion	Rapid polymerization to high molecular weight and narrow distribution, with ready heat control. Emulsion may be directly usable.	Contamination with emulsifier, etc., almost inevitable, leading to poor color and color stability. Washing, drying, and compacting may be required.

The addition of inert solvent to a bulk polymerization mass (*solution polymerization*) minimizes many of the difficulties encountered in bulk systems. This reduces the tendency toward auto acceleration, and the inert diluent adds its heat capacity without contribution to the evolution of heat. It also cuts the viscosity of the reaction mass at any given conversion. The heat of polymerization may also be conveniently and efficiently removed by refluxing the solvent.

In *suspension polymerization* the heat removal is facilitated by keeping the dimension of the reaction mass small. This is carried out by suspending the monomer in the form of droplets in an inert, nonsolvent liquid (almost always water). In this way each droplet becomes a single bulk reactor, but with dimensions small enough so that heat removal is not a problem, and the heat can easily be soaked up by and removed from the low-viscosity, inert suspension medium.

Emulsion polymerization differs from suspension polymerization in two important respects: the initiator is located in the aqueous phase, and the polymer particles produced are typically of the order of 0.1 μm in diameter, some 10 times smaller than the smallest encountered in suspension polymerization. Emulsion systems allow higher-molecular-weight polymers to be produced at higher rates than do bulk or suspension systems.

polymethyl methacrylate (PMMA)
See acrylic.

polymethylpentene (PMP) Polymethylpentene is a thermoplastic in the polyolefin family with higher branching than the polybutenes. The polymer is prepared by the dimerization of propylene. Polymethylpentene is the lowest-density plastic with a specific gravity of 0.83. It has high transparency and a relatively high melting point.

Polymethylpentene has a high crystalline melting point of 240°C, coupled with useful mechanical properties at 204°C and retention of form stability to near the melt point. However, the polymer is brittle (fiber or rubber additives are usually advised for improved toughness), ages poorly (the use of antioxidants is recommended), has high gas permeability, and is relatively expensive. Polymethylpentene's chemical resistance is very good and typical of the polyolefins. Its transparency is close to the theoretical optimum for thermoplastics. Polymethylpentene also has excellent electrical properties with power factor, dielectic constant, and volume resistivity on the same order as PTFE fluorocarbon.

Polymethylpentene must be processed with the care required for sharp-melting polymers. It also has a very low viscosity in its normal melting range, and care must be taken to prevent drooling in injection molding and in high-compression screws with sharp transition between feed and metering zones.

Applications for polymethylpentene have been developed in the field of lighting and in automotive, appliance, and electrical industries. These include thermoplastic encapsulation for electronic relays, central heating plant control valves, sight glasses, and piping in milking machines. Applications also include laboratory and hospital ware such as syringes, beakers, burettes, and tube fittings.

Polymethylpentene polymers are available from Mitsui Petrochemical Industries, Ltd. as *TPX* resins. Blow molding, extrusion, and injection molding grades are commercially available.

polyol A polyol is an alcohol having many hydroxyl groups. It is also known as a polyhydric alcohol or polyalcohol The term includes compounds containing alcoholic hydroxy groups such as polyethers, glycols, polyesters, and castor oil used in urethane foam and other polyurethane applications.

polyolefin
See olefinic.

polyoxyethylene (polyethylene oxide) Polyoxyethylene is a polymer produced by the polymerization of ethylene oxide or by the polycondensation of ethylene glycol (hence the alternative name of polyethylene glycol). Liquid forms of relatively low molecular weight are available in various viscosities. Higher-molecular-weight materials are hydrophilic, water-soluble waxes. The main applications are in cosmetic and pharmaceutical preparations.

Polymers with much higher molecular weights are crystalline materials with a melting point of 65–67°C. They are strong and tough in the dry state and can be processed by injection molding, extrusion, and calendering. They remain water soluble through to the final product. The main uses are film for water-soluble packaging applications and as thickening agents for aqueous solutions.

polyoxymethylene (POM) Polyoxymethylene (POM) is a polymer in which the repeated structural unit in the chain is oxymethylene. This is another name for polyacetal.

See also polyacetal.

polyphenylene oxide (PPO) Polyphenylene oxide resins are made by a patented process called oxidative coupling. This is the reaction of O_2 with active hydrogens from different molecules to produce water and coupled molecules. The PPO resins currently available are based on the copper-catalyzed oxidation of 2,6-exlenol. The basic phenylene oxide structure is shown in Fig. P. 16.

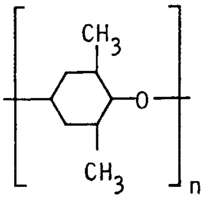


Figure P.16 General chemical structure of polyphenylene oxide.

The commercial PPO resins were developed by General Electric (*Noryl*) and defined as "modified" PPO. Their exact chemical nature is unknown. They may be polymer blends, likely with polystyrene or high-impact polystryene. In Europe PPO is recognized by a more generic name, *polyphenylene ether* (*PPE*).

This family of engineering materials is characterized by outstanding dimensional stability at elevated temperatures, broad temperature use range, outstanding hydrolytic stability, and excellent dielectric properties over a wide range of frequencies and temperatures.

Among their principal design advantages are excellent mechanical properties over temperatures from below −40°C to above 150°C. PPO resins have self-extinguishing, nondripping characteristics, and excellent dimensional stability with low creep, high modulus, and low water absorption. PPOs have good electric properties, excellent resistance to aqueous chemical environments, and excellent impact strength.

Several grades of PPO are available that have been developed to provide a choice of performance characteristics to meet a wide range of engineering application requirements. Glass-filled phenylene oxides provide up to double the mechanical strength, four times the modulus, and improved impact strength from −46 to 121°C.

PPO resins are easy to process by injection molding or extrusion. For optimum appearance, a preheating in a dehumidifying oven is recommended. The PPO resins are well suited for conventional assembly and finishing operations.

Applications for PPO resins include television and communication components such as terminal blocks and deflection yokes. Plumbing and automotive parts such as handles, vents, and brackets are a major end use. Housings, particularly those molded in the structural foam configurations, dominate the business machine and appliance market.

polyphenylene sulfide (PPS) Polyphenylene sulfide is a high-temperature, crystalline thermoplastic that has a symmetrical, rigid backbone chain consisting of recurring *para*-substituted benzene rings and sulfur atoms. It can be crosslinked by air aging at elevated temperatures. The commercial polymers are produced by the reaction of *p*-dichlorobenzene with sodium sulfide in a polar solvent. Its chemical structure is shown in Fig. P. 17.

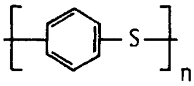


Figure P.17 General chemical structure of polyphenylene sulfide.

The polymers have a glass transition temperature of 150°C and a melting temperature of 285°C. They are stable in air for short exposures to around 350°C. Three basic types of polyphenylene sulfide are available. The first is a branched polymer with no crystalline melting point. The second resin is a linear polymer, which can be processed by compression molding including laminating with fiberglass. This resin oxidatively crosslinks at temperatures of greater than 173°C. It is typically used with high-filler loadings such as chopped glass. A moderate-molecular-weight grade can be injection molded at 340–370°C and then further crosslinked by air aging. The chemical structure is responsible for the high melting point, outstanding chemical resistance, thermal stability, and nonflammability of the polymer. There are no known solvents below 191–204°C. The polymer is characterized by high stiffness and good retention of mechanical properties at elevated temperature, which provide utility in coatings as well as in molding compounds.

Tensile strength and flexural modulus decrease with increasing temperature, leveling off at about 121°C, with good tensile strength and rigidity retained up to 260°C. With increasing temperature there is a marked increase in elongation and a corresponding increase in toughness. The long-term mechanical properties of PPS are unaffected by aging in air at 232°C. PPSs do not stress crack, but they are notch sensitive.

Polyphenylene sulfide resins are available in a variety of grades suitable for slurry coating, fluidized bed coating, flocking, electrostatic spraying, as well as injection and compression molding. A substantial increase in tensile strength and flexural strength is realized by the addition of fillers, especially glass.

Molded PPS items have applications in which chemical resistance and high-temperature properties are of prime importance. PPS has found significant use in high-release coating applications such as cookware and metal tire mold surfaces. Nonstick formulations can be prepared when a combination of hardness, chemical inertness, and release behavior is required. The largest end use is in electric/electronic components including interconnection devices, coil forms, bobbins, yokes, and terminal boards.

Polyphenylene sulfide resins are available in compression molding, extrusion, and injection molding grades. Major suppliers of these resins include International Polymer, Phillips Chemical (*Ryton*), Ticona (*Fortron*), Albis (*Tedur*), ComAlloy, Compound Technologies, DIC Trading (*Compodic*), DSM Engineering (*Fiberfil*), GE Plastics (*Supec*), International Polymer, LNP, and RTP.

polyphenyl sulfone (PPSU) Polyphenyl sulfone is a relatively new member of the *polysulfone* family. It is a high-temperature *engineering thermoplastic*. It has a glass transition temperature of 288°C and a heat-deflection temperature of 274°C. The continuous-use temperature has been suggested to be 260°C. In these high-temperature properties polyphenyl sulfone is superior to other polysulfones such as standard polysulfone, polyether sulfone, or polyaryl sulfone.

However, the difficulty in processing such a high-temperature resin has inhibited its widespread application and commercialization. PPSU is available in extrusion and injection molding grades from Amoco (*Radel*).

polyphthalamide (PPA) Polyphthalamide (PPA) resins are semiaromatic polyamides based on the polymerization of terphthalic acid or isophthalic acid and an amine. Both amorphous and crystalline grades are available. Polyphthalamides have a melting point near 310°C and a glass transition temperature of 127°C.

Polyphthalamides have good strength and stiffness along with good chemical resistance. Polyphthalamides can be attacked by strong acids or oxidizing agents and are soluble in cresol and phenol. Polyphthalamides are stronger and less moisture sensitive and possess better thermal properties compared to the aliphatic polyamides such as nylon 6/6. However, polyphthalamide is less ductile than nylon 6/6, although impact grades are available. Polyphthalamides will absorb moisture, decreasing the glass transition temperature and causing dimensional change. The material can be reinforced with glass and has extremely good high-temperature performance. Reinforced grades of polyphthalamides are able to withstand continuous use at 180°C.

The crystalline grades are generally used in injection molding, whereas the amorphous grades are often used as barrier materials. The recommended mold temperatures are 135–165°C with higher temperatures recommended for some applications where surface finish is important. Recommended melt temperatures are 320–340°C. The material should have a moisture content of less than 0.15 percent before processing.

Polyphthalamides were originally developed for use as fibers and later found application in other areas. They are used in automotive applications, where their chemical resistance and temperature stability are important. Applications include sensor housing, fuel line components, headlamp reflectors, electrical components, and structural components. Electrical components attached by infrared and vapor phase soldering are applications utilizing PPA's high temperature stability. Switching devices, connectors, and motor brackets are often made from PPA. Mineral-filled grades are used in applications that require plating, such as decorative hardware and plumbing. Impact-modified grades of unreinforced PPA are used in sporting goods, oil field parts, and military applications.

Both crystalline and amorphous grades are available under the tradenames *Amodel* (Amoco), and amorphous grades are available under the names *Zytel* (DuPont) and *Trogamid* (Dynamit Nobel). Crystalline grades are also available under the trade name *Arlen* (Mitsui). Other suppliers of PPA are LNP and RTP.

polypropylene (PP) Polypropylenes are similar chemically to polyethylene but have somewhat better physical strength at a lower density. The density of polypropylene is among the lowest of all plastic materials, ranging from 0.900 to 0.915. Polypropylene's most outstanding features are its very low density and its rigidity.

Polypropylenes offer more of a balance of properties than a single unique property, with the exception of flex-fatigue resistance. These materials have an almost infinite life under flexing, and they are often said to be self-hinging. Use of this characteristic is widespread in plastic hinges. Polypropylenes surpass all others in combined electrical properties, heat resistance, rigidity, toughness, chemical resistance, dimensional stability, surface gloss, and melt flow, at a low cost.

Unfilled polypropylene generally is not recommended for use in load-bearing applications, because the plastic creeps rapidly even under moderate stresses. Glass-reinforced grades, however, can be used in high-load applications. Polypropylene also has good unnotched and excellent notched impact strength. Polypropylene's heat resistance is much superior to that of polyethylene.

Because of their exceptional quality and versatility, polypropylenes offer outstanding potential in the manufacture of products through injection molding. Mold shrinkage is significantly less than that of the other polyolefins; uniformity in and across the direction of flow is appreciably greater. Shrinkage is, therefore, more predictable, and there is less susceptibility to warpage in flat sections.

Polypropylene is the only high-volume thermoplastic that is processable by all major fabrication methods: molding, extrusion, film, and fiber. Many new polypropylenes with improved engineering properties have been developed. The most promising are glass-reinforced polypropylene, foamed polypropylene, heat-resistant-polypropylene, and oriented sheeting.

Being a general-purpose plastic, polypropylene has found applications in almost every field in which plastics are used. Polypropylene has found wide use in the textile industry, where it is successfully competing with rayon and other synthetic fibers as well as the natural fibers. This is particularly true in the carpet industry. The largest use of extruded polypropylene is in thin-film packaging.

Polypropylene compounds are available in many grades and through many suppliers. Several of the major suppliers of PP molding compounds are Exxon Polymers (*Escorene*), Solvay (*Fortliene*), Aristech, Montell N.A. (*Pro-fax*), Discas (*Reprean*), Huntsman (*Rexene*), Amoco, TCA Plastics (*Tonen*), General Polymers (*HiVal*), Du Pont (*Bynel*), and Phillips Sumika (*Marlex*).

poly-p-xylene

See parylene.

polysiloxane

See silicone rubber; silicone resin.

polystyrene (PS) Polystyrene (PS) is one of the first commodity plastics. It is noted as a low-cost, easily processed polymer. Polystyrene parts, even with reinforcement, have low-performance properties that do not qualify as an engineering plastic. Glass transition temperature is only around 100°C depending on the grade. However, polystyrene parts are used in many applications in which mechanical properties and chemical resistance are not critical.

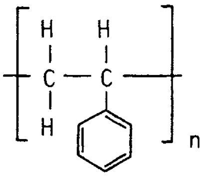


Figure P.18 General chemical structure of polystyrene.

Most commercial grades are amorphous, and the lack of crystalline regions provides transparency and no clearly defined melt temperature. Polystyrene can be polymerized via many mechanisms such as free radical, anionic, cationic, and Ziegler reactions. Commercially available polystyrene is generally produced via free radical-addition polymerization. The polymerized resin is a transparent solid having very low specific gravity (1.054–1.070)

Parts made from polystyrene have relatively high modulus and excellent electrical properties. Parts also have low shrinkage and high dimensional stability during molding and forming. Normal temperature capabilities are less than 93°C. Polystyrene has good resistance to water, inorganic chemicals, and alcohols, and poor resistance to many solvents. Major disadvantages with polystyrene parts are their brittleness (elongation is only 1–3%), solvent susceptibility, environmental stress cracking (often requiring annealing before finishing), and flammability. Other disadvantages include poor weathering and heat resistance. Polystyrene is also subject to creep.

Table P.8 Typical Properties of Polystyrene

Property	Polystyrene, General Purpose	Polystyrene, High Impact
Specific Gravity	1.04	1.04–1.07
Tensile Strength, psi	5,000–10,000	3,300–5,100
Elongation, %	1.0–2.3	30–50
Flexural Strength, psi	10,000–15,000	5,000
Continuous Use Temperature, °C	71–96	52–74
Dielectric Strength, volts/mil	>500	300–650

Typical properties of polystyrene parts are shown in Table P.8. Properties are very dependent on the type of filler, grade, and resin modification.

There are two primary types of polystyrene: general purpose and high impact. *General-purpose polystyrene* (*GPPS*) is characterized by transparency and brittleness. These resins can be easily colored and processed. They have relatively low cost. *High-impact polystyrene* (HIPS) is produced by physically blending styrene and various elastomers such as butadiene. Various grades of HIPS are available. HIPS are used for home electronic cases, toys, video- and audiocassettes, and food packaging.

Polystyrene is also graded according to its processing characteristics. *Easy-flow grades* have the lowest molecular weight and contain 3–4 percent mineral oil. They are used in disposable dinnerware, toys, and packaging. Easy-flow polystyrene is especially useful for thin-wall injection molding. *Medium-flow polystyrene* is used for injection-molded parts, medical ware, toys, blow-molded bottles, and extruded food packaging. A *high-heat-resistant grade* has the greatest molecular weight and the lowest level of additives. It is used for applications requiring sheet extrusion, thermoforming, and extruded film for oriented packaging.

Expanded polystyrene foam is used for thermal insulation and as a packaging material. It is often used for food trays. Polystyrene can also be crosslinked. Crosslinked polystyrene parts are often used in low-loss electrical and electronic applications requiring moderate resistance to temperature.

Polystyrene can be processed by almost all of the conventional thermoplastic processes. Common processes include sheet and profile extrusion, thermoforming, injection and extrusion blow molding, heavy- and thin-wall injection molding, rotational molding, direct-injection foam sheet extrusion, and biaxially oriented molding. Polystyrene parts can be finished by most methods including printing, painting, vacuum metallizing, and hot stamping. Parts can be joined by various methods of adhesive bonding and solvent or thermal welding.

The styrene family is well suited for applications where rigid, dimensionally stable molded parts are required. When the mechanical properties of the polystyrene homopolymer are modified to produce a tougher, more ductile blend, as in the case of rubber-modified high-impact grades of polystyrene (HIPS), a far wider range of applications becomes available. Copolymerization is also used to produce engineering-grade plastics of higher performance as well as higher price, with acrylonitrile butadiene styrene (ABS) and styrene acrylonitrile (SAN) being of the greatest industrial importance.

Polystyrene molding compounds come in blow molding, extrusion, and injection molding grades. The major suppliers of these compounds include Dow Chemical (*Styron*), BASF, Nova Chemicals (*Novacor, Dylene*), Chevron, American Polymers, Dart Polymers, ComAlloy, Ferro, LNP, RTP and Tshiba (*Emiclear*).

See also acrylonitrile butadiene styrene; styrenic resins; styrene acrylonitrile.

polysulfide rubber (PTR) Polysulfide elastomers are prepared by the addition of a suitable organic dihalide to a heated and stirred aqueous solution of sodium polysulfide. There are two types of polysulfide rubbers. The first is the linear polymer, which is prepared as a copolymer of ethylene dichloride with dichloroethyl formal. The second is a branched polysulfide, which is a polymer of dichloroethyl formal.

Both elastomers can be processed on conventional rubber equipment. Unlike natural rubber, the polysulfide elastomers do not undergo breakdown to a workable plasticity on the mixing mill. Vulcanization is possible by a wide variety of oxidizing agents including zinc peroxide.

Polysulfide rubber is especially resistant to hydrocarbon solvents, aliphatic liquids, or blends of aliphatic with aromatic. The common alcohols, ketones, and esters used in paints, varnishes, and inks have little effect on it. It is also resistant to some chlorinated solvents, but preliminary tests should be made before it is used for this purpose.

Nitrile base rubbers will swell considerably in such solvents, and polysulfide has found a special use in applications using such solvents. However, compared with nitrile, it has poor tensile strength, pungent odor, poor rebound, high creep under strain, and poor abrasion resistance.

Polysulfide has found many of its applications in solvent-carrying hose, printer's rolls, and newspaper blankets, and because of its excellent weathering properties, it is used heavily for caulking purposes. It is also used for impregnation of leather to impart water and solvent resistance and as protective coatings for metals. It is used as a binder in gaskets, sealing of aircraft gasoline tanks, deck caulking, patching hose, and adhesives. In the electrical industry, flexible cable connections are sealed with polysulfide compounds.

Morton Thiokol, Inc. markets a series of liquid polysulfides that can be oxidized to rubbers. These rubbers have excellent resistance to most solvents, good water and ozone resistance, very low specific permeability to many highly volatile solvents and gases, objectionable odor, poor physical properties, and a service temperature range of −55 to 150°C.

Polysulfides have been used extensively as a flexibilizing coreactant with epoxy resins. The effect of the concentration of the polysulfide on the heat distortion is to lower it with increasing polysulfide concentration. A series of epoxy-terminated polysulfide polymers is available that has all the attributes of the polysulfide polymer without the mercaptan (sulfur) odor. It is used at 25–50 phr resin of epoxy to yield a material that retains lap shear strength during water immersion better than toughened epoxies.

polysulfone (PSU) The polysulfone polymers are those with SO_2 groups in the backbone of the polymer. At present there are four basic polysulfone types: standard, polyaryl, polyether, and polyphenyl. (*See also* polyaryl sulfone; polyether sulfone; polyphenyl sulfone.)

Standard polysulfone is produced by the reaction between the sodium salt of 2,2-bis (4-hydroxyphenol) propane and 4,4′-dichlorodiphenyl sulfone. The chemical structure is shown in Fig. P. 19.

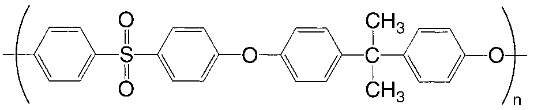


Figure P.19 General chemical structure of polysulfone.

Polysulfone is self extinguishing and has a high heat-distortion temperature. Its glass transition temperature is 185°C. Polysulfones have impact resistance and ductility below 0°C. Polysulfone also has good electrical properties. Both the electrical and mechanical properties are maintained to temperatures near 175°C. Polysulfones also have good hydrolytic stability.

Characteristics of special significance to the design engineer are the heat-deflection temperature of 174°C at 264 psi and the long-term-use temperature of 149–171°C. The excellent thermal resistance of polysulfones, together with outstanding oxidation resistance, provides a high degree of melt stability for molding and extrusion. Some flexibility in the polymer chain is derived from the ether linkage, thus providing inherent toughness.

Polysulfone has a second, low-temperature glass transition at −101°C similar to other tough, rigid thermoplastic polymers. These polymers also resist aqueous acid and alkaline environments. Properties such as physical aging and solvent crazing can be improved by annealing the parts. This also reduces molded-in stresses.

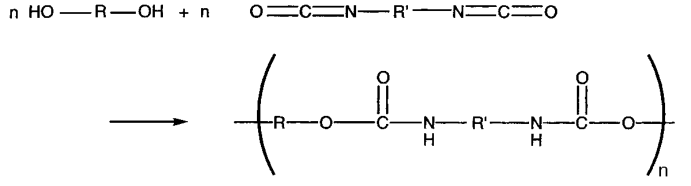
Polysulfone can be molded, extruded or thermoformed into a variety of shapes. Injection molding barrel temperatures should be in the range of 310–400°C, with mold temperatures of 100–170°C. In blow molding the screw type should have a low compression ratio, 2.0:1 to 2.5:1. Mold temperatures of 70–95°C with blow air pressure of 0.3–0.5 MPa are generally used. Polysulfone can be extruded into films, pipe, or wire coatings. High-compression-ratio screws should not be used for extrusion. Polysulfone shows high melt strength, allowing for good draw-down and the manufacture of thin films. Sheets of polysulfone can be thermoformed with surface temperatures of 230–260°C. Polysulfone may be bonded by heat sealing, adhesive bonding, solvent fusion, or ultrasonic welding.

Polysulfone is used in applications requiring good high-temperature resistance such as coffee carafes, piping, sterilizing equipment, and microwave oven cookware. Polysulfone is also used in electrical applications for connectors, switches, and circuit boards and in reverse osmosis applications as a membrane support.

Polysulfone is available in both glass- and mineral-filled grades. They are formulated for blow molding, extrusion, and injection molding. Major suppliers of polysulfone include BASF (*Ultrason*), Amoco (*Udel*), ComAlloy, DSM Engineering, Compound Technologies, LNP, and RTP. Armco has a polysulfone alloy available under the tradename *Mindel.*

polyterpene resin Polyterpene resins are thermoplastic resins obtained by the polymerization of turpentine in the presence of catalysts. These resins are used in the manufacture of adhesives, coatings, and varnishes and in food packaging. They are compatible with waxes, natural and synthetic rubbers, and polyethylene.

polyurethane (PUR) The term polyurethane (PUR) is used to cover materials formed from the reaction of isocyanates and polyols. The product that is formed from the reaction of a diisocyanate with a diol is shown in Fig. P. 20. Polyurethanes are very versatile polymers. They are used in elastomers, molding resins, foams, and coatings. Their hardness spans the range from rigid material to elastomeric. Polyurethanes are available as both thermosets and thermoplastics.



$$n\,HO-R-OH + n\,O{=}C{=}N-R'-N{=}C{=}O \longrightarrow \left(-R-O-\overset{O}{\overset{\|}{C}}-\underset{H}{N}-R'-\underset{H}{N}-\overset{O}{\overset{\|}{C}}-O-\right)_n$$

Figure P.20 Polyurethane reaction.

$$[-A-B-A-B-A-B-]_n$$

Figure P.21 General block structure of polyurethane.

Urethanes crosslink as well as undergo chain extension to produce a wide variety of compounds. They are available as castable liquids and solids or gums to be used on conventional rubber processing equipment. They are also available as thermoplastic resins, which can be processed similar to polyvinyl chloride.

Polyurethanes are phase-separated block copolymers in which one polymer segment is hard and rigid and the other is soft and elastomeric. (See Fig. P.21) The hard segments hold the material together at room temperature, but at processing temperatures the hard segments can flow and be processed. The heat resistance of the polyurethane is governed by the hard segments.

The properties of polyurethanes can be varied by changing the type or amount of the three basic building blocks of polyurethane chemistry: diisocyanate, short-chain diol, and long-chain diol. Polyurethanes are generally classified by the type of polyol used, for example, polyester polyurethane or polyether polyurethane.

Polyether polyurethanes are more resistant to hydrolysis than polyester-based urethanes, whereas the polyester polyurethanes have better fuel and oil resistance. Polyether polyurethanes generally have lower glass transition temperatures than polyester polyurethanes.

Polyurethanes in general are noted for their abrasion resistance, toughness, low-temperature impact strength, cut resistance, weather resistance, and fungus resistance. Specialty polyurethanes include glass-reinforced products, fire-retardant grades, and UV-stabilized grades.

They cure to tough elastic solid rubbers with outstanding resilience, abrasion resistance, and tensile strength. The outstanding properties are exceptionally high wear resistance and two to three times the tensile strength of natural rubber. Urethanes also exhibit very good resistance to oils, solvents, oxidation, and ozone. They have poor resistance to hot water and are not recommended for temperatures above 79°C. They are also quite stiff at lower temperatures. Polyurethanes are useful where load-bearing and wear properties are desirable and can be used on insulation as a protective coating.

Thermoplastic polyurethanes can be processed by a variety of methods including extrusion, blow molding, and injection molding. They tend to pick up moisture and must be thoroughly dried before use. The processing conditions vary with the type of polyurethane. Higher hardness grades usually require higher processing temperatures. Polyurethane tends to exhibit shear sensitivity at lower melt temperatures. Postmold heating in an oven shortly after processing can often improve the properties of the finished product. A cure cycle of 16–24 hr at 100°C is typical.

Thermoplastic polyurethane molding compounds are relatively nonelastic. They are available in blow molding, extrusion, and injection molding grades. Major suppliers of thermoplastic polyurethane include Dow Chemical (*Isoplast*) and LNP.

Thermosetting polyurethane resins may be formed in many ways. A popular high-volume production process is reaction injection molding (RIM). RIM polyurethane molding compounds are available from Bayer (*Baydur*), Dow Chemical (*Spectrim*), ICI Polyurethanes (*RIMLine*), Recticel, and Renosol.

Polyurethanes find applications in many areas. Applications include rollers or wheels, exterior body parts, drive belts, and hydraulic seals. Polyurethanes can be used in film applications such as textile laminates for clothing and protective coating for hospital beds. They are also used in tubing and hose in both reinforced and unreinforced forms. Their abrasion resistance allows them to be used in applications such as athletic shoe soles and ski boots. Polyurethanes are also used as coatings for wire and cable. They can also be used as impact modifiers for other plastics.

polyurethane catalyst Although thermosetting polyurethanes can be formed without the aid of catalysts, the reaction rate increases rapidly when a suitable catalyst is selected. A well-chosen catalyst also secures the attainment of the desired molecular weight and strength and, in the case of foams, the proper cellular structure. In some applications, catalysts are used to lower the temperature of the polymerization reaction.

The major applications for polyurethane catalysts are in flexible and rigid foam, which account for over 80 percent of the catalyst consumption. Other applications are in microcellular reaction injection molded (RIM) urethanes for automobile bumpers and a variety of noncellular end uses such as solid elastomer, coating, and adhesive.

There are more than 30 different polyurethane catalyst compounds. The two most frequently used catalyst types are tertiary amines and organometallic salts, which account for about equal shares of the market.

The tertiary amine-catalyzed reactions cause branching and cross-linking and are primarily used for polyurethane foam formation. They are used to accelerate the isocyanate-hydroxyl reaction and give off carbon dioxide. Triethylenediamine is the most prevalent of the tertiary amine catalysts used for polyurethane manufacture.

Organometallic salts, such as organotin catalyst, encourage linear chain extension and are used in flexible slabstock, rigid foam, and a variety of noncellular elastomer and coating applications. Stannous octoate is the most broadly accepted catalyst of this type for polyurethane formulation, although other organotins and potassium salts are also used.

Different catalyst types can also be combined to obtain a desired effect. For example, polyurethane foam production can use both organotin and amine catalysts for a balance of chain extension and cross-linking.

Air Products, BASF, Witco, Huntsman, and Goldschmidt are major suppliers of polyurethane catalysts.

polyurethane foam catalyst Catalysts used in urethane foam formulations are critical to production of uniform, efficient cellular structures. Their role is to control various reactions that take place during production (cream, rise, gel) to attain the balance needed to produce commercially acceptable foams.

There are two major families of catalysts for urethane foams: tertiary amines (primary amine react too rapidly with isocyanates to be suitable) and tin catalysts. Both act quite differently during foaming and influence different reactions. They are more likely to be used in combination to achieve the exact balance of reactions needed for a given application and/or the processing method chosen for the job. (*See also* polyurethane catalysts.)

Producers of urethane foam catalysis include Air Products & Chemicals Inc., Ashland Chemical Inc., Dow Chemical, Conap Inc., Ferro Corp., Mobay Corp., Olin Chemicals, and Witco Corp.

polyvinyl acetal Polyvinyl acetals are thermoplastics produced by the reaction of aldehydes with polyvinyl alcohol (PVA). These resins are amorphous, with rigidity and softening point dependent on the nature of the aldehyde. The hydroxyl content of commercial grades is low. The molecular weight has little effect on mechanical properties but does influence the flow temperature. The resins can be plasticized with normal effect on properties. Resins prepared in this way include *polyvinyl formal* and *polyvinyl butyral*. These resins are not used commercially as molding compounds but have found use in coatings, adhesives, and modifiers in other resins.

Polyvinyl formal is made by the condensation of formaldehyde in the presence of polyvinyl alcohol. Polyvinyl butyral is a thermoplastic material derived from a polyvinyl ester in which some or all of the acid groups, have been replaced by hydroxyl groups, and some or all of these hydroxyl groups are replaced by butyral groups by reaction with butyraldehyde. It is a colorless, flexible, tough solid.

The largest commercial use for polyvinyl formal is as wire enamel, usually in conjunction with cresylic phenolic resin. Similar resins are used also with phenolics as structural adhesives. They are very resistant to greases and oils. Some grades have been used as can coatings and wash primers. Although they can be molded, extruded, or cast, these grades have achieved little commercial significance.

The largest use of polyvinyl butyral is the interlayer in safety glass. It is used in this application because of its high adhesion to glass, toughness, light stability, clarity, and insensitivity to moisture. Polyvinyl butyral is also used in textiles and metal coatings and in adhesive formulations.

polyvinyl acetate (PVAc) Polyvinyl acetate (PVAc) is a member of the vinyl resin family that is a colorless, solid thermoplastic. It is prepared by all basic polymerization methods from the vinyl acetate monomer. It can be obtained in the form of granules, solutions, lattices, and pastes. Emulsion polymerization is primarily used because much of the polymer is used directly in its latex form.

Polyvinyl acetate is not used extensively as a moldable plastic because of its appreciable cold flow. However, the polymer has a high degree of adhesion to a wide variety of substrates, so it is mainly used as a water-based adhesive, coating base, and textile finish. It is also used for the production of polyvinyl alcohol and polyvinyl acetals.

Both homopolymers and copolymers are made. Homopolymers stick well to porous or cellulosic surfaces such as wood, paper, cloth, leather, and ceramics. Homopolymer films tend to creep less than the copolymer films. They are especially suitable in adhesives for high-speed packaging operations.

Copolymers wet and adhere well to nonporous surfaces such as plastics and metals. They form soft, flexible films, in contrast to the tough, horny films formed by homopolymers. Copolymers have greater resistance to water. As the ratio of the comonomer to vinyl acetate increases, the variety of plastics to which the copolymer will adhere also increases.

The largest use of PVAc is as a dry resin for paint. Lattices are low cost and light in color and have good stability, grease and oil resistance, good adhesion to a variety of substrates, and relatively high permeability to moisture vapor. In the textile industry, PVAc is used as a cotton sizing and binder for nonwoven fabrics. PVAc is also used in binders for pigmented paper coatings, clay, wood flour, and cellulose pulp as well as an extender for chewing gum and natural rubbers. It is also used extensively as a base for inks and lacquers.

polyvinyl alcohol (PVA) Polyvinyl alcohol (PVA) is prepared by alcoholysis of PVAc. It is a colorless, solid thermoplastic that is insoluble in most organic solvents and oils but soluble in water when the content of the hydroxyl groups in the polymer is sufficiently high. It can also be prepared from other vinyl esters and ethers.

The product is normally granular. Commercial PVA is available in various grades, which differ in molecular weight and residual acetate content. PVA is atactic and exhibits the same type of crystal lattice as polyethylene, thus allowing the polymer to have a high degree of crystallinity.

One of the most significant effects of the hydroxyl groups on PVA is that the polymer is hydrophilic and will dissolve in water. The most outstanding characteristics of PVA are resistance to hydrocarbons and animal and vegetable oils, extremely low permeability to organic liquids and gases, abrasion resistance, toughness, and resistance to UV. These properties greatly depend on humidity. Because water acts as a plasticizer, tensile strength will decrease with a corresponding increase in elongation and impact strength as water is absorbed in the polymer.

Polyvinyl alcohol is mainly used for adhesives and coatings. However, plasticized PVA can be compression molded or extruded. Tubing is used for lubrication equipment, paint lacquers, dry cleaning solvents, fire extinguisher fluids, and refrigerants. PVA fibers are formed by extrusion of aqueous gels, where water acts as the plasticizer. The fiber retains strength and integrity at temperatures over 100°C. PVA film is transparent, strong, and tear resistant. It is used in bags and protective laboratory clothing. The film can be extruded or produced from solution. PVA can into packaging materials that can be dissolved, thus dispensing its contents in premeasured portions. Typical uses include laundry detergents, paint fungicides, and medications.

polyvinyl carbazole Polyvinyl carbazole is a thermoplastic resin that is brown in color. It is obtained by reacting acetylene with carbazole. The resin has excellent electrical properties and good heat and chemical resistance. It is used primarily as an impregnant for paper capacitors.

polyvinyl chloride (PVC) Polyvinyl chloride (PVC) is one of the most widely used plastics in the vinyl family. PVC is prepared by the polymerization of vinyl chloride in a free radical-addition polymerization reaction. The polymer can be made by suspension, emulsion, solution, or bulk polymerization methods. The polymer is essentially linear, but a low number of short chain branches may exist. The structure of the PVC repeating unit is represented as $-(CH_2CHCl)_n-$.

The glass transition temperature of PVC varies with the polymerization method but falls within the range of 60 to 80°C. PVC is self-extinguishing and, therefore, has applications in the field of flame resistant wire and cable. PVC's good flame resistance results from removal of HCl from the chain, releasing HCl gas. Air is restricted from reaching the flame because HCl gas is denser than air. PVC also has excellent resistance to acids, bases, alcohol, oils, and many other hydrocarbons. It thus finds applications in parts for the chemical processing industries.

Because PVC is thermally sensitive, the thermal history of the polymer must be carefully controlled to avoid decomposition. Thus thermal stabilizers are often added at additional cost to the PVC. UV stabilizers are also added to protect the material from ultraviolet light, which may also cause the loss of HCl.

There are two basic forms of PVC: rigid and plasticized. Rigid PVC is an unmodified polymer and exhibits high rigidity. It is stronger and stiffer than polyethylene (PE) and polypropylene (PP). Plasticized PVC is modified by the addition of low-molecular-weight plasticizers to flexibilize the polymer. Plasticized PVC can be formulated to give products a rubbery behavior. The addition of plasticizers lowers the glass transition temperature of PVC, making it more flexible.

PVC resins are generally heavily compounded with additives to improve properties. A wide variety of applications for PVC exist because one can tailor the properties by the selection of additives. These additives include stabilizers, fillers, lubricants, pigments, and plasticizers. Fillers are often added to reduce cost. They include talc, calcium carbonate, and clay.

PVC raw materials are available as resins, lattices, organosols, plastisols, and molding compounds. Fabrication methods include injection, compression, blow or slush molding, extruding, calendering, coating, laminating, rotational and solution casting, and vacuum forming. Rigid PVC can be processed using most conventional processing equipment. Because HCl is given off in small amounts during processing, corrosion of metal parts is a concern. PVC joints can be solvent- or heat-welded. Plasticized PVC can be processed by methods such as extrusion and calendering into a variety of products.

Rigid PVC is used in products including house siding, extruded pipe, and thermoformed and injection-molded parts. Rigid PVC is calendered into credit cards. Plasticized PVC is used in applications such as flexible tubing, floor mats, garden hose, shrink wrap, and bottles.

There are many suppliers of both rigid and flexible PVC molding compounds. Common grades are for blow molding, extrusion, and injection molding. Major suppliers of this material include AlphaGary, Bayshore, Colorite (*Unichem*), Condea Vista, El Paso PVC, Geon (*Fiberloc*), Rimtec (*Kohinor*), Synergistics, and Technor Apex (*Firegard*).

Chlorinated PVC (*CPVC*) is prepared by passing chlorine through a solution of PVC. Commercial materials have chlorine contents of 66–67 percent. The materials have a higher softening point and higher viscosity than PVC, and they are known for good chemical resistance. Compared to PVC, chlorinated PVC has a higher modulus and tensile strength. Chlorinated PVC has a service temperature 4–16°C higher than standard PVC while maintaining good chemical, self-extinguishing, and electrical characteristics. These materials, however, have poor color and light stability, are brittle under shock, and have a comparatively low softening point. Compounding processes are similar to those for PVC.

Chlorinated PVC can be extruded, calendered, or injection molded. CPVC is used for water distribution piping, industrial chemical liquid piping, outdoor skylight frames, automotive interior parts, and a variety of other applications. Major suppliers of CPVC molding compounds are Georgia Gulf (*Protherm*) and B.F. Goodrich (*TempRite*).

Vinyl chloride copolymers are made from the copolmerization of PVC with vinyl acetate, called polyvinyl chloride acetate, and other polymers. This provides a polymer with a lower softening point and better stability than pure PVC. The composition can vary from 5 to 40 percent vinyl acetate. Copolymers with about 10 percent vinylidene chloride and copolymers with 10–20 percent diethyl fumarate or diethyl maleate are also available.

This *polyvinyl chloride acetate* copolymer is a colorless solid with good resistance to water as well as concentrated acids and alkalis. It can be obtained as granules, solutions, and emulsions. Compounded with plasticizers, it yields a flexible material superior to rubber in aging properties. This material has application in areas where PVC is too rigid and the use of plasticized PVC is not acceptable. Flooring is one application. It is also used in cable and wire covering, in chemical plants, and in protective garments.

PVC blended alloys that are commercially available include PVC-acrylic, PVC-EVA, PVC-nitrile rubber, and PVC-polyurethane.

PVC plastisols and *organosols* are made by adding a sufficient quantity of solvent to PVC. The resin then becomes suspended in the solvent, giving a fluid that can be used in coating applicants. PVC in this form can be processed by methods such as spread coating, rotational casting, dipping, and spraying. The parts are then dried with heat to remove any solvent and fuse the polymer. Parts such as handles for tools and vinyl gloves are produced by this method.

See also vinyl resin; plastisol; organosol; plastigel.

polyvinylidene chloride (PVDC) Polyvinylidene chloride (PVDC) is similar to PVC except that two chlorine atoms are present on one of the carbon groups. Like PVC, PVDC is polymerized by addition polymerization methods. Both emulsion and suspension polymerization methods are used. The repeat unit for PVDC is $—(CH_2CCl_2)_n—$.

The emulsion polymers are either used directly as a latex or dried for use in coatings or melt processing. Polyvinylidene chloride itself is a weak, transparent, pliable thermoplastic; however, the polymer crystallizes with aging and becomes stronger and more opaque.

PVDC has excellent barrier properties and is frequently used in food packaging applications. Films made for PVDC have good cling properties, which is an advantage for food wraps. The tradenames *Saran* and *Saran wrap* (Dow Chemical Co.) represent a series of vinylidene chloride copolymers with vinyl chloride or acrylonitrile. Saran films are commonly used in commercial and household food packaging applications.

Saran has general resistance to organic solvents, inertness at room temperature to common acids and alkalis, complete water resistance, negligible water vapor transmission, nonburning characteristics, toughness, and durability. The copolymers are attacked by halogens and strong organic amines. Saran plastics have good stability to aging and ultraviolet (UV) attack. The copolymer can be extruded and injection molded. It can be compression molded, although the resulting lack of orientation causes a loss in toughness. By stretching under controlled conditions at room temperature, orientation as well as recrystallization occur and much stronger products are formed.

Saran film has become a popular packaging material because of its high degree of transparency, moisture proofing, and vapor barrier properties. The typical method of making this film is through biaxially oriented blown film extrusion. Saran tubing and monofilament have also been developed. The Saran copolymer with acrylonitrile is used for coating purposes because of its solubility in ketones.

Commercial polyvinylidene chloride polymers are all copolymers of vinylidene chloride with vinyl chloride, acrylates, or nitrides. Copolymerization of vinylidene chloride with other monomers reduces the melting point to allow for easier processing.

See also Saran.

porous mold Porous molds are molds that are made up of bonded or fused aggregate such as powdered metal and coarse pellets. The resulting mass contains numerous open interstices of regular or irregular size. This formulation allows either gases or liquids to pass through the mass of the mold.

positive mold A positive mold is one that is designed to trap all of the molding material when the mold closes. It operates like a piston in a cylinder — the cavity being the cylinder and the plunger being the piston. It is used chiefly for cloth-filled materials and for parts having a long draw, such as cabinets. In using a positive mold, the compound must be weighed carefully because there is little means of escape for any excess compound.

The positive mold should not be used generally for simple designs or for parts made from free-flowing material because other types of molds are better adapted for these jobs. An important disadvantage in the use of the positive mold results from the plunger rubbing the side of the cavity wall. This scores the cavity wall and may mar the molded piece as it is ejected.

postcure Thermoset plastics harden by crosslinking under heat and pressure, but at the time of ejection from molding machines or other curing devices, parts may not be fully crosslinked and to some extent are "rubbery" at that stage of cure. Crosslinking, or polymerization, of thermosetting plastics is generally only about 90 percent complete at the time immediately following original molding. Thus irreversible reactions could continue for possibly hours and sometimes for days or months after molding with certain formulations. Mechanical properties of such materials are also not optimized, and shrinkage can occur as the material continues to cure.

A postcure or additional curing step, usually done out of the mold simply by placing the part in an air-circulating oven, will complete the cure. The part will then have achieved optimal properties, and further reaction will not be probable. Thermoset compounders generally can recommend postcuring cycles where appropriate.

Often it is a good process to postcure parts at least to the maximum temperature that they will be exposed to in service. This will ensure that any by-products from the polymerization process will be released during the postcure and not during service. It also ensures that the part can endure the thermal stresses expected in service.

postforming Postforming is the final shaping of a cured or partially cured thermosetting plastic product, usually with the use of heat and pressure. Generally, postforming is an operation used with thermoset laminates that are heated and shaped over a hot mold. On cooling, the formed product retains the contours and shape of the mold over which it has been formed.

pot life The pot life, or *working life*, is the time during which a liquid resin remains workable as a liquid after catalyst, curing agents, promoters, and the like are added and mixed. Pot life is generally measured at room temperature on a sufficient quantity of resin to be used in a particular process. It is roughly equivalent to the gel time. However, *gel time* is more accurately measured with generally smaller mass and controlled variables. Gel time is often used as a quality control parameter.

With many exothermic resin systems (e.g., epoxy) the pot life is a function of the mass of resin that is mixed. The larger the mass, the higher the heat produced by the exothermic reaction and the shorter the pot life.

potting Potting is a term used to indicate the process of casting a resin into or around an article in a mold. It is similar to encapsulating except that steps are taken to ensure complete penetration of all voids in the object before the resin polymerizes.

The processing of liquid potting compounds commences with dispersing curing agents and other ingredients with a simple propeller mixer. Potting compounds are capable of a variety of properties that are achieved by changes in formulation to gain stiffness, color, strength, and electrical properties meeting specific needs and applications. The liquid potting compound is poured into a receptacle or jacket, where the compound cures in place. This is done either with added heat or at ambient temperature. The receptacle or jacket generally remains as the permanent outer skin of the final product. Proper compounding can produce articles with negligible shrinkage and optical clarity along with a minimum of internal stress. Part and mold design, coupled with the proper placement of the reinforcement, are calculated beforehand.

Potting of high-reliability products is often done under vacuum to ensure void free products and may be followed with positive pressure in the casting chamber to speed the final penetration of the potting resin into the interstices of the component being embedded.

See also potting resin; casting resin.

potting resin Potting resins are liquid plastics that are used to embed an object. (*See* potting.) Commonly used potting resins are epoxies, polyesters, silicones, and acrylics. The potting process consists of adding and mixing desired additives (such as fillers, colorants, curing agents and hardeners) to the base resin, pouring the formulated resin mix into a container that remains a case for the assembly, and curing the entire assembly into a hardened, polymerized form.

These potting resins are commonly used to encase and ruggedize electronic assemblies.

See also electronic plastic; casting resin.

powder coating Powder coating is a method for applying finely divided, dry solid resinous coatings by dipping products in a fluidized bed or by spraying them electrostatically on the part. The fluidized bed is essentially a modified dip tank. When charged powder particles are applied during the electrostatic spraying method, they adhere to grounded parts until fused and cured. In all cases the powder coating must be heated to its melt temperature where a phase change occurs, causing it to adhere to the product and fuse to form a continuous coating.

Both thermosetting and thermoplastic powders can be applied by powder coating processes. (See Table P.9.) Elaborate reclaiming systems to collect and reuse oversprayed material in electrostatic spray powder systems boost transfer efficiency. Since the enhancement of the air quality standards this method has grown markedly.

The primary advantage of powder coating is that many of the resin types can be applied in low film thicknesses with no VOC emission at extremely high transfer efficiency. Thus there are no solvents to contend with during formulation or processing. Disadvantages include the difficulty in obtaining less than 1-mil-thick continuous coatings and the fact that, owing to the complex powder reclaiming systems, color changes are more difficult than with liquid spray systems.

The *fluidized bed* powder coating process is used to apply heavy coats, 3–10 mil, in one pass, uniformly to complex-shaped products. The film thickness is dependent on the powder chemistry, preheat temperature, and dwell time. It is possible to build film thickness of 100 mil with higher preheat temperatures and multiple dips. Advantages of the fluidized bed powder coating are uniform and reproducible film thicknesses on all complex-shaped product surfaces. Another advantage is heavy coating in one dip. A disadvantage of this method is the minimum of 3 mil film thickness required to form a continuous coating.

An electrostatic fluidized bed container is essentially a fluidized bed having a high-voltage DC grid installed above a porous plate to charge the finely divided particles. Once charged, the particles are repelled by the grid and repel each other, forming a cloud of powder above the grid. These electrostatically charged particles are attracted to and coat products that are at ground potential. Film thicknesses of 1.5–5 mil are possible on cold parts, and thicknesses of 20–25 mil are possible on heated parts. The advantage of the electrostatic fluidized bed is that small products such as electrical components can be coated uniformly and quickly. The disadvantages are that the product sizes are limited and inside corners have low film thicknesses owing to the well-known Faraday cage effect.

Electrostatic spray powder coating is a method for applying finely divided electrostatically charged plastic particles to products that are at ground potential. A powder air mixture from a small fluidized bed in the powder reservoir is supplied by a hose to the spray gun, which has a charged electrode in the nozzle, fed by a high-voltage DC power pack.

Table P.9 Plastics Used in Powder Coatings (Ref: Izzo, C.P., “Decorative and Protective Coatings”, *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

	Fluidizing Conditions					
		Cure or Fusion		Fluidized-bed Powder		
Resin	Preheat Temperature, °F	Temperature, °F	Time, min	Maximum Operating Temperature, °F	Adhesion	Weather Resistance
Epoxy	250–450	250–450	1–60	200–400	Excellent	Good
Vinyl	450–550	400–600	1–3	225	Poor	Good
Cellulose acetate butyrate	500–600	400–550	1–3	225	Poor	Good
Nylon	550–800	650–700	1	300	Poor	Fair
Polyethylene	500–600	400–600	1–5	225	Fair	Good
Polypropylene	500–700	400–600	1–3	260	Poor	Good
Penton	500–650	450–600	1–10	350	Poor	Good
Teflon	800–1000	800–900	1–3	500	Poor	Good

powder molding Powder molding is a general term used to denote several techniques for producing objects of varying sizes and shapes by melting or sintering polymeric powder, usually against the inside of a mold. The molds are either stationary, as in the case of *slush molding*, or rotating, as in the case of *rotational molding*.

power factor The power factor is the cosine of the angle between the voltage applied and the resulting current. It is a measure of the electrical loss in an insulating material under electrical stress.

See also dielectric properties.

precure Precure is the undesirable condition of a thermosetting molding compound in which the thermal hardening of the material has proceeded to a stage at which it will not adequately soften and flow under pressure. Precure usually arises as a result of undue delay in the application of pressure after the material has been loaded into the hot mold.

preform A preform is a compressed molding compound that fits easily in the mold. It simplifies preheating and allows quicker closing of the press, which minimizes the possibility of early hardening. A preform is a compressed tablet or biscuit of plastic composition used for efficiency in handling and accuracy in weighing materials. Preform also refers to the process of molding polymeric powder into pellets or tablets. Preforming is especially effective when feeding multicavity molds.

Another type of preform involves the bulk formation of chopped glass fiber against a screen that is shaped to the contour of the mold. Pressure against the screen can be applied by air or by water. Continuous glass fibers are also preshaped for mat molding. A *preform binder* is a resin applied to the chopped strands of a preform, usually during its formation, and cured so that the preform will retain its shape and can be handled.

preheating Preheating or predrying is the process of heating a compound before molding or casting to facilitate the operation or to reduce the molding cycle. Preheating is often used to dry the molding material so that moisture does not adversely affect the molding process or the finished part.

Preheating provides more uniform melt temperature, reduces the possibility of localized overheating or hot spots in the cylinder, and frequently permits faster molding cycles. Preheating is especially advantageous in those cases where the molded shot weight exceeds 70 percent of the rated machine capacity.

Preheating can be done in ovens, tray dryers, and hopper dryers. Hopper dryers offer the advantages of reduced handling and less possibility of contamination and keep the material hot in the machine hopper. The use of dehumidified air is preferable, particularly when high-humidity conditions exist.

preheat roll In extrusion coating, a preheat roll is a heated roll installed between the pressure roll and unwind roll whose purpose is to heat the substrate before it is coated.

preimpregnation Preimpregnation is the process of mixing resin and reinforcement before shipping it to the molder. Preimpregnation can apply to liquid or viscous molding compounds as well as to reinforced prepreg for composite construction.

premix A premix is the molding compound that is prepared before and apart from the molding operation, although usually on-site. The premix contains all components required for molding: resin, reinforcement filler, catalyst, release agents, and other compounds. It is most commonly associated with polyester A-stage mixes.

prepolymer A prepolymer is a polymer in some stage between that of the monomer and the final polymer. Thus it is a polymer that has not completely finalized its polymerization process and grown to full molecular weight. The molecular weight of a prepolymer is therefore also intermediate. As used in polyurethane production, a prepolymer is the reaction product of a polyol with excess of an isocyanate.

prepreg A prepreg is a ready-to-mold sheet that may be a cloth, mat, or paper that is impregnated with a resin and stored for use. Prepreg is also known as preimpregnated fabric, mat, roving, etc. The resin component of a prepreg is usually thermosetting, but thermoplastic prepregs are available as well. Thermoplastic prepregs are formed by heat and pressure. Typical processes are compression molding and filament winding.

For thermosetting prepregs, the resin is partially cured to a B-stage condition and supplied to the fabricator, who lays up the finished shape using the required layers of prepreg. (See Fig. P.22.) Prepreg may also be in the form of cord, thread, or tape. The fabricator then completes the cure with heat and pressure.

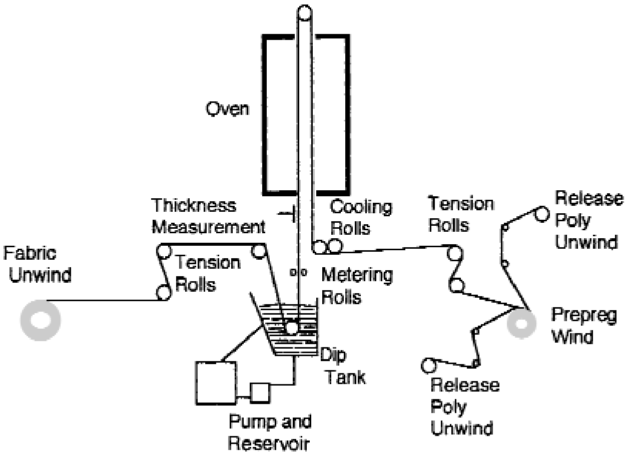


Figure P.22 Schematic of the typical solution prepreg process (Ref: Hull, J.L, “Processing of Thermosets”, *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

pressure bag molding Pressure bag molding is a process for molding reinforced plastics in which a tailored flexible bag is placed over the contact layup on the mold, sealed, and clamped in place. Fluid pressure, usually compressed air, is placed against the bag, and the part is cured. (See Fig. P.23.)

See also vacuum bag molding.

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Figure P.23 Pressure page molding process. (Ref: American Cyanamid Company also Schwartz, S.S. and Goodman, S.H., *Plastics Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 732)

pressure forming In thermoforming, pressure forming is a process in which pressure is used to push the sheet to be formed against the mold surface as opposed to using a vacuum to force the sheet flat against the mold.

pressure pads Pressure pads are reinforcements of hardened steel distributed around the dead areas in the faces of a mold to help the land absorb the final pressure of closing without collapsing.

pressure roll In extrusion coating, the pressure roll is the roll that, along with the chill roll, applies pressure to the substrate and the molten extruded web.

pressure-sensitive adhesive Pressure-sensitive adhesives instantly provide a degree of tackiness. Their tackiness is permanent, and there is no optimal time range when the substrates must be joined. Pressure sensitive adhesives are usually based on elastomer or thermoplastic solvent solutions. They can also be applied via water dispersions or hot melts. They are coated on the substrate or on a film backing that is used as a carrier. Pressure sensitive tape (e.g., office tape) is made in this manner. Once the solvent evaporates, the tape is ready to be applied or is packaged so that it can be dispensed at the point of need.

Most pressure-sensitive adhesives are made from formulations based on elastomer (natural, butyl, nitrile, and styrene butadiene thermoplastic), acrylate, or silicone resins.

Pressure-sensitive adhesives are specifically formulated for good flexibility, tack, and peel strength. Most pressure-sensitive adhesives are applied to plastic, paper, foil, or fibrous material as suitable backings. Pressure-sensitive tapes are made with adhesive on one side or on both sides (*double-faced tape).* Double-faced foam tapes are available to suit applications where substrates have surface irregularities, contours, and significant gaps in the bond line.

primer Primers are liquids that may be applied to a substrate before application of a coating, adhesive, or sealant. The reasons for their use are varied and may include, either singularly or in combination, the following:

- Protection of surfaces after treatment (primers can be used to extend the time between preparing the adherend surface and bonding)
- Adjusting the free surface energy by providing a surface that is more easily wetted than the substrate
- Dissolving low levels of organic contamination that otherwise would remain at the interface as a weak boundary layer
- Promoting chemical reaction between adhesive and adherend
- Inhibiting corrosion of the substrate during service
- Serving as an intermediate layer to enhance the physical properties of the joint and improve bond strength (e.g., adjustment of the rheological properties at the interface or strengthening weak substrate regions)

Being low in viscosity, primers can be used to penetrate porous or rough surfaces to provide better mechanical interlocking and for sealing such surfaces from the environment. Primers are often applied and appear as protective surface coatings. Application processes and equipment for applying primers are similar to those used in applying a paint coating to a substrate.

Primers are applied quickly after surface preparation and result in a dry or slightly tacky film. It is generally recommended that they have a dried coating thickness range of tenths of a mil to approximately 2 mil. It is necessary to control the primer thickness, because if the primer layer becomes too thick its bulk properties may predominate and the primer could become the weakest part of the joint.

Primers usually require solvent evaporation and several curing steps before the adhesive, coating, or sealant can be applied. Adhesive primers are usually not fully cured during their initial application. They are dried at room temperature and some are forced-air dried for 30–60 min at 66°C. This provides a dry, nontacky surface that can be protected from contamination and physical damage by good housekeeping practices until the substrate is ready to be bonded or coated. Full primer cure is generally achieved during the cure of the adhesive or coating.

Primers developed to protect treated surfaces before bonding are generally proprietary formulations manufactured by the adhesive producer to match the adhesive. These usually consist of a diluted solution (approximately 10% by weight) of the base adhesive in an organic solvent. Like the adhesive formulation, the primer may also contain wetting agents, flow control agents, and toughening compounds. If the primer is for a metal surface, corrosion inhibitors such as zinc and strontium chromate and other inorganic chromate salts may also be added to the primer formulation.

The application of corrosion-resistant primers has become standard practice for the structural bonding of aluminum in the automotive and aerospace industries. The adhesive-primer combinations are chosen to provide maximum durability in severe environments in addition to providing higher initial joint strength. Improved service life is typically achieved by establishing strong and moisture-resistant interfacial bonds and protecting the substrates' surface region from hydration and corrosion.

As with metallic substrates, primers may be used to protect treated nonmetallic substrates. After surface treatment, a high-energy substrate surface has an active surface that will readily adsorb atmospheric contamination. The primer protects the treated surface until the time when the adhesive or sealant is applied. Primers are especially useful in this way for the protection of polymeric parts that are treated by flame or corona discharge. Primers also find benefit on polymeric substrates in that their solvents will soften the surface and some of the primer resin will diffuse into the bulk of the substrate, thereby increasing adhesive strength by molecular diffusion.

printed circuit board A printed circuit board is a completely processed conductor pattern, usually on a rigid, flat laminate base. It serves as a means of electrical interconnection and physical attachment for conductors. Printed circuit boards, key elements in the electronics industry, are substrates onto which conductor lines are etched or deposited to form circuit patterns. Printed circuit boards are also sometimes called *printed wiring boards* or *circuit boards*.

Although some substrates may be molded plastic (3-D or *molded circuits*) or flexible film plastic materials (*flexible circuits*), the largest group of substrates is of rigid laminate construction. The laminate construction consists of many layers of resin-treated fibers, fabrics, or papers, which are called *reinforcements.*

There are numerous industry standard laminate constructions, and one of the leading sets of standards is that established by the National Electrical Manufacturers Association (NEMA). Some of the most commonly used resins are epoxies, polyesters, polyimides, cyanate esters, and phenolics. Some of the most common reinforcements are paper, glass fiber, glass fabric, and certain plastic fibers and fabrics.

See also electronic plastics; flexible circuits; laminates.

printing on plastics Printing on plastic is an important part of finishing in many plastic applications. The printing processes used for plastics are similar to those used in other industries, but the adaptation of the machinery and development of special inks has been a necessity, particularly as new plastic materials are developed, each with its own characteristics regarding printing.

Printing on plastics serves both for decoration and for placing information, such as bar coding and freshness dates on the part surface. The conventional techniques for printing include:

- Stamp printing
- Silk screening
- Non-contact methods

Other methods of printing such as *hot stamping* or *heat transfer* are also possible.

The surface condition of the part must be considered before any attempts are made for printing on plastic. Surface cleaning and treating methods described under the entry on adhesive bonding are applicable also for treating the surfaces before printing.

Stamp printing produces code or lettering by a metal or rubber die exposed to an ink. Letterpress, letterflex, gravure, and flexography are methods of applying the ink via various types of dies. For lay-flat film products, gravure and flexographic printing are most commonly used.

Letterpress printing is a method in which raised, rigid printing plates are inked and pressed against the plastics part. The raised portion of the plate transfers the image. Letterflex is similar to letterpress except that flexible printing plates are used. Flexible plates may transfer their designs to irregular surfaces.

Gravure (also called rotogravure) transfers ink from cells etched or engraved on a copper- and chrome-plated cylinder to the material being printed. The cylinder rotates in an ink fountain and the cells pick up the liquid ink. A doctor blade wipes excess ink from the roller, leaving ink only in the cells. The low-viscosity liquid inks used in this process contain volatile solvent. Gravure is mainly used when designs require good continuity of sharp pattern details and rich color effects. It is a high-speed process; however, it can be expensive for short runs because of the cost of the cylinders.

Pad transfer printing is a gravure-like process offering versatility for printing on a variety of shapes and surfaces. The image is transferred with a special silicone pad instead of the etched plate used in gravure. Pad printing can reproduce fine line engraving, and it can apply wet ink on wet ink. Pad printing is generally most useful for printing small areas. Pad printers are generally more expensive than hot stamping or screen printing. The ink costs, however, are much lower than the cost of hot-stamping foil.

Flexographic printing is more widely used for short and medium runs. This method prints by transforming images from a flexible raised printing palate directly to the material. A uniform film of ink is applied to the raised portion of the printing plate by bringing it in contact with a form roller. The plate continues to rotate until it contacts the substrate and transfers the image to it. Individual colors are applied by a series of separate printing stations.

Silk screening is a process in which ink or paint is forced by a rubber squeegee through fine metallic or fabric screen onto the product. The screen is blank or blocked off in areas where no ink is wanted. Printing from flat bed or rotary systems makes it possible to decorate large or complex parts. However, only one color can be applied per pass. Image sharpness is of lower quality than with other printing processes. The major uses for screen printing have been short runs on molded products with complex contours, on flat substrates, or to get special color effects.

Noncontact methods of printing are *electrostatic*, *ink jet*, and *laser etching*. Electrostatic applies dry ink to areas by a difference in electrical potential. Ink jet printing is a direct adaptation of the ink jet printer used to print on paper. Laser etching requires that a laser beam be aimed via a series of computer-controlled mirrors. The laser burns the surface of the plastic, thus creating the printed image. Noncontact printing methods generally allow the designer to print on most plastics regardless of the shape of the surface.

processing aid Processing aids are additives used to overcome the processing problems of various polymers. They are primarily classified as internal and external lubricants. *Internal processing aids* function generally by increasing the frictional forces between the polymers in melt form. This leads to better compound fusion and more uniform properties. *External processing aids* provide slip or release between the polymer and the surface that the molten polymer contacts such as cylinder, mold, or die.

Metallic stearates are the most widely used lubricant for both internal and external lubricants. Stearates and their complexes are usually supplied as fine powders. Organic processing aids typically consist of high-molecular-weight polymers, oligomers, or other resins that when added to the base resins improve melt properties. Examples of processing aids for polyvinyl chloride include methyl methacrylate, styrene acrylonitrile, and high-molecular-weight versions of polystyrene acrylonitrile.

Processing aides are available in many forms including low-viscosity liquid, powders, and pellets. They are used at a level of 0.1–2 percent by weight of the resin. Processing aids are often used with polyvinyl chloride, nylon, polycarbonate, and polyethylene terephthalate resins.

promoter A promoter is a chemical that greatly increases the activity of a given catalyst. Often the promoter itself is a weak catalyst. Promoters are often used in thermosetting polyester formulations. Examples of a promoter in this case would be organic cobalt salts and dimethyl- or diethylaniline that operate with peroxide catalysts such as methyl ethyl ketone peroxide or benzoyl peroxide.

proof pressure The proof pressure is the test pressure that a pressurized component must sustain without detrimental deformation or damage. The proof pressure test is used to give evidence of satisfactory workmanship and material quality. The proof pressure test is often used in plastic piping, filament wound tubes, etc. that are meant to hold pressure during service.

propagation Propagation is the second step in a free radical polymerization process. The chain radicals that are formed in the *initiation* step are capable of adding successive monomers to propagate the chain. This growth of the chains is known as propagation.

See also free radical polymerization.

proportional limit The proportional limit, also known as the *elastic limit*, is the greatest stress a material can sustain without deviating from the linear proportionality of stress to strain (*Hook's law*). The proportional limit is expressed in force per unit area. The proportional limit should not be confused with the elastic limit.

pulp molding Pulp molding is a process by which resin-impregnated pulp material is preformed by application of a vacuum and subsequently ovencured or molded. *Pulp* is a form of cellulose obtained from wood or other vegetable matter by prolonged cooking with chemicals.

pultrusion Pultrusion is the process of making structural profiles (rods, tubes, and structural shapes of a permanent cross section) continuously from reinforced plastics. In the pultrusion process glass or other roving is passed through a resin dip tank and drawn through a heated die to form the desired cross section and cure the composite. Because the process is continuous there is no theoretical limit on the length of the product. Figure P.24 shows the process schematically.

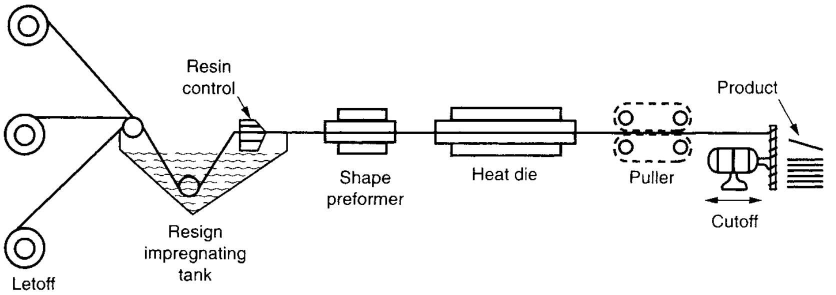

Figure P.24 Pultrusion Process (Ref: Hull, J.L, "Processing of Thermosets", *Modern Plastics Handbook*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

There are two primary pultrusion processes. In one method, the pultrusion passes through a long heated die or oven for cure. This is called the tunnel oven process. In the second method the composite is cured with radio frequency energy. This causes cure in a much shorter period of time.

The reinforcing fibers that are used determine the physical properties of a pultruded product. Because of its cost and physical properties, fiberglass is usually used, especially E-glass. With fiberglass, the product has highly directional properties. The tensile and flexural strengths in the fiber direction are extremely high, exceeding 100,000 psi, whereas the transverse properties are much lower. Transverse properties can be enhanced somewhat by incorporating glass mat, glass cloth, or chopped fibers, but with an attendant reduction in the longitudinal property. General properties for pultruded parts are provided in Table P.10.

Table P.10 Properties for Pultruded Parts (Ref: Harper, C.A., "Laminates and Reinforced Plastic Materials and Processes", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Property	Test Method	Value
Flexural strength	ASTM D 790–63	100,000 lb/in.^{2}
Tensile strength	ASTM D 638–64T	120,000 lb/in.^{2}
Compressive strength	ASTM D 695–63T	40,000 lb/in.^{2}
Impact strength	ASTM D 256–56	40 ft-lb/in, notch
Electric strength:		
Perpendicular	ASTM D 149–64	450 V/mil
Parallel	ASTM D 14–64	60 kV
Arc resistance	ASTM D 495–61	130 s
Water absorption	ASTM D 570–63	0.1%

Polyester, epoxies, acrylics, vinyl esters, and silicones have all been used in pultrusion, but the largest percentage of the products are vinyl esters and polyesters because of their favorable costs, desirable properties, and easy handling characteristics. Liquid systems with low viscosity are used to ensure rapid saturation of the fiber bundles. The resin determines the weather resistance, thermal resistance, burning characteristics, moisture sensitivity, chemical resistance, and most of the electrical properties.

The curing rate of the resin in the heated die must be carefully controlled. Most of the resins used are exothermic (give off heat while curing). Too rapid a curing results in voids and cracks; whereas, too slow a curing produces a poorly cured product with poor physical properties. Dies used in pultrusion are usually quite simple and inexpensive. Dies are heated electrically or with radio frequency (RF) generators up to 10 kW at 100 MHz. When RF heating is used, the dies are made of Teflon.

Applications for pultruded products include ladders, electrical poleline hardware, electric motor wedges, fishing rods, archery bows, hammer and ax handles, I-beams, and T-beams. Pultrusion can also be used for on-site construction of architectural structures.

Pulforming is a variation of pultrusion. The process uses continuous roving, a resin impregnation bath and forming dies. The dies are two-piece, and they are moveable. They clamp onto the roving and cure it as it moves. This process can be used to form tapered cross sections like hammer handles.

puncture strength, electrical
See dielectric strength.

purging Purging is the process of cleaning a color or type of material from the cylinder of an injection molding machine or extruder by forcing it out with the new color or material to be used in subsequent production. Purging materials specially developed for this purpose are available.

pyrolysis Pyrolysis is the chemical decomposition of a polymer by the action of heat alone. It is different from normal thermal aging, which generally includes oxidation (i.e., the reaction and ultimate degradation of the plastic on exposure to oxygen at elevated temperature). Generally, a polymer can resist pyrolysis at much higher temperatures than it can resist oxidation. Thus many polymers perform well at elevated temperatures in a vacuum or inert atmosphere, whereas they degrade relatively quickly at the same temperatures in air.

pyrrone Pyrrone polymers are the combination of polyimides and polybenzimidazoles that forms a material resistant to 482°C. Polyimidazopyrrolones, synthesized from dianhydride and tetramines, are soluble only in sulfuric acid and resistant to temperatures up to 600°C.

Q

qualified products list (QPL) A qualified products list, or QPL, is a list of commercial products that have been pretested and found to meet the requirements of a specification. A qualified product list is generally employed within the government relating to military or federal specifications. Qualified products lists for government specifications are generally available to the public.

quality control In its broadest meeting, quality control refers to all steps necessary in the establishment and maintenance of the desired degree and uniformity of quality in producing plastic materials and products. It also refers to the systems and processes used for the measurement of a probable quality level. This includes testing and measurement of standard samples from production and of critical parameters in the manufacturing process.

Standard test methods for plastics are provided by many different agencies including, American Society of Testing and Materials (ASTM), the US Government (Military and Federal Specifications), National Electrical Manufacturers' Association (NEMA), Society of Automotive Engineers (SAE), etc.

quartz Quartz is the most common variety of silica. Quartz (Mohs 7 hardness) is harder than most minerals, and the crushed material is often used for abrasive purposes. Finely ground quartz is also used as filler, and powdered quartz is employed as a flux in melting metals. When quartz is fused it loses its crystalline structure and becomes a silica glass with a specific gravity of 2.2.

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

Quartz fabric can be made by extruding the molten quartz through a stream of high-pressure hot air, which produces a fluffy mass of fine fibers of random lengths. There are various other methods of processing quartz fabric. *Astroquartz* (J.P. Stevens & Co.) is corded as a thread with outside diameters from 0.014 to 0.020 in. Quartz yarn made from these filaments is used for weaving into tape and fabric. Quartz paper, or ceramic paper, is made by mixing with bentonite and sheeting on a papermaking machine. It is used to replace mica for electrical insulation. Quartz has a very low dielectric constant and loss factor. Thus, it finds application in low loss dielectric insulation such as radomes, microwave fixtures, etc.

See also Silica.

quasi-isotropic laminate Many times there is a need to produce a composite that has some isotropic properties similar to metal because of the multiple and undefined load paths. A quasi-isotropic laminate lay-up accomplishes this for the x- and y-planes only; however, the z-plane through the laminate thickness is quite different. Most laminates produced for aircraft applications have been, with few exceptions, quasi-isotropic structures.

For a quasi-isotropic laminate, the following are requirements.

- It must have three layers or more.
- Individual layers must have identical stiffness matrices and thicknesses.
- The layers must be oriented at equal angles. For example, if the total number of layers is n, the angle between two adjacent layers should be 360 deg/n. If a laminate is constructed from identical sets of three or more layers each, the condition on orientation must be satisfied by the layers in each set.

quench Quench is a process of shock cooling thermoplastic materials from the molten state. The cooling medium used to quench molten thermoplastic materials to the solid state is known as a *quench bath.*

quench rolls In sheet extrusion, quench rolls are used to cool the extrudate immediately after the extruder and before entering the draw rolls. In addition to cooling the hot extrudate, quench rolls are also used to provide for a consistent, high gloss surface finish. To a lesser extent, the rolls are also used to smooth out minor variations in the thickness of the sheet.

Usually quench rolls consist of a set of three rolls. The rolls, especially the middle roll, are usually chrome plated and polished to a high finish, since this will to a large extent determine the surface gloss of the sheet.

quench tank extrusion In thermoplastic extrusion, quench tank extrusion is a process where the extruded film is cooled in a *quench bath.*

R

radiant panel test The surface flammability of sample plaques of plastic material can be assessed in a small-scale test (ASTM E162), often referred to as the radiant panel test. The test apparatus features a radiant panel kept at a temperature of about 670°C. The test specimen faces the radiant panel, but at an angle of 30°. A pilot burner, at the upper end of the test specimen, is used to ignite composition gases. Data are reported in terms of a flame spread factor, a heat evolution factor, and a flame spread index.

See also flammability.

radiation curing Polymeric films are formed and cured by bombardment with *ultraviolet (UV)* and *electron beam radiation* with little increase in surface temperature. *Infrared radiation*, on the other hand, increases the surface temperature of the films and is therefore a baking process.

The most notable radiation curing is UV curing. This process requires the use of specially formulated coatings. They incorporate photoinitiators and photosensitizers, which respond to specific wavelengths of the spectrum to cause a conversion reaction. Curing is practically instantaneous with little or no surface heating. Radiation curing is therefore useful in curing coatings on temperature-sensitive substrates. Because radiation-cured coatings are 100 percent solids, there are no volatile organic components (VOCs). Although most UV coatings are clear (unpigmented), certain pigmented paints can also be cured.

See also photopolymerization.

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radiation resistance High-energy or ionizing radiations are associated with radioactivity. Some radiations (e.g., α and β) are of particulate nature and have a relatively low penetrating power in solids. However, γ-radiations are of particular concern. In the case of polymeric materials these radiations can trigger unwanted detrimental chemical reactions such as bond rupture, chain scission, and undesirable crosslinking.

Figure R.1 Relative radiation resistance of organic materials. TFE has the poorest resistance. (Ref: English, L.K., "How High Energy Radiation Affects Polymers", *Materials Engineering*, May 1986)

Deteriorating effects of radiation are similar and complementary to those of thermal aging. It has been fairly well demonstrated that damage is dependent only on total dosage, or the amount of radiation energy absorbed, irrespective of the form of radiation within a factor of 2. Dosage rate is an important factor only where significant degradation from other agents, such as oxygen, has access to the system.

Often low-heat-resistant resins show the greatest radiation resistance. Some otherwise excellent plastics are known to be rather strongly affected by high-energy radiations. These are polyvinylidene chloride, polymethylmethacrylate, polytetrafluoroethylene, butyl rubber, etc. Fig. R.1 shows relative radiation resistance data for some of the more commonly used plastics and elastomers.

The resistance of polymeric materials to high-energy radiation is important in view of their application as insulating materials for electrical systems as well as seals and gaskets in the nuclear industry or in equipment involving radiation sources.

radical When more than two atoms are present in a compound, some of them occasionally group themselves into what are called radicals and behave as a unit in a chemical reaction. For example, the $—SO_4$ group is called a sulfate radical; $—OH$ is termed a hydroxyl radical.

radical, free A free radical is a reactive substance with one unpaired electron. It is the chain carrier in the addition or chain-reaction polymerization process. A free radical is usually formed by the decomposition of a relatively unstable material called an *initiator*.

The free radical is capable of reacting to open the double bond of a vinyl monomer and add to it, with an electron remaining unpaired. In a very short time, usually a few seconds or less, many more monomers add successively to the growing chain. Finally, two free radicals react to annihilate each other's growth activity and form one or more polymer molecules. This process is called *addition* or *chain-reaction polymerization*.

radio frequency preheating Radio frequency preheating is one of several processes (others are hot air heating and infrared heating) that could be used to precondition molding powder to form a *preform* and preheat the product. Radio frequency or dielectric heating is the fastest method of heating and is particularly effective with preforms.

The process is similar to the cooking action in the familiar home microwave oven. The preforms are usually placed in a nonmetallic tray that is positioned between two flat plate electrodes in the preheater. By the action of radio frequency (generally 10–100 MHz) the preforms can be brought to a temperature of 130–150°C in 7–10 s. The preforms are heated from the inside out, so that maximum removal of volatiles occurs with minimal stresses developing in the preform.

In placing a batch of performs in the preheater, it is important that all be of the same thickness so that all may be heated at the same rate. By adjusting the cure cycle to take advantage of the preheated material, it is possible to reduce the overall cure cycle 10–40 percent.

Radio frequency preheating can also be used to dry molding pellets or other molding materials before molding or incorporating into a mixture. It has also been used in the furniture industry to speed the drying and handling strength of water-based adhesives.

See also dielectric curing or heating.

radio frequency welding Radio frequency is a method of welding thermoplastics by using a radio frequency field to apply the necessary heat to a joint. This process is also known as *high-frequency welding* or *dielectric welding*.

See also dielectric heat sealing/welding.

ram The ram is the portion of a mold that enters the cavity block and exerts pressure on the molding compound. It is designated as top force or bottom force by position in the assembly. The *ram travel* is the distance the ram moves in filling the mold, in either injection or transfer molding.

See also force plug.

ram extrusion In ram extruders, a hydraulic ram forces the polymer through the die. Although high pressures are achieved, the process is discontinuous. All heating occurs by conduction from the barrel walls. The absence of shear gives ram extruders limited melting capacity and poor temperature uniformity.

Ram extrusion is generally used for specialty processing. Ram extruders are sometimes used to process polymer slurries such as PTFE or UHMWPE. These polymers will degrade if they are heated to their melt temperature, so they are sometimes mixed with a liquid and processed via ram extrusion. Ram extrusion is also used on polymers that are sensitive to shear. Often the absence of shear is an advantage when processing thermoset materials and composites.

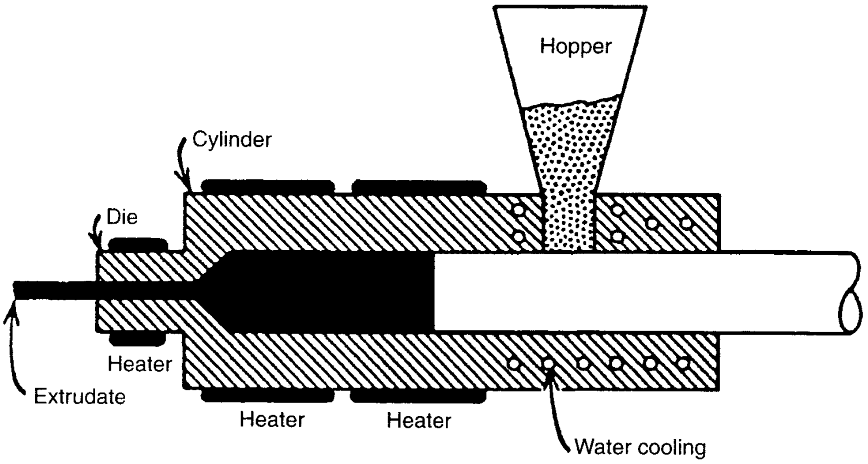

Figure R.2 Ram extruder. (Ref: Bikales, N.M., *Extrusion and other Plastic Operations,* Wiley Interscience, New York, 1971)

random copolymer If, instead of starting out with a pure monomer and polymerizing it by addition to form a *homopolymer*, a mixture of two difunctional monomers A and B is used, the resulting linear polymer will often have a random arrangement of monomers A and B in the chain (the degree of randomness depends on the relative amounts and reactivites of A and B). The resulting polymer is known as a random copolymer or just copolymer.

See also copolymer.

rapid prototyping In rapid prototyping, prototypes are produced by curing photosensitive compounds with ultraviolet (UV) radiation. A beam of UV light controlled by a computer sweeps out a pattern that represents one layer of the part wanted. The liquid resin polymerizes to a solid where the UV strikes it. The process is repeated until the entire part is formed. Acrylic functional compounds are frequently used in rapid prototyping.

In the past few years there has been a dramatic switch from acrylics to epoxies. Also, software that controls the process has advanced rapidly. Sometimes the rapid prototyping process is called *desktop manufacturing*. Accuracy and finish of the parts have also improved.

Du Pont has developed a series of materials for rapid prototyping with *photopolymers*. The various members of the series are described as flexible and opaque, tough and transparent, and rigid and high accuracy. These are relatively expensive materials. Layer thickness ranges from 0.003 to 0.015 in. Excess resin is removed by rinsing the part in solvent such as isopropyl alcohol. Heat and/or UV light exposure is used to postcure the parts.

rapid tooling Rapid tooling is a process of manufacturing a mold or tool in a very fast manner for experimentation, prototype manufacturing, or process analysis. Urethane and epoxy polymeric casting materials, ultraviolet (UV) light-cured resins, and powdered thermoplastics are generally the materials that are used. Various processes are used to form the tool. Processes used in rapid prototyping are also applicable for rapid tool formation. Of course, the rapidly formed tool may have a very short life because of temperature degradation, thermal cycling, and wear.

rayon Rayon is a generic term for fiber, staple, and continuous-filament yarns composed of regenerated cellulose. The term is also used frequently to describe fibers obtained from cellulose acetate, cellulose nitrate, cellulose triacetate, or other cellulose derivatives. Rayon fibers are similar in chemical structure to natural cellulose fibers (e.g., cotton) except that the synthetic fiber contains shorter polymer units.

Rayon fibers are resistant to caustic solutions, which would easily destroy natural silk. They are also mildew proof, durable, and easily cleaned. But they do not have the permeability and soft feel of silk.

Rayon manufactured by different processes varies both chemically and physically. Most rayon is made by the *viscose process*, where the cellulose is treated with caustic soda and then with carbon disulfide to form cellulose xanthate, which is dissolved in a weak caustic solution to form the viscose. With the *cuprammonium process*, the cellulose is digested in an ammonia solution of copper sulfate and the solution is forced through the spinnerets into dilute acid for hardening.

The acetate rayons are more resistant than the viscose or cuprammonium. *Fiber 40* (FMC Corp.) is a type of rayon called *Avril*, made by a special pulping process that decreases the tendency to shrink when the fiber is wet. *Avlin Fabray* (Stearness Technical Textiles Co.) is a thin, lightweight, porous, nonwoven fabric of rayon fiber used for throw-away garments.

High-tenacity rayon is produced by stretching the fibers so that the molecular chains run parallel to the filament axis and a number of small crystalline regions act as anchors for the cellulose chains. Tire cord stretched in this way has greater tensile strength.

reaction injection molding (RIM) Reaction injection molding (RIM) is a process in which two low-molecular-weight, highly reactive, low-viscosity liquids are injected at a high pressure into a small mixing chamber and then into a mold cavity. In the mold, the polymerization reaction takes places as the part is formed.

Rapid-curing, low-viscosity resins are required. Polyurethanes are the most common resins used with RIM processing. Polyureas, polydicyclopentadiene, acrylamate, and caprolactam resins have also been used.

The RIM process offers a number of advantages over conventional injection molding. The primary advantage is the ability to mold large, complex polyurethane parts quickly and with relatively low-cost tooling as compared to conventional injection molding. Parts as large as 100 lbs can be molded in a single shot in 2–3 min. The disadvantages are that the molds are more expensive than those used in resin transfer molding and that there is generally a limitation on the size of the parts produced.

A variation of RIM is *reinforced reaction injection molding* (RRIM). RRIM refers to a molding process in which the resin is pumped into a closed mold that has been preloaded with dry reinforcements. Polyester resins are often used, but polyurethanes, vinyl esters, and epoxies can be molded via RIM. The advantages of RIM over other reinforced plastic molding processes are:

- Two finished surfaces are molded.
- Gel coats can be used.
- Little postmold finishing is required.
- Tooling costs are low to modest.
- Volatiles are minimum and easily controlled.
- Inserts and cores can be molded.
- The process is energy efficient.
- Complex parts are possible, such as fenders, pickup truck beds, and tub and shower units.

The reinforcements may have several forms. If the reinforced plastic part is simple, the reinforcement can be precut glass mat that is placed by hand in the mold. If a deeper draw is needed, a fabricated glass preform is manufactured. A third common process is to use a continuous-strand glass mat prepared with a special binder. This mat can be precut and then shaped thermally on a mold equipped with clamps and heaters. This produces a three-dimensional fiber preform ready for molding. Glass, polyester, carbon, and aramid fibers have been used for RIM processes.

When the mold has been loaded with preform, it is clamped shut and liquid catalyzed resin is heated and pumped under modest pressure in the mold, saturating the preform and pushing air out through vents. Cycle times vary from 1 to 20 min depending on size and complexity of the part. Weights vary from a few ounces to several hundred pounds. Molds can be made of reinforced plastic for short runs of product or steel for high-volume runs.

reactive diluent
See diluents.

reaming High-speed or carbide-steel machine reamers will ream accurately sized holes in plastic parts. When reaming thermoplastics, it is advisable to use a reamer 0.001–0.002 in. larger than the desired hole size to allow for the resiliency. Tolerances as close as ± 0.0005 in. can be held in through holes that are 1/4 in. in diameter. Fluted reamers are best for obtaining good finished surface. Reamer speeds should approximate those used for drilling. The amount of materials removed per cut will vary with the hardness of the plastic. Reaming can be done dry, but water-soluble coolants will produce better finishes.

See also drilling.

reciprocating-screw machine Reciprocating-screw injection molding is a process that combines injection molding and plasticating. Here an extrusion device with a reciprocating screw is used to plasticate the material, and the injection of material into the mold can take place by direct extrusion into the mold, by reciprocating the screw as an injection plunger, or by a combination of the two. When the screw serves as an injection plunger, this unit acts as a holding, measuring, and injection chamber.

A reciprocating-screw machine is an extruder system that has the advantages of screw plastification and ram injection in the same unit. In this design, as the screw rotates, it is pushed backwards by the molten polymer that collects in front of the screw. At a predetermined point, rotation stops and the nozzle moves in the forward position, acting as a ram to force the melt into the mold. It remains forward until the mold gates freeze, then pumps back to repeat the cycle while the mold opens.

It was originally believed that the reciprocating-screw mechanism would be mainly applicable only to the larger machines; however, both very large machines and small machines are currently being used.

See also injection molding.

recycled plastics Recycled plastics are resins made at least partially from thermoplastic articles that have been cleaned and reground. For successfully recycled plastics several processes are involved including collecting and sorting, processing, and product design for recycled material. Plastic materials that are conventionally recycled include polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polystyrene (PS), and polypropylene (PP). However, other thermoplastics are also recycled.

Processing of recyclables is necessary to transform the collected materials into raw materials for the manufacture of new products. Three general categories of processes are commonly used. *Physical recycling* involves changing the size and shape of materials. Within this category the usual processing methods include grinding, air classifications, washing, screening, rinsing, drying, and often melting and pelletizing. *Chemical recycling* involves breaking down the molecular structure of the polymer with chemical reactions. *Thermal recycling* also involves breaking down of the chemical structure of the polymer, but in this case it is done with heat.

Recycled plastics are used in a variety of applications, including automobiles, housewares, packaging, and construction. Recycled materials, including plastics, also are an important segment of world trade activities.

Petra 140 (Allied Signal) is a 40 percent glass-reinforced polyethylene terephthalate from recycled soda bottles. It has a tensile strength of 26,000 psi and a heat-deflection temperature of 225°C at 264 psi. *PC23MS-200* (MCR Polymers) contains at least 25 percent recyclate from personal computer compact disks and polyethylene terephthalate beverage bottles. *DMDA-1343NT polyethylene* (Union Carbide) contains 28 percent color-sorted recyclate and has physical properties similar to those of virgin stock. *Encore resins* (Hoechst Celanese) are a family of plastics based on 100 percent reclaimed thermoplastics such as acetal, polyester, polyphenylene sulfide, nylon 6/6, and liquid crystal polymer.

refractive index The refractive index is the ratio of the velocity of light in a vacuum to its velocity in a substance. It is also the ratio of the sine of the angle of incidence to the sine of the angle of refraction. Refractive index can be measured by processes specified in ASTM D542.

Low indexes of refraction tend to reduce surface or back reflection and are desirable for certain applications such as antiglare coatings. High indexes of refraction tend to correspond to higher part brilliance and thinner optical lenses for a given distance. A high refractive index makes a plastic useful for optical components. Polystyrene has a relatively high refractive index (1.60), and polytetrafluoroethylene has a relatively low refractive index (1.375).

See also optical properties.

regenerated cellulose
See cellophane.

regrind Regrind is the excess or waste material in a thermoplastic molding process that can be reground and mixed with virgin raw material, within limits, for molding future parts. As used in thermoplastic processes such as injection molding, regrind material is ground material from flash and trimmings that, after mixing with a certain amount of virgin material, is fed back into the molding machine.

Plastic *granulators* are used to regrind the used material. Granulators are available with various types of knives and sizes so scrap as thin as film and small parts may be reground, or the machine may be of a size to regrind large pipes, refrigerator doors, or similar massive parts.

reinforced plastics Reinforced plastics are those plastics or polymers to which fibrous materials, such as glass or cotton, have been added to increase the physical properties. Reinforced plastics especially have significantly improved impact strength and heat-deflection temperatures over the nonreinforced grades. The function of the resin is to bond the fibers together to provide shape and form and to transfer stresses on the structure from the resin to the fiber.

Different mineral fillers are added to plastics for many reasons, but this does not necessarily make the fillers reinforcements. True fiber reinforcements dramatically increase the structure's tensile, compressive, flexural, and impact strengths and cause great stiffness. Because of this increased stiffness, those plastics that are noted for their great flexibility are not generally used with stiff reinforcement.

The fiber diameter is usually 10 mm or less, and the fibers are longer than 100 mm. The fiber length to diameter is greater than 10. Glass fibers are the most common form of reinforcement, but others, notably carbon, graphite, aramid, and boron fibers, are also used. Generally, only high-strength fibers with high moduli are used. For example, E-glass fibers have a tensile strength of over 500,000 psi and a modulus of over 10.5×10^6 psi.

Although fiberglass is the most common reinforcement, many other types of fiber reinforcements are used. Table R.1 lists common reinforcing fibers and the special properties that they contribute to reinforced plastics.

Reinforced plastics can be either thermoset or thermoplastic. Virtually all thermosetting polymers can be reinforced with fibers. Thermoset reinforced molding materials of phenolic, alkyd, or epoxy are used extensively in the electronics industry for connectors, terminals, sockets, and housings. Several materials (especially alkyds and epoxies) reinforced with conductive graphite or carbon fibers are being used to provide electromagnetic interference (EMI) protection. Thermoset reinforced molding compounds are molded in conventional compression, transfer, and injection molding processes.

Polyester resins are particularly useful in reinforced plastics because of their relatively low viscosity, low molding pressures, and capacity of being cured at either room or elevated temperatures. Polyesters are used extensively in manufacturing very large components such as swimming pools, truck parts, saunas, boat hulls, bath and shower enclosures, and building components. Reinforced polyester resin parts can be manufactured by most processes used for reinforced plastics such as pultrusion, filament winding, hand layup, vacuum bag, and autoclave molding processes.

Reinforced epoxy resins are often used where low shrinkage and good physical properties are required. They can be manufactured by most processes (see above for polyester resins). Filament winding is often used for aerospace applications and other high-strength structures.

Reinforced polyurethane resins are often used in a molding process called *reactive injection molding* (*RIM*), also known as resin-transfer molding. Polyurethanes are selected for their low viscosity and rapid polymerization. Reinforced applications include large automotive parts and building components.

Table R.1 Properties of Reinforced Plastics and of Reinforcing Fiber (Ref: Harper, C.A., "Laminates and Reinforced Plastic Materials and Processes", *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Reinforcing Fiber	Laminate properties									
	Mechanical Strength	Electrical Properties	Impact Resistance	Chemical Resistance	Machining and Punching	Heat Resistance	Moisture Resistance	Abrasion Resistance	Low Cost	Stiffness
Glass strands	×		×	×		×	×		×	×
Glass fabric	×	×	×	×		×	×			×
Glass mat			×	×		×	×		×	×
Asbestos		×	×			×				
Paper		×			×				×	
Cotton/linen	×	×	×		×				×	
Nylon		×	×	×				×		
Short inorganic fibers	×		×						×	
Organic fibers	×	×	×	×	×			×		
Ribbons		×					×			
Metals	×		×				×			×
Polyethylene	×		×		×					×
Aramid	×	×	×			×		×		×
Boron	×		×			×				×
Carbon/graphite	×		×			×				×
Ceramic	×		×						×	

Many thermoplastic materials can be reinforced with fibers. Reinforced thermoplastic materials are commonly injection molded or extruded, and some reinforced thermoplastic materials can be pultruded.

In formulating reinforced thermoplastics, glass fibers with lengths less than 1/4 in. are generally used. Commonly, "milled" fibers are selected. The fibers improve the physical properties of the base resin, in particular the heat-deflection temperature. Some thermoplastics are reinforced with graphite fibers to give electromagnetic interference protection. Aramid fibers with thermoplastics result in excellent wear and abrasion resistance.

The following thermoplastic resins realize important gains from added glass fiber reinforcement: nylon (tensile strengths improved by a factor of 3 and heat-deflection temperature from 150 to 260°C), polycarbonate (10–40% glass fiber loadings significantly improve physical properties), and thermoplastic polyester (2-fold increase in tensile strength and 4-fold increase in flexural strength with the addition of 40% by weight of glass fibers). Other thermoplastic resins greatly benefiting from the addition of glass fibers are polyphenylene sulfide, polypropylene, and polyether sulfone.

reinforcement Reinforcements are strong, inert materials into formulated plastics to improve their strength, stiffness, and impact resistance. Many reinforcing fibers are used in laminates and reinforced plastics. Reinforcements are usually long fibers of glass, cotton, etc. in woven or nonwoven form. However, they may also be several types of nonfiber fillers that lend property improvement to a base resin. To be effective, the reinforcing material must form a strong adhesive bond with the base resin.

See also additive; filler.

relative humidity (RH) Relative humidity is the ratio of the actual amount of vapor in the air to the maximum amount it can hold at a given temperature. The values of many plastic material properties, particularly the electrical properties and dimensional stability, are affected by relative humidity. As a result, when reporting test measurements, the properties of polymeric materials are generally given for a stated temperature and relative humidity along with a conditioning time in that environment.

relative temperature index (maximum continuous-use temperature) Underwriters' Laboratories Inc. (UL) has devised a thermal aging test protocol (UL746B) whereby a subject material is tested in comparison to a material with an acceptable service experience. The relative temperature index correlates numerically with the temperature above which the material is likely to degrade prematurely.

The end of life of a material is regarded as the point where the values of the critical properties have dropped to half of their original value. The polymeric resin manufacturer must submit his materials to UL to have it tested. When this has not been done, the designer can use the generic value for the polymer, which is usually considered conservative.

relaxation Relaxation or *stress relaxation* is the reduction of stress in a sample that has been suddenly strained and held in the strained position. It is an important test to study viscoelastic response of polymers.

The *relaxation time* is the time required for a stress under a stustained constant strain to diminish by a stated fraction of its initial value. The *relaxed stress* is the initial stress minus the remaining stress at a finite time during a stress-relaxation test.

release agent
See mold-release agent.

release film A release film is a thin, impermeable film that does not bond to the resin being cured and acts as a mold-release agent. The release film is also called a *separator*. For laminating simple shapes, cellophane is often used as an inexpensive release film.

release paper Release paper is an impermeable paper film or sheet that is coated with a material (e.g., silicone resin) to prevent adhering to a dry or semidry resin. Release paper is often used as a carrier to transport and support films of prepreg, B-stageable resins, pressure-sensitive adhesives, etc.

removable plate mold A removable plate mold is a mold generally used for the production of parts having molded threads. The name is descriptive of the plate, which is taken from the mold to a place where the molded parts can be removed, inserts loaded, or other work performed.

A variation of the removable plate mold is the *removable plunger mold*. This is generally used when the stroke of the press does not allow ejection of the molded part because of its length. The plunger may also be removed for loading inserts or for mechanical or hand ejection of the molded parts.

reprocessed plastic
See recycled plastic.

resiliency Resiliency is the ability of a material to quickly regain original shape after being restrained or distorted. *Resilience* is the ratio of energy returned, on recovery from deformation, to the work input required to produce the deformation. This is usually expressed as a percentage.

resin A resin is a high-molecular-weight organic material with no sharp melting point. Resins usually exhibit a tendency to flow when subjected to stress, and they fracture in a ductile mode. Most resins are polymers. For general purposes, the terms *resin*, *polymer*, and *plastic* can be used interchangeably.

In reinforced plastics, the resin is the material used to bind together the reinforcement material (i.e., the matrix).

See also polymer.

resin dispensing Resin dispensing is the controlled dispensing of liquid resins, usually in casting, potting, encapsulating, or resin underfill processes. Dispensing of very small quantities of resin, for high-density electronic systems, is referred to as *microdispensing*. Microdispensing is very important and very critical in modern, high-density electronic systems.

See underfill compound; electronic plastic.

resin mixer Resin mixing equipment is as diverse as its processing requirements. Resin mixers include everything from the bent rod in the hand drill motor to the continuous, vacuum-deaerated, proportional pump in-line mixer. The type of manufacturing operation normally dictates the type of mixing equipment used.

For high-production molding and encapsulation, metered, shot-dispensing mixing equipment is used to eliminate pot life problems, provide shot weight control, allow multistation dispensing from a single system, and improve housekeeping. The continuous laminator or extruder will use an in-line proportional metering pump system to get higher running speeds with hotter catalytic systems while providing a steady and controllable flow of resin mix.

The motionless or static mixer has found significant advantages in mixing two or more resinous components. This device is used in many modern automatic meter-mix-and-dispense systems. (*See* motionless mixer).

Whatever system is used, it should be accompanied by deaeration of the mix and/or the base resin if a high-quality end product is to be attained. This is usually accomplished by applying vacuum several times to the mixed formulation.

resin pocket A resin pocket is an apparent accumulation of excess resin in a small, localized section that is visible on the cut edges of molded surfaces of highly filled or reinforced parts. It is also called a *resin-rich area*. In the opposite connotation, the localized area of insufficient resin is usually called a *resin-starved area* or *dry spot*. It is identified commonly by low gloss or fibers showing on the surface.

resin-transfer molding Resin-transfer molding (RTM) is a process similar to transfer molding that is used in preparing composites. Resin-transfer molding involves the placement of dry fiber reinforcement into a close-mold and then injecting a catalyzed resin into the mold to encapsulate the reinforcement and form a composite. Usually slow-curing, low-viscosity resins such as epoxy and polyester are used.

The driving force for the use of this process comes from the large cost reductions that can be realized in raw materials and layup. The process can utilize low injection pressure (i.e., 80 psi); therefore, the tooling can be lower-cost plastic rather than metal. The process is most appropriately used for non-aerospace composites (e.g., automotive and truck sections) but has been extended to many advanced applications. The advantages of using RTM include the possibility of producing very large and complex shapes efficiently and inexpensively, reducing production times, and the ability to include inserts in the composite.

For large structures such as boats, the *SCRIMP process* uses a vacuum bag instead of the two plates of a typical mold. Advantages for this technique are the one-sided mold, better control of and higher fiber volume, and lower porosity in the composite. It has been used for structures that need higher quality than can be obtained by other RTM processes.

RTM is also a way of preparing a composite structure from a knitted preform. Knitting, braiding, and sewn three-dimensional reinforced preforms offer complex shapes that are not attainable by other techniques. These techniques can possibly lower costs because of reduction of labor. The product could also gain increased impact resistance because of the multiple, interlocked directions of the fiber.

See also transfer molding.

resistance (electrical) Electrical resistance is the electrical property of a material that indicates its resistance to an electrical current flow. Low resistance and, hence, good current flow are exhibited in electrical conductors such as copper, gold, and diamond. High resistance and poor current flow are exhibited in poor conductors (which are also good insulators) such as plastics, ceramics, and glasses.

The electrical resistance of plastics is commonly measured both through the volume of the plastic (known as *volume resistivity*, ASTM D257) and on the surface of the plastic (known as *surface resistivity*). The term for volume resistivity is ohm-cm, and the term for surface resistibility is ohms per square. Both terms are derived from a mathematical expression based on the dimensions of the test piece and the resistance measured for that test piece.

For high-performance electronic plastics, it is desired that the volume resistivity exceed 10^9 ohm-cm. One other term used to describe the resistance characteristics of an electronic plastic part, such as a circuit board or connector, is *insulation resistance*. This is simply the resistance, in ohms, between two conductors that are embedded within the plastic part.

See also dielectric properties.

resistance wire welding The resistance wire welding method of joining uses an electrical resistance heating element laid between mating plastic substrates to generate the needed heat of fusion. Once the element is heated, the surrounding plastic melts and flows together. Heating elements can be anything that conducts current and can be heated through Joule heating. This includes nichrome wire, carbon fiber, woven graphite fabric, and stainless steel foil. After the bond has been made, the resistance element that is exterior to the joint is cut off. Implanted materials should be compatible with the intended application, because they will remain in the bond line for the life of the product.

Like hot-plate welding, resistance welding has three steps: heating, pressing, and maintaining contact pressure as the joint gels and cures. The entire cycle takes 30 s to several minutes. Resistance welders can be automated or manually operated. Processing parameters include power (voltage and current), weld pressure, peak temperature, dwell time at temperature, and cooling time. With resistance wire welding, no surface preparation steps are necessary other than normal cleaning of the part.

Resistance wire welding can be used to weld dissimilar material including thermoplastics, thermoplastic composites, thermosets, and metal in many combinations. When the substrate is not the source of the adhesive melt, such as when bonding two aluminum strips together, a thermoplastic film with an embedded heating element can be used as the adhesive. Large parts can require considerable power requirements. Resistance welding has been applied to complex joints in automotive applications, including vehicle bumpers and panels, joints in plastic pipe, and medical devices. Resistance wire welding is not restricted to flat surfaces. If access to the heating element is possible, the repair of badly bonded joints is possible. Joints can be disassembled in a reverse process to that by which they were made. A similar type of process can be used to cure thermosetting adhesives when the heat generated by the resistance wire is used to advance the cure.

resistivity The resistivity of a polymer is its ability to resist passage of electric current, either through its bulk or on a surface. The unit of *volume resistivity* is the ohm-centimeter, and the unit of *surface resistivity* is ohms per square.

See also resistance (electrical); dielectric properties.

resistor A resistor is a component made of a controllable resistance material (such as carbon) that is used to provide a specified resistance or opposition to the flow of electrical current. Resistors are used to control, or limit, the amount of current in a circuit to provide a determined voltage drop. Resistance is measured in ohms. In electronics, resistors are often mounted on plastic substrates, such as printed circuit boards.

resol In the polymerization of phenolic resins, when alkaline catalysts are used in the reaction between phenol and formaldehyde, phenol alcohols are formed, called resols. If acid catalysts are used, diphenyl methane derivatives are formed, called *novolacs*. The phenol alcohol condensation to resinous form is very complex and requires three stages.

The first stage is the A-stage or resol. This represents the initial condensation product consisting principally of phenol alcohols. The resin at this point is soluble in organic solvents and has a thermoplastic nature. The second stage is the B-stage or *resitol*. This represents a degree of condensation where the molecular weight has increased to such a point that the solubility has decreased. The resin is soft and fusible when hot but hard and brittle when cold. The last stage is the C-stage or *resite*. This represents the final stage of polymerization.

resorcinol Resorcinol is one of the compounds used to produce resorcinol-formaldehyde. It is prepared by fusing the sodium salt of *m*-benzene disulfonic acid with an excess of caustic soda and acidifying the resulting compound.

resorcinol-formaldehyde Resorcinol-formaldehyde is in the phenolic family of resins, and it is produced from the reaction of resorcinol and formaldehyde. It is a thermosetting resin that is so reactive it cannot be used as a molding compound by itself. It is therefore used to modify other thermosetting resins, to which it imparts a heightened reactivity.

Its principal use, however, is as an adhesive for wood. In this application, resorcinol-formaldehyde has the unique property of setting at room temperature. The bond becomes completely waterproof in 24 h, and in another 2–4 days the bond is stronger than wood itself. Resorcinol resins also find application in bonding cellulose acetate, molded urea plastics, nylon, and various plastic laminates to wood core. They also bond to porous materials such as paper, textiles, leather, and fiberboard.

Resorcinol adhesives are resistant to boiling water, oil, many solvents, and mold growth. Their service temperature ranges from −184 to +177°C. Because of high cost, resorcinol-formaldehyde resins are often modified by the addition of phenolic resins to form *phenol resorcinol-formaldehyde*.

restricted gate A restricted gate is a very small orifice between the runner and cavity in an injection or transfer mold. When the piece is ejected, this gate breaks cleanly, simplifying separation of the runner from the piece.

retarder A retarder is a minor additive incorporated in a reactive polymeric system to slow down the rate of reaction. It is the opposite of an *accelerator*.

return pin In molding of plastics, return pins are the pins that return the ejector mechanism to the molding position.

reworked plastic (rework) Reworked plastic is a thermoplastic material generated in a manufacturing process in the form of trimmings, reject molding, and the like. It can be reused, after grinding, pelletizing, etc., in the same process by which the pieces were originally produced. Many specifications stipulate that any rework used in a process should be clean and essentially equal in quality to the relevant virgin material. A further common requirement is that the amount of rework in a plastic material or product should be limited to a specified percentage.

See also regrind.

rheology In general terms, rheology is the study of the flow of polymeric materials on a macroscopic and microscopic level. It is the study of the change in form and flow of matter, embracing elasticity, viscosity, and plasticity. It is the science of deformation and flow of matter.

The rheological behavior of polymers can be related to several different molecular mechanisms.

- *Viscous flow*, the irreversible bulk deformation of a polymeric material, is associated with irreversible slippage of molecular chains past one another.
- *Rubberlike elasticity*, where the local freedom of motion associated with small-scale movement of chain segments is retained but large-scale movement (flow) is prevented by the restraint of a diffuse network structure.
- *Viscoelasticity*, where the deformation of the polymer specimen is reversible but time dependent and is associated (as in rubber elasticity) with the distortion of polymer chains from their equilibrium conformation through activated segment motion involving rotation about chemical bonds.
- *Hookean elasticity*, where the motion of chain segments is drastically restricted and probably involves only bond stretching and bond angle deformation: the material behaves like a glass.

rigid plastic A rigid plastic is one having a modulus of elasticity either in flexure or in tension that is high enough to be of practical importance as a property parameter, for example 100,000 psi or greater at 23°C and 50 percent RH. *Semirigid plastics* are generally considered to be those with flexure or tensile moduli between 10,000 and 100,000 psi. Rigidity is generally tested in accordance with ASTM Methods D747 or D790, *Test for Stiffness of Plastics.*

rise time Used in urethane foam molding, the rise time is the time between the pouring of the urethane mix and the completion of foaming.

Rockwell hardness Rockwell hardness represents a quantitative measurement of the hardness of a material. It is a measure of the resistance to indentation in which a diamond or steel ball, under pressure, is used to pierce the test specimen. ASTM D785 specifies Rockwell hardness measurement of various materials.

The load used is expressed in kilograms. In the Rockwell hardness test a 10-kg weight is first applied, and the degree of penetration is noted. Then, the so-called major load (60–150 kg) is applied, and a second reading is obtained. The hardness

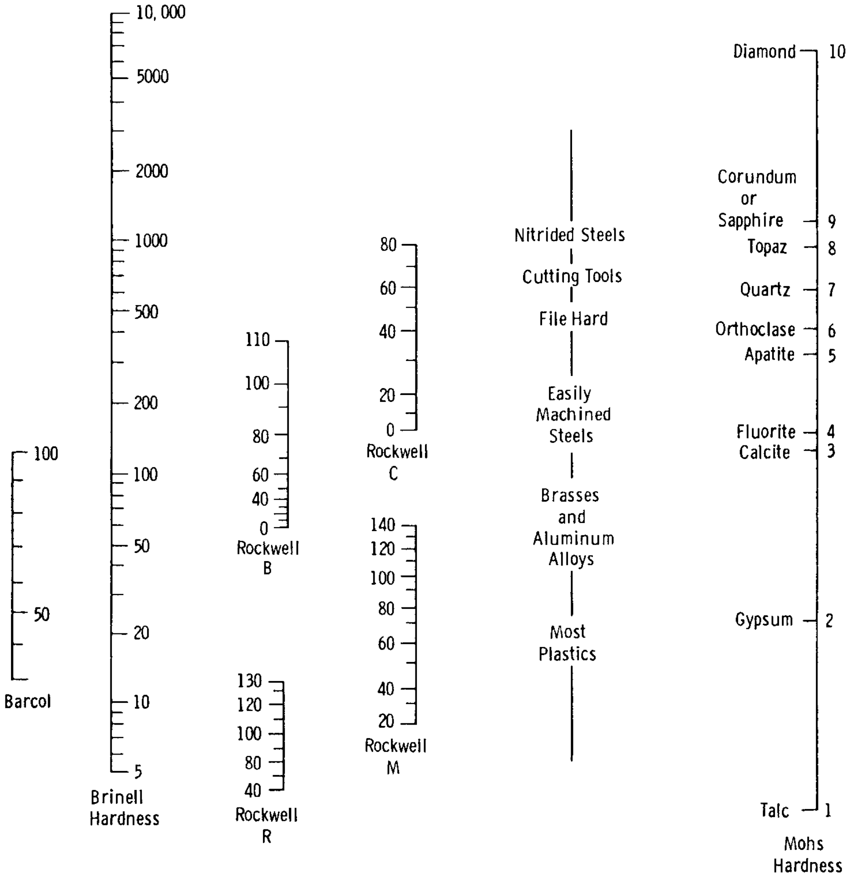

Figure R.3 Comparison of hardness scales. (Ref: Meier, J.F., “Fundamentals of Plastics and Elastomers”, *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

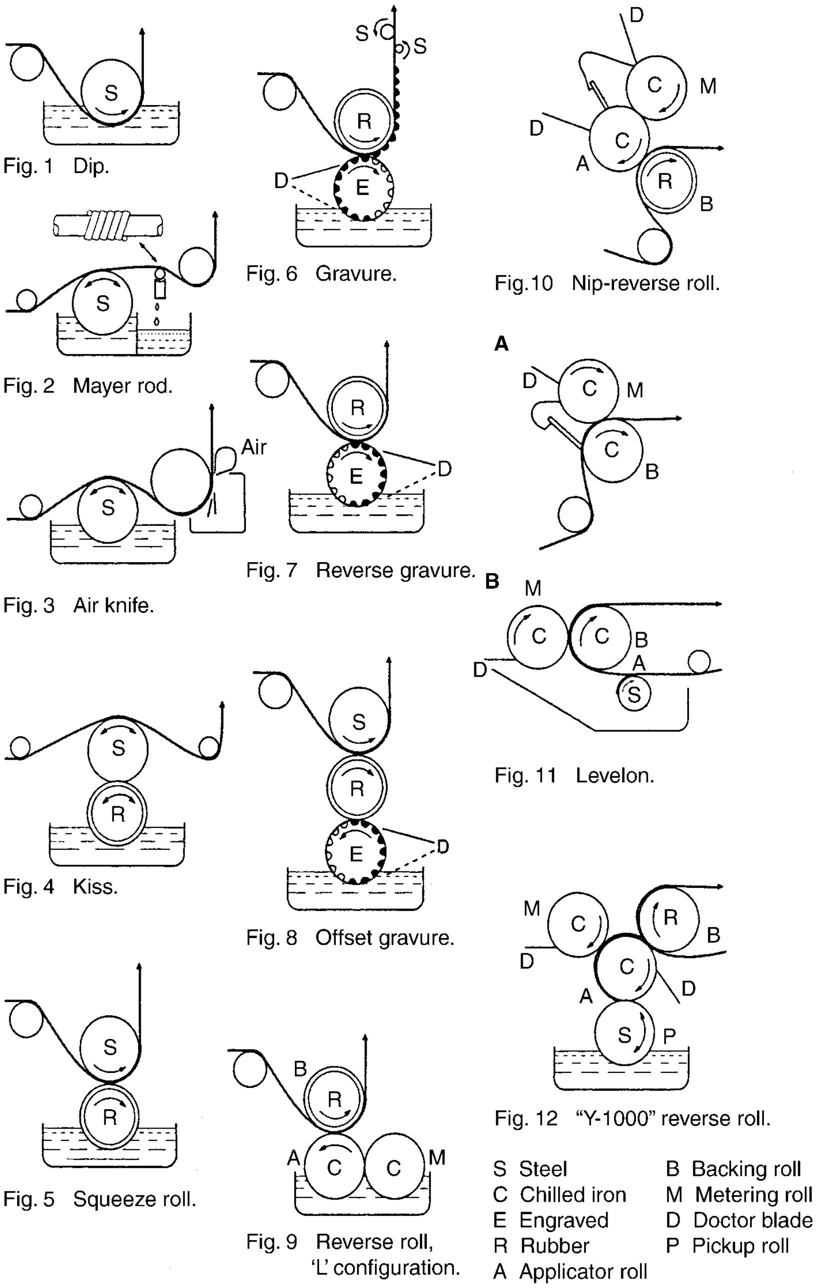

Fig. 1 Dip.

Fig. 2 Mayer rod.

Fig. 3 Air knife.

Fig. 4 Kiss.

Fig. 5 Squeeze roll.

Fig. 6 Gravure.

Fig. 7 Reverse gravure.

Fig. 8 Offset gravure.

Fig. 9 Reverse roll, 'L' configuration.

Fig. 10 Nip-reverse roll.

Fig. 11 Levelon.

Fig. 12 "Y-1000" reverse roll.

Figure R.4 Schematic representation of the twelve different roll coating processes in common commercial use. (Ref: Somerset Technologies, Inc.)

is then calculated as the difference between the two loads and expressed with nine different prefix letters to denote the type of penetrator used and the weight applied as the major load (e.g., M70).

Figure R.3 compares Rockwell R and M scales to Barcol, Brinell, and Mohs hardness measurements. Also shown for comparison are typical materials.

See also hardness.

roll coating In its simplest form a roll coater uses a single roll to carry a web below the surface of the coating material in a pan or a reservoir. This simple dip usually is followed by a scraper or wiper to remove excess material and smooth the surface. There are several popular forms of roll coating that are used depending on the coating material, application, and processing requirements. These include single-coating processes such as *dip*, *Mayer rod*, and *air knife coating*. Double-roll processes exist such as the *kiss*, *squeeze roll*, *gravure*, and *reverse gravure processes*. Multiple-roll processes such as *offset gravure*, *reverse roll L-configuration*, *nip reverse roll*, *Levelon*, and *Y-1000 reverse*. Figure R.4 represents 12 different roll coating processes that are in common commercial use.

Reverse roll coating is the most versatile of all coating methods. It offers full weight control both across and down the web despite web variations, good performance at high and low speeds, and the ability to handle a broad range of viscosities and coating materials including emulsions and hot melts. The Y-1000 reverse roll coater is primarily for ultraprecision coating applications.

Roller coating is used mainly by the coil coating industry for prefinishing metal coils that will later be formed into products. It is also used for finishing flat sheets of material. There are two types of roller coaters, direct and reverse, depending on the direction of the applicator roller relative to the direction of the substrate movement. Roller coating can apply multiple coats to the front and back of coil stock with great uniformity.

The advantages of roller coating are consistent film thickness and elimination of painting operations at a fabrication plant. The disadvantages are limited metal thickness, limited bend radius, and corrosion of unpainted edges.

roll mill A roll mill is an apparatus used to mix a plastic material with other substances. It consists of two and three rolls placed a predetermined distance apart. Each roll turns at different speeds to produce a shearing action to the materials being com-

Figure R.5 Three roll processing. (Ref: Driver, W.E., *Plastics Chemistry and Technology*, van Nostrand Reinhold, New York, 1979, p. 181) pounded. Because high temperatures are often required, it is necessary to heat the rolls with hot oil or high-pressure steam. With thermosetting type mixtures, even cooling is desired. The types and concentrations of materials that are being processed determine the roll separation distance and the relative roll speeds. The capacity of the mills varies with the roll size, accommodating mixes of 1 lb to 1 ton.

room-temperature vulcanizing (RTV) Room-temperature vulcanizing, or RTV, is a term generally used for certain silicone resins that do not require elevated temperatures to cure. RTV systems come in one- and two-component systems and do not require external heating for cure. Common silicone caulking sealants for buildings, bathrooms, and aquariums are silicone RTV elastomers. RTV systems are also often used to encapsulate delicate electric/electronic equipment.

Curing agents for two-component silicone RTV compounds normally are metallic soaps. Dibutyl tin dilaurate is the curing agent generally used for most applications. It is used in concentrations ranging from 0.1 to 0.5 percent by weight. It cures at moderate speeds and is considered the most reliable RTV catalyst. Tin octoate is the fastest curing agent available (cures within 30 min at room temperature). Levels up to 0.5 percent are used. Platinum catalysts are available for additional polymerized systems.

One-component silicone RTV systems give off acetic acid or methyl alcohol during cure. These systems require airborne moisture to cure, and the by-product evolution can cause shrinkage, offensive odors, and/or corrosion of contacting metals like copper for the acetic acid off-gassing system.

See also silicon resins.

rosin A rosin is a naturally occurring resin obtained as a residue in the distillation of crude turpentine from the sap of the pine tree (gum rosin) or from an extract of the stumps and other parts of the tree (wood rosin).

rotational molding Rotational molding, also known as *rotoforming* or *rotomolding*, is a process in which finely ground powders, usually thermoplastics, are heated in a rotating mold until melting or fusion occurs. The melting or fusion of the resin results in a uniform coating that lines the inner surface of the mold. After the resin cools, it is removed as a finished plastic part. Rotoforming thus offers a technique for producing large, complex, plastic parts by a method quite different from all other methods used to make similar parts.

The primary advantage of rotation molding is in its simple, inexpensive tooling. The process can also be used to make very large and/or very complex parts with single or double walls. Parts produced are strain free. Parts with square corners are thicker at the corners rather than thinner, as is the case with thermoformed parts. Parts are usually made with very uniform wall thickness, except as indicated above. Parts are usually made with no weld lines, sprue marks, ejection marks, etc. Very little scrap is produced. Hollow parts are easily produced with simple tooling. Usually, no secondary operations are required. Wall thickness changes can be easily made with no need for new tooling or modification of the starting raw material. The process can be operated with relatively unskilled labor.

The disadvantages of rotation molding include material costs that are relatively high because most materials are produced as pellets and then must be reduced to a fine powder. The process is not suited for production of parts with wall thickness of less than 0.030 in. It is also not suited, generally, for large production runs of small parts.

Rotational molding is well suited for prototype production of large parts such as boats, camper tops, missile containers, gasoline tanks, toys, and similar items. Almost any thermoplastic can be used for rotoforming. However, the greatest number of parts is made from polyethylene of both high and low density.

A relatively new technique of rotoforming is the production of composite moldings in which two resins are used to form the part. One resin melts first and forms the outer skin of the part. The second resin then melts, fuses to the first, and forms the inner skin. This process is being used in the production of small boats, camper tops, and similar parts.

Rotational molding can also be used for producing thermosetting parts. Here the catalyzed resin is poured into a mold, and the mold is rotated biaxially in a heated chamber. The resin is distributed solely by gravitational force. Centrifugal force is not a factor. Epoxies, silicones, and polyurethanes are adaptable to this process.

See also centrifugal casting.

roving Roving is a collection of bundles of *continuous filaments* either as untwisted *strands* or as twisted yarns. Rovings may be lightly twisted, but for filament winding they are generally wound as bands or tapes with as little twist as possible. Rovings are used in such fabrication processes as preform, press molding, filament winding, spray-up, pultrusion, and centrifugal casting.

Several forms of roving are available. *Spun roving* is among the least expensive, consisting of a single continuous strand that is looped and wound into rovinglike form. Roving products for use in gun spray-up processes can be easily cut.

RTP RTP is an abbreviation for *reinforced thermoplastic*.

rubber A rubber is a material capable of rapid elastic recovery after being stretched to at least twice its length at temperatures from −18 to 66°C at any humidity. The standard of comparison for rubbers is usually natural rubber, *Hevea*.

See elastomer.

runners Runners are all the channels in a mold through which molten or liquid plastic raw material flows into the cavity. A *runner system* includes all sprues, runners, and gates through which material flows from the nozzle of an injection molding machine or the pot of a transfer mold to the mold cavity.

The runners are as short as possible and provide minimum pressure and temperature drop from the sprue to the cavity. There are four basic types: round, half-round, trapezoid, and modified trapezoid. Round runners are the most efficient types but are the most expensive because they must be machined into both plates of the mold. Because half-round runners produce the highest pressure drops and greatest cooling of the melt, they are seldom recommended. Trapezoidal runners are a compromise between round and half-round, and modified trapezoidal runners

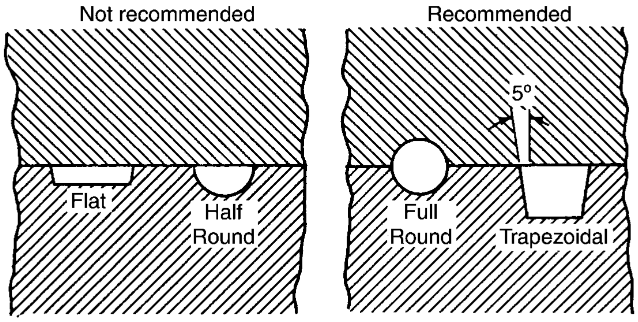

Figure R.6 Runner designs. (Ref: Monsanto Plastics and Resins Co. also Schwartz, S.S. and Goodwin, S.H., *Plastics Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 876)

merely have rounded bottoms. These runners are machined into only one mold plate but reduce the pressure and temperature losses observed with half-round runners.

Runner sizes are determined for the part wall thickness. The diameter of the runner connected directly to the cavity is typically equal to the part thickness, and each upstream branch is increased in diameter.

Although runners should deliver melt to each cavity at the same time, they may be naturally balanced or artificially balanced. In naturally balanced runners the distance from sprue to all gates is the same, whereas artificially balanced runners have the same pressure drop from sprue to all gates. Cold runner molds also incorporate cold slug wells at each turn in the melt flow. These collect the cold melt from the *sprue plug* (melt frozen at the nozzle), thereby preventing this melt from entering the cavities.

The runner network should be designed for even flow and balance where possible. If *balanced runners* are not possible, then the runner diameter may be varied to help balance the flow. The runner should enter the flow chamber in an offset manner. This configuration will allow the resin to flow around in a swirling action, reducing the chance of dead spots in the flow. The size of runners should be matched to the cavity size. In general, the manifold runner size is greater for general-purpose materials and smaller for the engineering thermoplastics.

Runnerless molds eliminate the runner system entirely (and usually the sprue system as well). The basic idea behind the runnerless mold is that, although sprue and runner channels are included in the mold, the sprue and runners are kept molten and are never formed as items that are ejected. The resin is maintained in the fluid state by various techniques, which include several types of supplementary heaters in the runner plate.

S

S-glass S-glass is a type of glass fiber that has a high nominal tensile modulus and strength relative to the more standard E-glass fiber. S-glass is produced via fiber drawing at significantly higher temperatures than other glass fibers. S-glass is inherently strong. Combined with optimized sizing, its composite strength also dramatically increases.

S-glass composites are used in the majority of aerospace applications. The glass is used to the greatest extent in combination with epoxy resins. The resultant composite maintains excellent structural characteristics up to the degradation of the epoxy resin. A primary supplier of S-glass fiber is Owens Corning.

See also glass fiber.

salt spray test Salt spray tests, or *salt fog tests*, are a group of tests whose results are indicative of one aspect of resistance of a material to corrosion in a marine environment. ASTM B117 describes a salt fog test that includes an acidified seawater exposure and SO_2 salt spray test. Such tests are more commonly applied to metals and to coatings on metals than to pure plastic materials.

Pure plastics are generally resistant to salt spray environments, although they can be significantly affected by ultraviolet (UV) light exposure. Structural laminates are an exception because of the possible degradation through moisture wicking along fibers at cut edges of the laminate.

sandblasting Sandblasting or *abrasive blasting* is generally the preferred method for removing contamination from most metal surfaces. It is particularly appropriate for

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removal of rust, oxide layers, old coatings, and other heavy contamination. Blasting is fast, efficient, and an easily controlled process. It requires containment of the blast medium and the resulting dust. The abrasive medium must be regularly renewed and/or cleaned to maintain efficiency and avoid contamination. Blasting is impractical for thin or delicate parts because of warping and possible physical damage to the part. Blasting is also a line-of-sight process, and certain part geometries may be inappropriate.

Blasting is also generally used to clean molds, provide a surface texture on plastic parts, and remove flash or other unwanted material from plastic parts and as a surface treatment before adhesive bonding or coating.

In surface treatment before bonding or coating, dry abrasive blast consists of a uniform blasting of the adherend surface with clean, fine, nonmetallic grit such as flint stone, silica, silicon carbide, aluminum oxide, or glass beads. The particle size will vary with the surface and the type of material. The degree of blasting for metal substrates should be a *white metal blast*—complete removal of all visible rust, mill scale, paint, and foreign matter. The degree of blasting for polymeric substrates before bonding or coating should be sufficient to remove the surface glaze from the part.

Written definitions and visible standards as to the degree of surface abrasion are available. A white metal blast is defined in SSPC-SP5 (Steel Structures Painting Council) or NACE No. 1 (National Association of Corrosion Engineers).

See also abrasive finishing; grit blasting.

sandwich construction A sandwich construction is a panel consisting of a lightweight core material bonded to strong, stiff skins on both faces. A honeycomb panel with skins on both faces is an example of a sandwich construction.

Bonding of the skins is done in several ways. In one technique, an epoxy cement or cement-impregnated scrim cloth is used to bond already cured facings or aluminum skins to the core. In another technique, noncured resin-impregnated and catalyzed skins are simply laid up on the core stock and cured, usually with a vacuum bag to furnish pressure. B-staged fabrics are often used for these applications.

Polyurethane foams used as a core in sandwich structures are usually made by the foam-in-place process. In this process, the skins (cured polyester, epoxy fiberglass, or aluminum) are laid up in a mold, and the urethane foamant is injected into the space between the skins.

See also honeycomb.

sandwich heating Sandwich heating is a method of heating a thermoplastic sheet before forming that consists of heating both sides of the sheet simultaneously. Sandwich heating can be performed in an oven, but usually it involves placing the thermoplastic sheet between two resistance blanket heaters or between two platens in a heated mold under very light pressure.

sandwich molding Sandwich molding is a molding process in which two different materials are injected consecutively into a mold cavity to produce products having surfaces of one plastic possessing desirable surface characteristics and with a core of another plastic possessing desirable bulk property characteristics.

One of the major advantages of the sandwich molding process is that two different resins may be used for the skin and core. Thus a hard, relatively expensive material can be used for the outer skin and an inexpensive resin, or even *regrind*, may be used for the core. The two resins used should be chemically and physically compatible.

Sandwich foam molding, also called *coinjection molding* may be considered a special form of sandwich molding. Two injection units are used to produce the skin and core as separate operations. First the skin material is injected; then, through the same sprue, the core foamant is injected. The mold cavity expands, allowing the core to foam. This is a process that has been patented by ICI of Great Britain.

Saran The names Saran and Saran Wrap are tradenames for vinylidene chloride copolymer produced by Dow Chemical Co. They represent a series of vinylidene chloride copolymers with vinyl chloride or acrylonitrile. The vinyl chloride copolymers are best known. Other copolymers with vinyl acetate, allyl esters, unsaturated ethers, acrylates, methacrylates, and styrene have appeared but have not achieved significant commercial interest.

Sarans have general resistance to organic solvents, inertness at room temperature to common acids and alkalis except for concentrated ammonium hydroxide, complete water resistance, negligible water vapor transmission, nonburning characteristics, toughness, and durability. The copolymers are attacked by halogens and strong organic amines. Saran plastics have good stability to aging and ultraviolet (UV) light. Softening temperatures range from 70 to 180°C, with physical characteristics ranging from soft, flexible products to hard, rigid materials.

The copolymers can be extruded and injection molded. They can also be compression molded with a loss of orientation and toughness. By stretching under controlled conditions at room temperature, orientation as well as recrystallization occurs, and much stronger products are formed.

Saran film, with its moisture proofing and vapor barrier properties plus its high degree of transparency, has become a popular packaging material. The typical method of processing this film is through biaxially oriented, blown film extrusion. The film's busting strength is high. Aging and UV exposure have little effect on its properties, and it maintains high chemical resistance, toughness, and serviceability to subzero temperatures.

Saran tubing is also a popular material used in laboratories and industrial plants to transport acids and corrosive chemicals. Saran and Saran-lined pipe have also been used for transporting acids and alkalis.

Saran monofilament is used in automobile seat covers and bus and restaurant upholstery. Saran has also been made into filter cloths, cordage, and industrial brushes. Its strength, aging properties, and resistance to bacterial and insect attack make it very useful for insect screens.

See also polyvinylidene chloride.

saturated compound Saturated compounds are organic compounds that do not contain double or triple bonds and, thus cannot add on elements or compounds.

sawing, cutting, shearing Nearly all types of saws have been adapted to cutting plastics. In sawing plastic sheet, there is likely to be concentrated heat buildup in the saw blade because of poor heat conductivity of the material. To allow for this, the blade should be selected according to the gauge of material. Finer pitch blades should be used for thinner material. The saw blade for cutting thicker material should be heavier and should be hollow ground.

Circular saws have unlimited use in cutting thermoplastics. With thermosets above 3/4-in. gauge, the cut should be made on a band saw. Circular saws provide a better finish, but band saws run smoother and are generally preferred. The band saw will cut through thick plastic with less heating than a circular saw because the length of blade allows the saw teeth to cool between cuts. Band saw cutting speeds range from 500 to 3000 ft/min. In cutting thermoplastics, feed ranges from 2 to 20 ft/min depending on thickness. Feed rates must be slow in thick plastic. For band sawing thin plastic, it is best to use a fine-pitch blade; thick plastics require a coarse blade. The number of teeth per inch may vary from 8 to 22. Appendix I shows circle and band power sawing parameters for various plastic materials.

For frequent cutting of reinforced, filled thermoplastics, or many thermosetting plastics, carbide-tipped blades will give accurate cuts and reasonably long blade life. Abrasive or diamond-tipped blades may also be used; however, a liquid coolant is recommended. All cutting tools should have protective shields and safety devices.

Shearing can be used for cutting of light-gauge thermoplastic sheets. All shearing should be accomplished with the material at least at room temperature. Shearing of plastic at low temperatures may crack the part. Thermoplastics may be heated to a more flexible condition to aid the shearing action.

A *CO_2 laser* can be used to punch intricate holes and cut delicate patterns in plastics. The laser can be directed to etch the plastic surface barely or actually vaporize and melt it. There is no physical contact between the plastics and the laser equipment, and no dust or drill chips are produced.

High-pressure water can also be used to *water jet* cut many plastic materials. A fine jet of water (either plain or with abrasives added) is directed at the part at pressures of 60,000 psi from a fine nozzle. Automated robotic equipment is available to water jet cut intricate patterns. This method is very attractive for many hard-to-cut materials such as aramid fiber-reinforced composites. The water jet cuts most materials quickly without a burr and does not introduce stresses in the material.

scale Scale is a condition in which resin plates or particles are on the surface of a pultruded part. Scales can often be readily removed, sometimes leaving surface voids or depressions.

scorch (scorching) Scorching is a premature vulcanization of a rubber compound. Such undesirable crosslinking also sometimes occurs in the processing of other chemically crosslinkable polymers such as polyethylene. In plastics technology, the terms *scorching* or *scorch mark* are also occasionally used synonymously with *burn* or *burn mark*.

Mooney scorch is the time to incipient cure a rubber compound in a test in the Mooney shearing disk viscometer.

scrap In plastics processing, scrap is any product of a molding operation that is not part of the primary product. In thermoset molding, this includes flash, culls, and runners. Thermoset scrap is not reusable as a molding compound. Injection molding and extrusion scrap from thermoplastic resins can usually be reground and remolded. This scrap may be runners, rejected parts, sprues, etc.

screw length Screw length is commonly expressed in terms of the *L/D ratio*, where L is the effective screw length and D is the screw diameter. The L/D ratio ranges from 12:1 to 24:1 on commercial injection screws. Reciprocating screws having an L/D ratio of greater than 20:1 are more difficult to support properly for concentric rotation and, therefore, may be prone to excessive wear. However, because a large L/D ratio provides delivery of a more uniform melt, L/D ratios of 18:1 to 20:1 are most commonly used.

See also L/D ratio; extrusion screw.

screw-plasticating injection molding Screw-plasticating injection molding is a process in which the plastic is converted from pellets to a viscous melt by means of an extruder screw that is an integral part of the molding machine. Machines are either single stage (in which plastication and injection are done by the same cylinder) or double stage, in which the material is plasticated in one cylinder and then fed to a second cylinder for injection into the mold.

Because of newer polymers that are harder to plasticate and the need for larger machines, which could produce more parts per hour, new designs have been developed for plasticating. One of the first improvements was the two-stage plunger or ram preplasticator. In this system the first stage is similar to a conventional plunger machine, in that the material is heated and liquefied in the cylinder. However, instead of delivering the melt directly to the mold, the material is injected into a second cylinder, which in turn injects it into the mold.

An improvement in the two-stage plunger machine is the replacement of the preplasticating ram with a rotating screw. The screw extrudes the plastic, which is melted by the combination of mechanical work by the screw and the heat for the heater bands. The use of the screw results in more thorough plastication combined with better control of the melt temperature through the mixing action of the screw.

screw speed The plasticizing capability of screw-injection machines is controlled primarily by screw speed. The higher the speed, the greater the output rate. The frictional heat generated by screw rotation is approximately proportional to the square of the speed. However, increasing the screw speed reduces the total time of screw rotation during the molding, thereby reducing the indicated temperature shown on the cylinder pyrometer.

Optimum screw speed is a function of the screw design characteristics (compression ratio and L/D ratio) as well as the rheological properties of the polymer involved. The melt temperatures of the higher-viscosity resins is particularly sensitive to changes in screw speed.

Excessive screw speed can cause thermal degradation, resulting in dark streaks, stray marks, and weaker molded parts. However, high screw speeds ensure a fast recharge rate and more uniform melt, thus permitting faster cycles.

See also L/D ratio; compression ratio.

scrim A scrim is a low-cost reinforcing fabric made from continuous filament yarn in an open-mesh construction. A scrim cloth is often used in the processing of tape or other B-stage material to facilitate handling. It is sometimes used as a carrier for a B-staged adhesive.

A scrim cloth can also be used in adhesive bonding as a automatic means of retaining a certain adhesive thickness. In this process, the scrim is used as a cloth spacer, impregnated with adhesive. The glass fibers in the scrim cloth act as shims to separate the two adherends regardless of the amount of pressure placed on the joint.

sealant A sealant is a substance capable of attaching to at least two surfaces, thereby filling the space between them to provide a barrier or protective coating. Sealants are generally chosen for their ability to fill gaps, resist relative movement of the substrates, and exclude or contain another material. Although similar to adhesives, they are generally lower in strength than adhesives but have better flexibility. Common sealants include urethanes, silicones, and acrylic elastomers.

The large number and diversity of sealant formulations make their classification difficult. Often sealants are divided into the same product classes, chemical families, and industrial applications as adhesives. However, there are also particular methods of classification that have been developed specifically for sealants. These unique methods of classifying sealants are by their:

- Hardening ability (hardening and nonhardening types)
- Cure
- End use
- Performance.

Appendix K lists the common sealants and their performance and application characteristics. These sealants are classified by hardening ability (i.e., hardening sealants, rigid; hardening sealants, flexible; and nonhardening sealants.)

secant modulus The secant modulus is the ratio of stress to strain given at any specific point on the stress-strain curve. In some standards it is defined as the slope of a straight line drawn from the origin to a specified point on the stress-strain curve. On materials for which the modulus changes with stress, the secant modulus is the average of the zero applied stress point and the maximum stress point being considered. The term is defined in ASTM D907.

secondary crystallization Secondary crystallization processes are slow crystallization processes that occur after the main solidification process is complete. They are often associated with impure molecules.

secondary plasticizer The secondary plasticizer or *extender plasticizer* is used in plasticized plastics along with the primary plasticizer. The secondary plasticizer has insufficient affinity for the resins to be compatible as the sole plasticizer and must be first blended with a primary plasticizer. The secondary plasticizer acts as a diluent with respect to the primary, and the primary-secondary blend has less affinity for the resins than the primary alone.

See also plasticizer.

self-extinguishing Self-extinguishing is a somewhat loosely used term describing the ability of a material to cease burning once the source of flame has been removed.

See also flammability.

self-fastening It is often possible and desirable to incorporate fastening mechanisms in the design of the molded part itself. The two most common methods of doing this are by *interference fit* (including press fit or shrink fit) and by *snap fit*. Whether these methods can be used will depend heavily on the nature of the plastic material and the freedom one has in part design.

In *press or interference fits*, a shaft of one material is joined with the hub of another material by a dimensional interference between the shaft's outside diameter and the hub's inside diameter. This simple, fast assembly method provides joints with high strength and low cost. Press fitting is applicable to parts that must be joined to themselves or to other plastic and nonplastic parts. The advisability of its use will depend on the relative properties of the two materials being assembled. When two different materials are being assembled, the harder material should be forced into the softer. For example, a metal shaft can be press-fitted into plastic hubs. Press-fit joints can be made by simple application of force or by heating or cooling one part relative to the other.

Press fitting produces very high stresses in the plastic parts. With brittle plastics, such as thermosets, press-fit assembly may cause the plastic to crack if conditions are not carefully controlled.

Where press fits are used, the designer generally seeks the maximum pullout force using the greatest allowable interference between parts that is consistent with the strength of the plastic. Figure S.1 provides general equations for interference fits (for when the hub and shaft are made of the same materials and for when they are a metal shaft and a plastic hub). Safety factors of 1.5–2.0 are used in most applications.

Figure S.1 General calculations of interference fit between a shaft and a hub. (Ref: “Mechanical Fastening”, *Handbook of Plastics Joining*, Product Design Laboratory, Norwich, NY, 1997)

For a press-fit joint, the effect of thermal cycling, stress relaxation, and environmental conditioning must be carefully evaluated. Testing of the factory-assembled parts under expected temperature cycles, or under any condition that can cause changes to the dimensions or modulus of the parts, is obviously indicated. Differences in coefficient of thermal expansion can result in reduced interference due to one material shrinking or expanding away from the other, or they can cause thermal stresses as the temperature changes. Because plastic materials will creep or stress relieve under continued loading, loosening of the press fit, at least to some extent, can be expected during service. To counteract this, the designer can knurl or groove the parts. The plastic will then tend to flow into the grooves and retain the holding power of the joint.

In all types of *snap-fit joints*, a protruding part of one component, such as a hook, stud, or bead, is briefly deflected during the joining operation and it is made to catch in a depression (undercut) in the mating component. This method of assembly is uniquely suited to thermoplastic materials because of their flexibility, high elongation, and ability to be molded into complex shapes. However, snap-fit joints cannot carry a load in excess of the force necessary to make or break the snap fit. Snap-fit assemblies are used to attach lids or covers that are meant to be disassembled or that will be lightly loaded. The design should be such that after the assembly, the joint will return to a stress-free condition.

The two most common types of snap fits are those with flexible cantilevered lugs and those with a full cylindrical undercut and mating. Cylindrical snap fits are generally stronger but require deformation for removal from the mold. Materials with good recovery characteristics are required.

To obtain satisfactory results, the undercut design must fulfill certain requirements:

- The wall thickness should be kept uniform.
- The snap fit must be placed in an area where the undercut section can expand freely.
- The ideal geometric shape is circular.
- Ejection of an undercut core from the mold is assisted by the fact that the resin is still at relatively high temperatures.
- Weld lines should be avoided in the area of the undercut.

In the cantilevered snap-fit design, the retaining force is essentially a function of the bending stiffness of the resin. Cantilevered lugs should be designed in a way so as not to exceed allowable stresses during assembly. Cantilevered snap fits should be dimensioned to develop constant stress distribution over their length. This can be achieved by providing a slightly tapered section or by adding a rib. Special care must be taken to avoid sharp corners and other possible stress concentrations. Cantilever design equations have been recently developed to allow for both the part and the snap fit to flex. Many more designs and configurations can be used with snap-fit configuration than only cantilever or snap-fit joints. The individual plastic resin suppliers are resources for design rules and guidance on specific applications.

self-ignition Self-ignition is ignition of a polymeric material from self-heating. ASTM D1929 is used to measure the temperature (self-ignition temperature or *spontaneous ignition temperature*) at which ignition results from raising the temperature of a sample in the hot-air ignition furnace test. When the sample glows rather than ignites, the term *self-ignition by temporary glow* is used.

See also flammability.

semiautomatic molding machine A semiautomatic molding machine is a molding machine in which only part of the operation is controlled by the direct action of a human. The machine controls the automatic part of the operation according to a predetermined program.

semicrystalline polymer A semicrystalline polymer is one whose morphology is characterized by the presence of both crystalline and amorphous phases. Most "crystalline" plastics are really semicrystalline polymers with both amorphous regions and crystalline regions.

A standard test method of determination of heats of fusion and crystallization of polymers is given in ASTM D3417. This test method uses differential scanning calorimetry.

semipositive mold A semipositive mold is a type of compression mold that allows a small amount of excess material to escape when it is closed. The semipositive mold combines some of the compression loading possible with the fully *positive mold* with, at the last moment, a flash cut-off and a land to assure good dimensional accuracy. A minor disadvantage of this type of mold is the fact that, if the land is made very narrow so as to cut off of the flash, the lands will wear very quickly, thus resulting in dimensional instability.

The semipositive mold serves a wide variety of applications. It is especially desirable for parts requiring a long draw, for parts that have a heavy section at the bottom of a deep piece, and for parts that must combine heavy and thin sections. This mold tends to produce a better surface finish on medium-impact materials because of their higher density, and also because the greater pressure forces the resin to the surface. Another advantage of the semipositive mold is that it produces a vertical flash line that may be removed easily by finishing on a belt sander.

See also flash mold; positive mold.

semirigid plastic For the purposes of general classification, a semirigid plastic is a plastic that has a modulus of elasticity either in flexure or in tension of between 10,000 and 100,000 psi at 23°C and 50 percent relative humidity when tested in accordance with ASTM D747 or D790, *Test for Stiffness of Plastics*.

See also rigid plastic.

separator ply A separator ply is a permeable layer that also acts as a *release film*. Porous fluorocarbon-coated fiberglass is an example. The separator ply is often placed between the layup and the bleeder to facilitate removal of the gases from the laminate after cure.

See also release film.

set When used as a noun, set refers to the strain remaining after complete release of the load producing deformation. *Compression set* is often used as a characteristic of an elastomer. It is the deformation remaining after a compressive force is applied, held for a stated period of time, and then released.

When used as a verb, set refers to the process to convert a polymer into a fixed or hardened state by chemical or physical action, such as condensation, polymerization, oxidation, vulcanization, gelation, hydration, or evaporation of volatile constituents. *Setting temperature* is the temperature to which a material is subjected to obtain set. *Setting time* is the period of time during which a material must be subjected for setting to occur.

shape factor The shape factor is the ratio of the loaded area to the force-free area of an elastomeric sheet that is loaded in compression.

shark skin Shark skin is a term used for a surface irregularity in the form of finely spaced sharp ridges caused by a relaxation effect of the melt at the die exit.

shear Shear is the action or stress resulting from applied forces that causes two contiguous parts of a body or two bodies to slide relative to each other in a direction parallel to their plane of contact. In thermoplastic molding, *shear rate* is the overall velocity over the cross section of a channel with which molten polymer layers are gliding along each other or along the wall in laminar flow. *Shear stress* is the stress developing in a polymer melt when the layers in a cross section are gliding along each other or along the wall of the channel in laminar flow.

In material characterization, *shear strength* is the maximum shear stress a material is capable of sustaining. In testing, the shear stress is caused by a shear or torsion load and is based on the original specimen dimensions. Shear strength is rarely a factor in molded and extruded plastic products because of their relatively thick wall sections. However, it can be important in film and sheet products and in adhesive joints.

In plastics testing, shear strength (ASTM D732) is determined with a 2-in.-diameter or 2-in.-square test specimen, ranging in thickness from 0.005 to 0.500 in. placed in a punch type shear fixture. Pressure is applied to the punch at the rate of 0.005 in./min until the moving part of the sample clears the stationary portion. The force divided by the area sheared determines the shear strength.

In adhesive bonding, shear is a major type of stress when one substrate is forced to move parallel and relative to the other substrate. The entire bonded area is efficiently used when joints are stressed in shear. Thus *tensile-shear* overlap design is a common joint design used in adhesive bonding. (*See* adhesives tests, Fig. A.6.)

shear ply A shear ply is a thin, low-modulus layer of plastic, rubber, or adhesive interposed between metal and composite to reduce differential shear stresses.

sheet molding compound (SMC) Sheet molding compound is a *premix molding compound* made from unsaturated polyester systems. These compounds have been modified to accommodate fabrication into B-staged sheets that are molded with matched-die molding techniques. Such systems include *sheet molding compounds* (*SMC*), *bulk molding compounds* (*BMC*), *thick molding compounds* (*TMC*) and *solid polyester molding compounds* (*SPMC*).

General-purpose SMC is used principally for structural applications in which a smooth appearance is not required. It is made from compression molding material consisting of glass fibers longer than 1/2 in. and thickened polyester resin. SMC has excellent flow and a range of surface properties. A high glass content (30–35% by weight) is used to achieve high tensile strength. Low-profile SMC is more suitable for applications that must have a smooth surface and generally good appearance.

A series of even higher-strength structural molding compounds have also been developed. They are distinguished from other SMCs by their very high percentage of fiberglass (up to 80%). *XMC* (PPG Industries) uses filament-winding techniques to incorporate continuous fiberglass strands. The uncured composite is then removed from the winding mandrel and cut into preforms for molding. *HMC* (PPG Industries) uses chopped glass stands and is processed like XMC. Major applications for these materials are automotive structures.

See also bulk molding compounds; thick molding compounds; solid polyester molding compounds.

shelf life When a polymeric resin is stored for a considerable length of time, physical and chemical changes may occur within the materials that will affect its performance either during processing or as an end product. Shelf life is generally defined as the time for which a material can be stored without losing any of its original physical or molding properties.

For example, shelf life is the time that an uncatalyzed epoxy resin can be stored and still maintain its original reactivity, flow, and final physical properties once cured. It is also the time a molding compound can be stored in which it can be molded consistently under the same conditions. Generally, shelf life is given at a specified storage condition (e.g., tightly sealed cans at 23–25°C).

ASTM D1337 provides a method for determining the shelf life of liquid polymeric systems (e.g., resin, coating, adhesive, sealant). The changes in consistency (viscosity) of the product or an end property (bond strength) are measured after various storage periods at a specified temperature.

All of the materials tested for shelf life are stored in unopened containers. Storage in containers that are opened exposes the resin to oxygen and humidity that, depending on the type of resin, could drastically reduce the shelf life and affect the final properties. Most polymeric resin products have a shelf life of greater than 6 months at room temperature. However, some precatalyzed, single-component systems need to be stored under refrigerated conditions to have a practical shelf life.

shielding compound Shielding compounds, or *shielding plastics*, are formulated or modified base plastics having some degree of electrical conductivity that will allow current flow and resultant dissipation of electrostatic discharges, leakage current, or other undesired electrical charges or signals.

Electrical conductivity in plastics is commonly achieved by adding electrically conductive fillers such as copper powder to the plastic formulation or by depositing a conductive film on the surface of the plastic.

See electrostatic discharge; dielectric strength; leakage current; conductive plastics.

shore hardness Shore hardness is a quantitative hardness measurement that uses the indentation of a material by means of a durometer (spring-loaded indentor). The higher the number, the greater the resistance to indentation. Shore range designations are given to tests made with a specified Shore durometer instrument (e.g., Shore A).

See also hardness.

short A short is an imperfection in a molded plastic part due to an incomplete fill. In molded parts this is generally a part that must be scrapped because it has voids or missing areas. This imperfection is also sometimes called a *short shot*.

In reinforced plastics, such imperfections may be evident either from an absence of surface film in some areas or as lighter, unfused particles of materials showing though a converging surface film. These types of imperfections may be accompanied by thin skin blisters.

shot A shot is the yield from one complete molding cycle, including scrap. The *shot capacity* is the maximum weight of material that an accumulator can push out with one forward stroke of the ram, screw, or plunger.

shrinkage Shrinkage of a plastic almost always occurs as it polymerizes (except for expanding monomers and cellular materials). Shrinkage of molded parts is often specified in parts per thousands. Such shrinkage occurs because the fully cross-linked plastic is denser than the molten or non-cross-linked liquid plastic. There is also mold shrinkage of the part because of the different thermal expansion coefficients of the plastic material and the metal mold. This type of shrinkage is reasonably easy to compensate for by making the cavity proportionately larger in all dimensions compared to the desired part dimension.

The use of filler can scientifically alter both the amount of shrinkage as well as its direction. Shrinkage in many materials is different when measured in different directions. This is especially true for composites and molding compounds when they are measured transverse to the material flow as opposed to when they are measured longitudinal to the flow. In reinforced or heavily filled materials, this difference is significant. This differential shrinkage results in a greater tendency of the part to warp.

See also dimensional stability; expanding monomers.

shrink mark A shrink mark is an imperfection on a molded article. It is a depression in the surface of a molded material where it has been retracted from the molded surface.

shrink wrapping Shrink wrapping is a process used in packing in which the strains in a plastic film are released by raising the temperature of the film, thus causing it to shrink over the package. These shrink characteristics are built into the film during its manufacture by stretching it under controlled temperatures to produce orientation. On cooling, the film retains its stretched condition, but reverts toward its original dimensions when heated. Shrink film gives good protection to the products packaged and has excellent clarity.

shuttle press A shuttle press is a molding machine with a reciprocating platen to permit alternate injection into two molds.

SI The International System of Units (Système International d′Unites) is a modernized version of the metric system established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units.

side corings Side corings are projections that are used to core a hole in a direction other than the line of closing of a mold. The side corings must be withdrawn before the part is ejected from the mold. Side corings are also called *side draw pins*.

silane coupling agent
See coupling agent.

silica Silica is a common filler used in many plastic formulations. In addition to reducing costs by filling and extending the polymeric resin, silica can enhance properties, provide reinforcement, and act as a processing aid, depending on which of several forms of silica are used. The modification of silica's surface by silanes, titanates, and other coupling agents broadens even further the chances for more effective application. Because of its many forms, silica's contribution to the plastics industry has been extremely significant.

Silica is a simple compound, silica dioxide (SiO_2), but complex in its phases. Silica is known to occur in 17 crystalline phases, or modes, and 5 amorphous phases. The more important forms of silica for use in compounding plastic include crystalline, microcrystalline, amorphous, and microamorphous.

Crystalline silica has a regular shape determined by an orderly three-dimensional atomic latticework. Examples are quartz crystal or well-defined, rather spherical particles from sandstone or quartzite sand. The crystalline particles may range from 70 mesh to pieces weighing several ounces. The smaller particles can be used in a mixture calculated to impart maximum strength to plastic formulations, or large pieces of quartz can be held together in a resin matrix of epoxy resin and used as decorative and strength-giving aggregates.

Crystalline silicas are used where a coarse, high-wear finish is desirable. However, they are abrasive. These materials are used mostly in thermosets and highly specialized thermoplastics. Available types include screen grades, quartzite sand, sandstone, quartz rock, and novaculite.

Microcrystalline silica is similar to crystalline, except that the fine particles are from 1 μm to as large as 74 μm (200 mesh). Much microcrystalline silica is difficult to detect with the naked eye. Pulverized and air-classified microcrystalline silica is available as quartzite sand, sandstone, tripoli, and microcrystalline novaculite. Depending on the degree of fineness, reinforcing is possible. However, microcrystalline silica is usually used for rheological adjustments of resins from low viscosity to thixotropic. These fillers are compatible with thermosets and thermoplastics. They are also used with silicone rubbers.

Amorphous silica lacks a definite shape and an orderly atomic latticework. Types of amorphous silica include glass, vitreous glass fiber, large flocculated silica gel, diatomaceous earth, and opaline phase-fused silica in granular and powder form. These products provide high purity, reinforcement, great surface area, flatting properties, and thixotropy. Fused silica has an extremely low coefficient of linear thermal expansion and has become quite popular, especially in electronics applications. The amorphous silicas are compatible with thermosets, thermoplastics, silicone rubber, and other elastomers.

Microamorphous silica is similar to amorphous silica except that particles measure in the submicrometer range. Examples of microamorphous silica are fumed silica and precipitated silica. These are used when high surface area, high purity, high gloss, and superior reinforcement properties are needed. They are compatible with thermosets, thermoplastics, silicone rubber, and other elastomers. Fumed silica is often used to provide thixotropy in resin mixtures.

Manufacturers of silica include Ashland Chemical Inc.; Harbison-Walker Refractories; Harwick Chemical Corp.; KMG Minerals Inc.; PPG Industries Inc.; Unimin Specialty Minerals Inc.; US Silica Co.; and Whittaker, Clark & Daniels.

silicone resin (rigid) Silicone resins were the first of the true high-temperature plastics. They are a family of unique synthetic polymers that are partly organic and partly inorganic. Silicone has a quartzlike polymer structure, being made up of alternating silicon and oxygen atoms rather than the carbon-to-carbon backbone that is characteristic of the organic polymers. Cured silicone resins can be flexible elastomers or rigid plastics.

Silicones have outstanding thermal stability. Some of the other properties that distinguish silicone polymers from their organic counterparts are (1) relatively uniform properties over a wide temperature range, (2) low surface tension, (3) high degree of slip or lubricity, (4) excellent release properties, (5) extreme water repellency, (6) excellent electrical properties over a wide range of frequencies and temperatures, (7) chemical inertness, and (8) weather resistance.

Silicone polymers are available in the form of liquids, gels, elastomers, and brittle solids. The resinous polymers, when combined with glass fabrics, constitute the silicone laminate used mostly in the electrical and electronics industry. When combined with chopped glass and other fillers they provide a thermoset molding compound.

Rigid silicone resins exist as solvent solutions or as solvent-free solids. The most significant uses of these resins are as paint intermediates to upgrade thermal and weathering characteristics of organic coatings or as electrical varnishes for glass tape and circuit board coatings. Glass cloth, asbestos, and mica laminates are prepared with silicone resins for a variety of electrical applications. Laminated parts can be molded under high or low pressures, vacuum bag molded, or filament wound.

Thermosetting molding compounds made with silicone resins as the binder find wide applications in the electronic industry as encapsulants for semiconductor devices. Inertness toward devices, stable electrical and thermal properties, and self-extinguishing characteristics are important reasons for their use. In general, silicone resins and composites exhibit outstanding long-term thermal stabilities at temperatures approaching 300°C along with excellent moisture and electrical properties.

Silicone molding compounds are available as compression, injection molding, extrusion, and transfer molding grades. Major suppliers include Dow Corning, GE Silicones, Bayer (*Baysilone*), Transene, Cytec Fiberite, and Wacker (*Elastosil*).

silicone rubber Silicone elastomers remain flexible as low as −80°C and stable at temperatures as high as 300°C for extended periods of time. They are virtually unchanged after long weathering, and their excellent electrical properties remain constant with temperature and frequency. They are strongly hydrophobic, but they readily transmit water vapor and other gases. Almost all castable materials readily release from silicone surfaces without pretreatment. Silicone rubber's use has been limited by its high cost, low strength, high thermal expansion, and cure inhibition of some compounds.

Silicone polymers may be filled or unfilled, depending on the properties desired and the application. They can be cured by several mechanisms, either at room temperature by *room-temperature vulcanization* (*RTV*) or at elevated temperatures. Their final form may be fluid, gel, elastomer, or rigid plastic. There are three primary types of silicone resins: (1) flexible two-part, (2) flexible one-part, and (3) rigid silicones. Silicone rubber resins for casting, potting, and other liquid processes are available from Dow Corning (*Silastic*) and GE Silicones.

Flexible two-part silicone resins are available in filled and unfilled forms. Their viscosities range from 3000 cP to viscous thixotropic fluids of greater than 50,000 cP. The polymer base for these resins is primarily *dimethylpolysiloxane*. Its molecular configuration is shown and compared to natural rubber in Fig. S.2. Some vinyl and hydrogen groups attached to silicon are also present as part of the polymer.

These products are cured at room or slightly elevated temperatures. During cure there is little if any exotherm, and there are no by-products from cure. The flexible resins have a Shore A hardness of from 0 to 60. Flexibility can be retained from −55°C or lower to 250°C or higher. Flexible resins find extensive use in electrical and electronic applications where stable dielectric properties and resistance to harsh

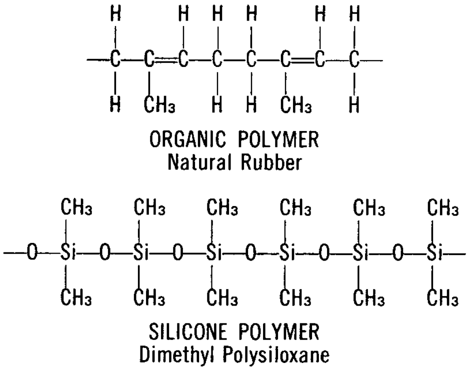

Figure S.2 General chemical structure of silicone rubber compared to natural rubber.

environments are important. They are also used in many industries to make rubber molds and patterns.

Single-component flexible silicone resins cure by reacting with moisture in the air in about 24 h at room temperature. These formulations are commonly used as adhesives and sealants. They form flexible bonds with high peel strength to many substrates, but because of their unique relative humidity-initiated curing mechanism, they cannot cure in sections of greater than 1 in. of depth. With most RTV single-component silicone formulations, acetic acid is released during cure. Consequently, metals such as copper and brass that are near to the curing silicone rubber may become corroded. For applications where the silicone is cured near or in contact with corrosive substrates, RTV silicone formulations are available that cure by liberating methanol rather than acetic acid.

Liquid silicone rubbers (*LSRs*) are two-part injection-molded compounds that can be cured rapidly. They cure in 20 s at 175°C, and new grades can cure at 95°C. They have low compression set, low durometer, and outstanding adhesion and are biocompatible. The LSRs have been coinjection molded with thermoplastics to produce vent flaps and door locking systems. LSRs cost 50 percent more than conventional moldable silicone rubber and the initial cost of a mold can be three times higher, but the cure time is three to four times faster with the LSRs.

The principal companies supplying flexible silicone resin products are General Electric, Dow Corning Corp. (*Silastic*), Stauffer Chemical Co., Union Carbide Corp., Wacker, and Shin Etsu.

silk screen printing Silk screen printing in its basic form involves laying a pattern of an insoluble material, in outline, on a finely woven fabric, so that when ink is drawn across it, it is able to pass through the screen only in the desired areas.

single-cavity mold A single-cavity mold is a mold having only one cavity in the body of the mold, as opposed to *multiple-cavity molds* or *family molds*, which have numerous cavities.

single-screw extruder A single-screw extruder consists of a screw in a metal cylinder or barrel. One end of the barrel is attached to the feed throat, and the other end is open. A hopper is located above the feed throat, and the barrel is surrounded by heating and cooling elements. The screw itself is coupled through a thrust bearing and gearbox, or reducer, to a driven motor that rotates the screw in the barrel. A die is connected to the "open" end of the extruder with a breaker plate and screen pack (or a screen changer) forming a seal between the extruder and die.

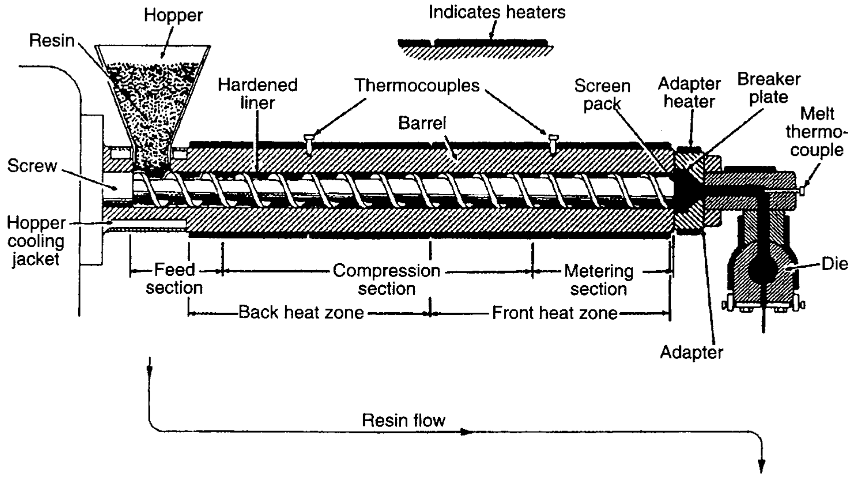

Figure S.3 Single screw extruder. (Ref: Barry, C.M.F. and Orroth, S.A., "Processing of Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

During extrusion, resin particles are fed from the hopper, through the feed throat of the extruder, and into the extruder barrel. The resin falls onto the reciprocating screw and is packed in the first section or feed zone of the screw. The packed particles are melted as they travel through the middle section (transition or compression zone) of the screw, and the melt is mixed in the final section or metering zone. Pressure generated in the extruder forces the molten polymer through the die.

See also extrusion and specific extrusion parts.

sink mark A sink mark is a depression or dimple on the surface of an injection molded part caused by collapsing of the surface after local internal shrinkage. Sink marks may also form from an incipient short shot.

Sink marks in a molded part (see Fig. S.4) often occur in relatively thick sections, reflecting progressive hardening of the molded part from the cavity wall to the inside area. The outside wall hardens while the mass of plastic in the thick sections is still somewhat fluid. As this inside mass subsequently hardens and shrinks, the cured outer wall is distorted inward, resulting in a sink mark.

The best way to avoid such deformation is to avoid thick sections, by including one or more judiciously designed thin ribs in selected locations to give equivalent strength yet reduced wall thickness.

See also shrinkage.

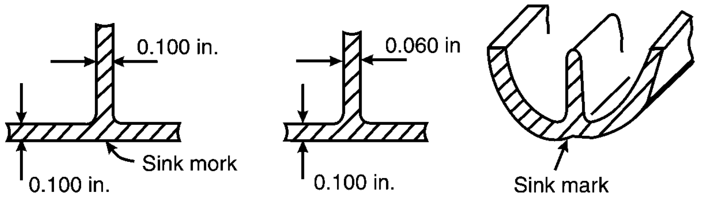

Figure S.4 Sink marks. (Ref: Hull, J.L., "Design and Processing of Plastic Parts", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

sizing Sizing is a thin coating of material that is applied to glass fibers to provide a degree of protective surface treatment on the filaments. It is generally a chemical treatment containing starches, waxes, and the like that is applied directly to the fibers, making them more resistant to breakage during the weaving process. The sizing agent is often removed after weaving, as its presence could cause delamination and moisture pickup problems if it remained in the final laminate made from the woven fiber.

The sizing treatment may also bond the filaments together into a strand so that they can be handled more efficiently. In certain cases the sizing may also incorporate a *coupling agent*, which subsequently improves adhesion of the resin matrix to the galls.

See also finish.

skiving Skiving is a method of continuously cutting thin sheets or films from a round section of material that may be cast or sintered. Skiving is usually applied to polymers that are not normally amenable to extruding or solution casting. In practice, it has been used almost exclusively for production of films of *Teflon* (DuPont), a polytetrafluoroethylene (TFE), and other polymeric materials that cannot be easily extruded or cast into film. (See Fig. F.3 under film.)

slip Slip is the degree of tack, adhesion, or "stickiness" that one plastic has when it is stacked with similar materials (film, sheet, etc.) or when it is matched with other plastics. Slip properties in plastics can be tested by the static coefficient of friction test. This test measures the ratio of the force required to move one film surface over another to the total force pressing the two surfaces together. Those plastics with a ratio of greater than 0.8 show no slip properties; those with a ratio less than 0.2 show high slip properties.

slip agent Slip agents provide surface lubrication during and after processing of plastics. In essence, they function as lubricants. They have limited compatibility and are designed to migrate to the surface of the plastic, where they lower the coefficient of friction and reduce the sticking of the plastic to itself by minimizing tack (*see also* antiblocking agents). The reduced friction facilitates processing on high-speed packaging equipment as well as easing the end use of plastic film products.

Slip agents also impart improved antistatic properties (*see* antistatic agents), lower plasticity, and better release from mold surface or other parts of processing equipment (*see also* mold-release agents).

Slip agents are typically used in applications where surface lubrication is desired—either during or immediately after processing. To accomplish this, the materials must exude quickly to the surface of the film. To function properly they should have only limited compatibility with the resin. Slip agents, in addition to lowering surface friction, can also impart the following characteristics:

- Lower surface resistivity (antistatic properties)
- Reduce melt viscosity
- Mold release

Slip agents are often referred to as lubricants. However, they should not be confused with lubricants, which act as processing aids. Although most slip agents can be used as lubricants, many lubricants cannot be used as slip agents because they do not always function externally.

The major types of slip agents include fatty acid amides (primarily erucamide and oleamide), fatty acid esters, metallic stearates, waxes, and proprietary amide blends.

The most popular applications to make use of slip agents are polyvinyl chloride (PVC) and polyolefin film and sheet. The agents are usually modified fatty acid esters and are effective in concentrations of 1–3 phr. Fatty amides, which have FDA acceptance for a wide variety of applications, are also finding use as slip agents in engineering thermoplastics as well as PVC and polyolefins. The most frequently used amides are erucamide and oleamide.

Slip agents come in several physical forms including flakes, pellets, and powders. Other factors to be considered in choosing a slip agent are (1) whether a quick-blooming slip agent is required (oleamide, for example, migrates to the surface faster than erucamide); (2) processing temperature and duration (erucamide, for example, has better thermal stability properties than oleamide); and (3) whether the application requires an FDA accepted additive.

There are many manufacturers of slip agents. Major manufacturers include Akxo Chemicals Inc.; Crowley Chemical Co.; C. P. Hall Co.; Emery Group, Henkel Corp.; ICI Americas Inc.; Struktol Co.; Wacker Silicones Corp.; and Witco Corp.

See also antiblocking agent; mold-release agent; lubricant; slip.

slip forming Slip forming is a sheet forming process in which some of the plastic sheet material is allowed to slip through the mechanically operated clamping rings during a stretch-forming operation.

slot extrusion Slot extrusion is a method of extruding film sheet in which the molten thermoplastic compound is forced through a straight slot.

slush molding Slush molding is a method for casting hollow thermoplastics in which the resin in liquid form is poured into a hot mold, where a viscous skin forms. The excess slush is drained off, the mold is cooled, and the molding is stripped out.

Slush molding is often used with PVC plastisols, and it is like dip coating in that a hot mold is filled with plastisol and the material is immediately poured out. The temperature of the mold and its heat capacity determine the final thickness of the molded part, as in the dip coating process.

smoke/toxic gas generation Burning or smoldering polymeric materials usually generate smoke, which is undesirable but often serves to trigger fire detection devices. Several standard tests are designed to provide a quantitative measurement of the amount of smoke generated by the combustion of polymeric materials.

The ASTM smoke density test (ASTM D2843) involves a smoke density chamber featuring a horizontal specimen and a propane-fueled burner. An optical device is used to record light transmitted over a horizontal light path across the chamber. A blower is used to purge the chamber after test. The NBS smoke test (ASTM E622) uses a somewhat different chamber than ASTM D2843, with a test specimen held vertically and subjected to an electric radiant panel. The Steiner tunnel test (ASTM E84) can also be instrumented to measure smoke density of large samples.

All smoke tests are controversial as to their absolute value and the meaning of the result. However, they are useful for making comparisons between materials tested under identical conditions.

See also flammability; smoke suppressant.

smoke suppressant The potential smoke evolution from burning polymers and compounds has become an important issue in various applications. Transportation and construction are two large markets where the awareness of smoke density during pyrolysis has materialized into specifications for maximum smoke density values.

Aluminum trihydrate, magnesium carbonate, and magnesium hydroxide are three functional fillers that on thermal decomposition will emit water of hydration, and in the case of magnesium carbonate the emitant is carbon dioxide. The use of these fillers in commercial applications confirms their performance and effectiveness as smoke supperessants.

See also flame retardants; smoke/toxic gas generation.

smoothing Smoothing or *polishing* can provide lustrous finish on plastic parts or remove surface defects, light or residual flash, and marks from machining operations. The smoothing and polishing techniques for finishing plastics are similar to those used on wood, metal, and glass. Lathers, buffing wheels, and suitable polishing compositions are used in these processes. For production buffing of articles with simple contours, automatic machines are available that must be engineered for the particular job. All dry buffing and polishing operations require an efficient exhaust system because many of the dusts are combustible. Usually the smoothing or polishing operation is completed after the part has undergone rough grinding or sanding.

Several types of finishing operations are available to smooth plastic surfaces. All consist of holding the surface to be finished next to a soft rotating wheel containing a moderately abrasive substance. *Ashing* is a finishing operation in which a wet abrasive is applied to a loose muslin wheel. *Buffing* is an operation in which grease- or wax-filled abrasive cakes are applied to a loose or sewn muslin wheel. *Polishing* uses wax compounds filled with fine abrasives. Polishing wheels are generally made of loose flannel or chamois.

In the polishing of thermoplastics, overheating must be avoided. Thus it is necessary to avoid exceedingly hard buffing wheels and excessive speeds or pressures. For the buffing of thermoplastics, fine silica powders in special grease binders are available. For thermosetting plastics, a polishing operation using a greaseless compound on a more rigid buffing wheel is recommended. A large variety of various polishing waxes are available. It is necessary to determine experimentally, case by case, which wax is to be used for the best results.

Plastics should never be finished on polishing wheels used for metal. Small metal particles left on the wheel may damage the plastic surface. All rotating machines should be electrically grounded because frictional movement of the wheels against the plastic surface readily generates static electricity.

Polishing of certain plastic parts may also be accomplished by dipping the part in a solvent to dissolve surface irregularities. Cellulosic and acrylic parts may be polished in this manner. The parts are either dipped or sprayed with a selected solvent for approximately 1 min. The plastic supplier should recommend specific solvents. Solvents are sometimes also used to polish edges or drill holes. Annealing of the part may be necessary before solvent dipping to prevent crazing.

Surface coatings may also be used on most plastics to produce a high surface gloss. This operation may be less costly than other finishing operations. Flame polishing with an oxygen-hydrogen flame may be used to polish several plastics. This procedure is much like the flame treatment described for surface-treating plastics before adhesive bonding.

snap back forming Snap back forming is a sheet-forming technique in which an extended, heated plastic sheet is allowed to contract over a male mold form that is shaped to the desired contours.

See thermoforming.

sodium aluminum silicate Sodium aluminum silicate is a tailorable filler useful in both thermoplastics and thermosets as a color extender or reinforcement. It is prepared by the reaction of aluminum sulfate with sodium silicate, producing an insoluble white precipitate that is filtered, washed, dried, and milled to various degrees of fineness. The structure level is controllable.

Sodium aluminum silicate has been found to be an effective extender of colorants, replacing up to 10 percent of TiO_2 in a variety of compounds. The grades with higher structure also produce higher levels of reinforcement. In a polyvinyl chloride plastisol, for example, replacing 10 percent TiO_2 increases tensile properties by about 25 percent.

Suppliers of sodium aluminum silicate include Degussa Corp.; Ethyl Corp.; J.M. Huber Corp.; Thiele Kaolin Co.; and Kaopolite Inc.

softening temperature range The softening range is the range of temperatures in which a plastic changes from a rigid to a soft state. Actual values will depend on the method of test. Depending on the plastic, the softening temperature can be a sharp temperature or a broad temperature range.

solid polyester molding compound Solid polyester molding compounds (SPMC) differ from other molding compounds such as SMC, BMC, and TMC, in their physical form. Solid polyester molding compounds are in the form of convenient and free-flowing dry pellets containing up to 20 percent glass. The extrusion processing techniques used to produce SPMC permit the addition and wetting of glass fibers with minimal fiber degradation. The resulting pellets can be easily fed to an in-line screw-injection molding machine to mold parts with high impact strengths.

SPMC materials are developed specifically for use in automatic molding systems such as injection, transfer, and compression molding. SPMC is available in various colors, flow grades, and shrinkage factors.

See also sheet molding compound; bulk molding compound; thick molding-compound.

solids content The solids content refers to either the nonvolatile component of a resinous system or the inorganic component of the system. The nonvolatile solids content is usually determined by weighing a small amount of material in a clean container, heating or curing until a constant weight is obtained, and then weighing the container again. The percentage of solids is determined as the ratio of the sample weights before and after curing multiplied by 100.

The percent solids measured in this way is an indirect measurement of the amount of volatile material in the sample that was driven off during the heating cycle. ASTM D1489 offers a test for determining the nonvolatile content of nonaqueous adhesives.

The *ash test* is a measure of the total inorganic content in a sample. In this test, a weighted sample is placed in a *muffle furnace* at approximately 538°C for 30 min or at a temperature and time long enough to completely pyrolize all organic matter. The remaining material is inorganic filler, reinforcement, etc. ASTM D5040 provides a method of measuring the ash content of polymer systems.

solution casting Plastic sheet or film may be produced by dissolving the polymer in an appropriate solvent, spreading the viscous solution into a polished surface, and evaporating the solvent. This process is known as solution casting.

In the manufacture of photographic film base, the solution is spread with a knife onto a slowly rotating wheel about 2 ft wide and 20 ft in diameter. As the wheel revolves, heated air evaporates the solvent (which is recovered for reuse), and the dried film is stripped from the wheel before the casting point is again achieved.

solvation Solvation is the process of swelling, gelling, or dissolving a resin by a solvent or by a plasticizer.

solvent A solvent is any substance, usually a liquid, that dissolves other substances. Solvents are sometimes needed to disperse a polymeric resin to a consistency that is more easily applied such as by brush or spray. Solvents are also used to aid in formulating by reducing the viscosity so that additions of other components and uniform mixing may be more easily achieved.

Solvents used with synthetic resins and elastomers are generally organic in nature. Often a mixture of solvents is required to achieve the desired properties. Polar solvents are required with polar resins; nonpolar solvents with nonpolar resins. Water is sometimes used as a solvent for water-soluble resins. Certain polymers are also available as a water-based emulsion or latex formulation.

When solvents are used in the adhesive or coating formulation, they must be completely evaporated from the bondline before cure. Otherwise, bubbles could form in the bond line, causing a weak joint. In the early 1970s, during the time of the petroleum crisis, water-based adhesives were thought of as a possible replacement for solvent-based adhesives systems. However, water-based adhesives never met the lofty expectations, primarily because of the time and energy required to remove water from the bond line, the corrosion that the water causes in drying ovens, and the poor moisture resistance of the final product.

solvent cementing Solvent cementing is the simplest and most economical method of joining noncrystalline thermoplastics. In solvent cementing, the application of the solvent softens and dissolves the substrate surfaces being bonded. The solvent diffuses into the surface, allowing increased freedom of movement of the polymer chains. As the parts are then brought together under pressure, the solvent-softened plastic flows. van der Waals attractive forces are formed between molecules from each part, and polymer chains from each part intermingle and diffuse into one another. The parts then are held in place until the solvent evaporates from the joint area.

Solvent-cemented joints of like materials are less sensitive to thermal cycling than joints bonded with adhesives because there is no stress at the interface caused by differences in thermal expansion between the adhesive and the substrate. When two dissimilar plastics are to be joined, adhesive bonding is generally desirable because of solvent and polymer compatibility problems. Solvent-cemented joints are as resistant to degrading environments as the parent plastic. Bond strength greater than 85 percent of the parent plastic can generally be obtained. Solvents provide high-strength bonds quickly because of rapid evaporation rates.

Solvent bonding is suitable for all amorphous plastics. It is used primarily on ABS, acrylics, cellulosics, polycarbonates, polystyrene, polyphenylene oxide, and vinyls. Solvent welding is not suitable for crystalline thermoplastics. It is not effective on polyolefins, fluorocarbons, or other solvent-resistant polymers. Solvent welding is moderately effective on nylon and acetal polymers. Solvent welding cannot be used to bond thermosets.

A disadvantage of solvent welding is that many solvents are flammable and/or toxic and must be handled accordingly. Proper ventilation must be provided when bonding large areas or for high-volume production. The bonded part should not be packaged or stressed until the solvent has adequate time to escape form the joint. Complete evaporation of solvent may not occur for hours or days. Some solvent-joined parts may have to be “cured” at elevated temperatures to encourage the release of solvent before packaging.

Table S.1 Typical Solvents for Solvent Cementing of Plastics (Ref: Raia, D.C., “Adhesives-King of Fasteners”, *Plastic World*, June 1975)

Solvents for bonding plastics	Acetic acid (glacial)	Acetone	Acetone: ethyl acetate: R (40:40:20)	Acetone: ethyl lactate (90:10)	Acetone: methoxyethyl acetate (80:20)	Acetone: methyl acetate (70:30)	Butyl acetate: acetone: methyl acetate (50:30:20)	Butyl acetate: methyl methacrylate (40:60)	Chloroform	Ethyl acetate	Ethyl acetate: ethyl alcohol (80:20)	Ethylene dichloride	Ethylene dichloride: methylene chloride(50:50)	Methyl acetate
ABS														
Cellulose acetate		■		■	■	■	■			■				■
Cellulose acetate butrate		■	■	■	■	■	■			■				■
Cellulose propionate						■								
Ethyl cellulose											■			
Nylon	■													
Polycarbonate												■	■	
Polymethyl methacrylate												■		
Polyphenylene oxide									■			■		
Polystrene										■				
Polysulfone														
Polyvinyl chloride														
SAN								■		■				
Styrene butadiene		■												

(*Continued*)

Table S.1 (*Continued*)

Solvents for bonding plastics	Methylene chloride	Methylene chloride: methyl methacrylate (60:40)	Methylene chloride: methyl methacrylate (50:50)	Methylene chloride: thrichloroethylene (85:15)	Methyl ethyl ketone	Methyl isobutyl ketone	Methyl methacrylate	Tetrachloroethylene	Tetrachloroethane	Tetrahydrofuran: cyclohexanone (80:20)	Toluene
ABS					■	■					
Cellulose acetate											
Cellulose acetate butrate											
Cellulose propionate											
Ethyl cellulose											
Nylon											
Polycarbonate		■							■		
Polymethyl methacrylate		■	■				■				
Polyphenylene oxide	■			■							
Polystrene	■				■		■				
Polysulfone	■										
Polyvinyl chloride					■	■					■
SAN					■						
Styrene butadiene					■	■					

Table S.1 (*Continued*)

Solvents for bonding plastics	Toluene: ethyl alcohol (90:10)	Toluene: methyl ethyl ketone (50:50)	Trichloroethane	Trichloroethylene	Xylene	Xylene: methyl isobutyl ketone (25:75)
ABS		■				■
Cellulose acetate						
Cellulose acetate butrate						
Cellulose propionate						
Ethyl cellulose			■			
Nylon						
Polycarbonate						
Polymethyl methacrylate				■		■
Polyphenylene oxide				■		
Polystrene	■					
Polysulfone					■	
Polyvinyl chloride						
SAN						
Styrene butadiene						

Solvent cements should be chosen with approximately the same solubility parameter as the plastic to be bonded. Table S.1 lists typical solvents used to bond major plastics. Solvents used for bonding can be a single pure solvent, a combination of solvents, or a solvent(s) mixed with resin. It is common to use a mixture of a fast-drying solvent with a less volatile solvent to prevent crazing. The solvent cement can be bodied up to 25 percent by weight with the parent plastic to increase viscosity. These bodied solvent cements can fill gaps and provide less shrinkage and internal stress than when only pure solvent is used.

solvent molding Solvent molding is a process for forming thermoplastic articles by dipping a male mold in a solution or dispersion of the resin and drawing off the solvent to leave a layer of plastic film coated on the mold. When the solvent evaporates and the coating hardens, the product can be removed from the mold.

Table S.2 Solvents that Affect Plastics (Ref: Izzo, C.P., "Decorative and Protective Coatings", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Resin	Heat-distortion Point, °F	Solvents that Affect Surface
Acetal	338	None
Methyl methacrylate	160–195	Ketones, esters, aromatics
Modified acrylic	170–190	Ketones, esters, aromatics
Cellulose acetate	110–209	Ketones, some esters
Cellulose propionate	110–250	Ketones, esters, aromatics, alcohols
Cellulose acetate butyrate	115–227	Alcohols, ketones, esters, aromatics
Nylon	260–360	None
Polyethylene:		
High density	140–180	
Med. density	120–150	None
Low density	105–121	
Polypropylene	210–230	None
Polycarbonate	210–290	Ketones, esters, aromatics
Polystyrene (G.P. high heat)	150–195	Some aliphatics, ketones, esters, aromatics
Polystyrene (impact, heat-resistant)	148–200	Ketones, esters, aromatics, some aliphatics
ABS	165–225	Ketones, esters, aromatics, alcohol

solvent resistance Solvents affect thermoplastics, rubber, and thermosets in different ways. Thermoplastics usually dissolve in an adequate solvent. Solvent molecules separate the chains, forming a solution. Drying will return the thermoplastic to its normal state. Table S.2 shows the solvents that will affect surfaces of certain plastics.

Rubber generally swells as the solvent penetrates between the chains. The chemical bonds between polymer chains (due to crosslinking or vulcanization) are not ordinarily broken. On removal of the solvent, the rubber will often return to its original size and strength.

Highly crosslinked plastics are usually not affected by solvents. This type of plastic cannot be dissolved unless the chemical crosslinks are broken. If this should occur by a suitably aggressive solvent for the particular polymer, strength will be severely degraded.

specific gravity Specific gravity is a measurement that reflects the density of the material. It is the ratio of the density gm/cm^3 or lb/ft^3 of the test material to that of water. A specific gravity of 1.0 is equivalent to the density of water. This test is not normally performed until 24 h after molding to permit most of the postmolding shrinkage to take place. See Fig. D.2 under *density* for specific gravities of common polymers.

It is important to consider the specific gravity (or density) in establishing the actual cost of a resin. Density is also used to determine the extent of molecular orientation and packing in molded parts.

See density.

specific heat The specific heat of a material is the ratio of a material's thermal capacity to that of water at 15°C. Specific heat determinations are made with a drop-type adiabatic calorimeter. Specific heat of plastics remain constant with temperature but will vary if filler or reinforcements are added. A relevant standard method of determining specific heat capacity is given in ASTM C351.

specific modulus The specific modulus of a material is *Young's modulus* of the material divided by the material's density.

specific strength The specific strength of a material is the *ultimate tensile strength* of the material divided by the material's density.

spherulite Not only are polymer chains often arranged to form crystalline regions or *crystallites*, but these crystallites are often arranged in large aggregates known as *spherulites*. These spherulites grow radially from a point of nucleation until other spherulites are encountered. Thus the size of the individual spherulites can be controlled by the number of nuclei present, more nuclei resulting in more but smaller spherulites.

Spherulites are in some ways similar to the grain structure in metals. They are typically about 0.01 mm in diameter and have a Maltese cross appearance between crossed Polaroids. Large spherulites contribute to brittleness in polymers. To avoid this, nucleating agents are often added or the polymer is shock cooled to promote smaller spherulites.

See also crystallites; nucleating agents.

spider In a molding process, the spider is the part of an ejector mechanism that operates the ejector pins. In the extrusion process, it is a term used to denote the membranes supporting a mandrel within the head/die assembly.

See also injection molding; injection mold; extrusion.

spinning The conversion of bulk polymer to fiber form is accomplished by spinning. In most cases, spinning processes require solution or melting of the polymer. The conversion of the spun polymer melt or solution to a solid fiber involves cooling, solvent evaporation, or coagulation, depending on the type of spinning used.

If a polymer can be melted under reasonable conditions, the production of a fiber by melt spinning is preferred over solution processes. When melt spinning cannot be carried out, a distinction as to type of process is made depending on whether the solvent is removed by evaporating (dry spinning) or by leaching out into another liquid that is miscible with the spinning solvent but is not itself a solvent for the polymer (wet spinning). Dry spinning has some advantages over wet spinning, but the two processes have many features in common.

In the *dry spin process*, the filament is formed by the evaporation of solvent from the polymer solution into air or an inert gas atmosphere. The solvent must, of course, be volatile. Dry spinning has been used for many years for spinning cellulose acetate from acetone solution, and is now used for several vinyl fibers including polyvinyl chloride and its copolymers and polyacrylonitrile spun from solution in organic solvents. Spinning is done in a vertical tubular cell (see Fig. S.5), jacketed for temperature control in which air, steam, or inert gas may be passed through either concurrently or counter currently as required. Downward spinning is preferred for small-denier fibers and upward spinning for high deniers, to control draw better by eliminating the influence of gravity. Dry spinning is carried out at rates as high as 2500–3000 ft/min.

In the *wet spinning process*, a solution of a polymer or polymer derivatives is spun through a spinneret into a liquid, which can coagulate the polymer or derivative. The chemical reaction to convert the derivative to the final polymer can take place simultaneously or later. Wet spinning is commonly used for viscose, cellulose, and some synthetic fibers such as polyacrylonitrile spun from salt solution The essential feature in wet spinning is the transfer of the mass of the solvent from the polymer to the coagulating bath. The need for sufficient time for coagulation and other treatments depending on diffusion and the considerable viscous drag of the coagulating baths limit the rates of wet spinning to 150–300 ft/min.

In *melt spinning*, molten polymer is pumped at a constant rate under high pressure through a plate called a *spinneret*. A spinneret is a type of extrusion die through which a plastic melt is forced to make fine fibers and filaments. The liquid polymer streams emerge downward from the face of the spinneret, usually into air, on bobbins. A subsequent drawing step is sometimes necessary to orient the fibers. The filaments emerge from the spinneret face into air and begin to cool. An air blast may be used to speed up the cooling process. After the filaments have traveled far enough to become solid (about 2 ft) they are brought together and wound up. Speeds of about 2500 ft/min are usually used.

spin welding Spin welding uses the heat of friction to provide the heat of fusion required at the interface. One substrate is rotated very rapidly while in touch with the other substrate, which is fixed in a stationary position. The surfaces melt by frictional

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Figure S.5 Schematic diagrams of the three principal methods of spinning fibers. (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 516) heating without heating or otherwise damaging the entire part. Sufficient pressure is applied during the process to force out a slight amount of flash along with excess air bubbles. Once the rotation is stopped, position and pressure are maintained until the weld sets. The rotation speed and pressure are dependent on the thermoplastics being joined.

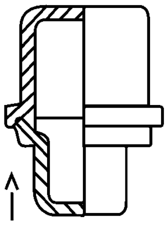

Figure S.6 Spin Welding. (Ref: Hull, J.L., "Design and Processing of Plastic Parts", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1996)

Spin welding is an old and uncomplicated technique. The equipment required can be as simple as lathes or modified drills. Spin welding has a lower capital cost than other welding methods. The base equipment required is comparatively inexpensive; however, auxiliary equipment such as fixtures, part feeders, and unloaders can drive up the cost of the system. Depending on the geometry and size of the part, the fixture that attaches the part to the rotating motor may be complex. A production rate of 300 parts/min is possible on simple circular joints with an automated system containing multiple heads.

The main advantages of spin welding are its simplicity, high weld quality, and the wide range of possible materials that can be joined with this method. Spin welding is capable of very high throughput. Heavy welds are possible with spin welding. Actual welding times for most parts are only several seconds. A strong hermetic seal can be obtained that is frequently stronger than the material substrate itself. No foreign materials are introduced into the weld, and no environmental considerations are necessary. The main disadvantage of this process is that spin welding is used primarily on parts where at least one substrate is circular.

When considering a part as a candidate for spin welding, there are three items that must be considered: (1) the type of material and the temperature at which it starts to become tacky, (2) the diameter of the parts, and (3) how much flash will develop and what to do with the flash.

The weld can be controlled by the rpm of the motor and somewhat by the pressure on the piece being joined, the timing of the pressure during spin and during joining, and the cooling time and pressure. In commercial rotation welding machines, speed can range from 200 to 14,000 rpm. Welding times range from tenths of a second to 20 s; cool-down times are in the range of 1/2 s. A typical complete process time is 2 s. Axial pressure on the part range from 150 to 1000 psi. A prototype appraisal is usually completed to determine the optimum parameters of the process for a particular material and joint design.

Typical applications include small parts such as fuel filters, check valves, aerosol cylinders, tubes, and containers. Spin welding is also a popular method of joining large-volume products such as packaging and toys. Spin welding can also be used for attaching studs to plastic parts.

spiral flow test The spiral flow test is a test method for measuring flow properties of a resin in which the resin flows along a spiral path in a mold. It is used to measure flow of a resin under transfer-or injection-molding conditions. The variation in flow for different resins or different molding conditions can be compared. Flow is expressed in inches of flow in a standard spiral flow mold.

The five-turn spiral mold is known as the *Mesa spiral* test mold, which has a spiral length of 48 in. It is used for transfer molding of materials in the 1000 to 10,000-psi range. The 10-turn mold, known as the *IBM spiral*, has a total length of 102 in. It is used for testing very soft, long-flow materials used for encapsulation, where the pressures range from 25 to 1000 psi. There is currently no agreed-upon spiral flow test standard for the industry.

spiral mold cooling Spiral mold cooling is a method of cooling injection molds or similar molds in which the cooling medium flows through a spiral cavity in the body of the mold. In injection molds, the cooling medium is introduced at the center of the spiral near the sprue section, because more heat is localized at this section.

split-wedge or split-cavity mold A split-wedge or split-cavity mold is a mold in which a split-cavity block is assembled in a chase to permit the forming of undercuts in a molded piece. A split-wedge mold can be used for the production of a spool as shown in Fig. S.7.

Parts A and B are ejected from the mold and then separated from the piece. These sections are made with a taper to fit the chase or housing. Mold sections and other loose parts are generally called *wedges*.

spray coating Spray coating is the most common type of coating. Eight types of spray painting equipment are available. Spray coating was originally developed in the automotive industry in the 1920s for improved appearance and increased production.

Rotating spray coaters rely on the centrifugal force to atomize droplets of liquid as they leave the highly machined, knife-edged rim of an electrically charged rotating applicator. Disk- or bell-shaped applicators are used. An advantage of rotating disk and bell spray coating is its ability to atomize high-viscosity coating materials. A disadvantage is maintenance of the equipment.

High-volume, low-pressure spray coaters use turbines rather than pumps to supply high volumes of low-pressure, heated air to the spray guns. Newer versions use ordinary compressed air. The air is heated to reduce the tendency to condense atmospheric moisture and to stabilize solvent evaporation. Low atomizing pressure results in lower droplet velocity, reduced bounce-back, and reduced overspray. The

Figure S.7 Cross section of a split cavity mold for producing a molded spool. A and B form the two halves of the cavity. Chase, C, folds the halves together. Other parts are: D, core pin; E; bottom plate; and F, the force plug or plunger. (Ref: Buckleitner, E.V., ed., “Basic Mold Types and Features”, *Plastics Mold Engineering Handbook*, 5th ed., Chapman & Hall, New York)

main advantage of this process is the reduction of overspray and bounce-back and the elimination of the vapor cloud usually associated with spray painting.

The *airless electrostatic spray* process uses airless spray guns with the addition of a DC power source that electrostatically charges the coating droplets. Its advantage over airless spray is the increase in transfer efficiency due to electrostatic attraction of charged droplets to the product.

The *air-assisted airless electrostatic spray* process is a hybrid of technologies. The addition of atomizing air to the airless spray gun allows the use of high-viscosity, high-solids coatings. Although the theoretical transfer efficiency is in a high range, it is lower than that of airless electrostatic spray coating because of the higher droplet velocity. Its advantage is its ability to handle high-viscosity materials and better pattern control.

The *air electrostatic spray coating* method uses conventional equipment with the addition of electrostatic charging capability. The atomizing air permits the use of most high-solids coating. Its advantage is being able to handle high-solids materials. However, it has the lowest transfer efficiency of the electrostatic spray coating methods.

In the *airless spray coating* process the coating material is forced by hydraulic pressure through a small orifice in the spray gun nozzle. As the liquid leaves the orifice it expands and atomizes. The droplets have low velocities because they are not propelled by air pressure as in conventional spray guns. To reduce the coating's viscosity without adding solvents, in-line heaters are added. Its advantages are less solvent used, less overspray, less bounce-back, and compensation for seasonal ambient air temperatures and humidity changes. A disadvantage is its slower curing rate.

Multicomponent spray coating equipment is used for applying fast-curing coating systems components simultaneously. They have two or more sets of supply and metering pumps to transport components to a common spray head. Its advantage is the ability to apply fast-curing, multicomponent coatings. The disadvantages are equipment cleanup, maintenance, and low transfer efficiencies.

Air-atomized spray coating has been used to apply protective and decorative coatings since the 1920s. A stream of compressed air mixes with a stream of liquid coating, causing it to atomize or break up into small droplets. The liquid and air streams are adjustable, as is the spray pattern, to meeting the finishing requirements. Its advantage is that a skilled operator can adjust fluid flow, air pressure, and coating viscosity to apply a high-quality finish on most products. The disadvantages are its low transfer efficiency and ability to spray only low-viscosity coatings, which may emit significant amounts of VOCs to the atmosphere.

Spray coating can also be used for coating polymer powders. Spray powder coating is especially useful for articles that are too large for dip coating or fluidized bed coating. The process consists of blowing out fine polymer powder thorough a specially designed burner nozzle, which is usually flame heated by means of acetylene or some similar gas or can be heated electrically. Compressed air or oxygen is used as the propelling force for blowing the polymer powder. Generally, the substrate must be preheated to a temperature over the melt temperature of the powder.

sprayed-metal mold Sprayed-metal molds are molds that are made by spraying molten metal onto a master until a shell of predetermined thickness is achieved. The shell is then removed and backed up with plaster, cement, casting resin, or other suitable material. The sprayed mold is used primarily as a mold for the sheet-forming processes.

spray-up Spray-up covers a number of techniques in which a spray gun is used as the processing tool. In reinforced plastics, for example, fibrous glass and resin can be simultaneously deposited in a mold. In essence, glass roving is fed through a chopper and ejected into a resin stream, which is directed at the mold. In foamed plastics, very fast-reacting urethane foams or other types of polymeric foams are fed in liquid streams to the gun and sprayed on the surface. On contact, the liquid starts to foam and then sets.

See also hand layup.

spreader The spreader is a streamlined metal block placed in the path of the flow of the plastic material in the heating cylinder of extruders and injection molding machines to spread it into thin layers, thus forcing it into intimate contact with the heating areas.

spring box mold The spring box mold is a variation of other mold types such as landed plunger, loading shoe, positive, flash, etc. This construction is frequently used to solve difficult molding problems involving inserts.

In the open position, the insert and molding compound have been loaded in place by the conventional procedure and the mold is ready for pressure to be applied. A spacing fork is inserted between the mold cavity and the parallels to prevent compression of the die spring and hold the inset below the bottom of the cavity. As the plunger enters the cavity, a complete molded shape will be formed except that the insert will not be in its proper place. After the compound has reached its plastic state, and before curing begins, the pressure is momentarily released by the operator so that the spacing form may be pulled out. Immediately after, the pressure is applied again. This time the die spring will be compressed and the cavity assembly forced down so the insert will remain in the proper position throughout the cycle. After the part is cured, release of pressure will permit the die springs to open the gap between the cavity assembly and the parallels so that the fork may be placed in position for the next cycle.

sprue A sprue is a feed opening provided in the injection or transfer mold. It is also a term for the slug formed at this hole. *Sprueless molds* are created by sprueless runner systems that are designed with the nozzle extending as close as possible to the main runner.

sprue bushing A sprue bushing is a hardened steel insert in an injection mold that contains the tapered sprue hole and has a suitable seat for the nozzle of the injection cylinder. The sprue bushing is sometimes called an *adapter*.

The front end of the sprue bushing contains a spherical depression or recess to fit the cylinder nozzle in order to permit easy release of the plastic sprue. Standard taper should be 1/2 in./ft. The orifice at the nozzle end of the sprue will separate readily from the nozzle when the mold opens. The sprue orifices should be at least 1/4 in. in diameter. The length of the sprue channel should be as short as possible and never longer than 4 in.

spun roving Spun roving is a heavy glass or aramid fiber strand consisting of filaments that are continuous but doubled back on themselves.

stabilizer Stabilizers are chemicals used in plastic formulation to assist in maintaining physical and chemical properties during processing and service life. Stabilizers are generally characterized by the specific property they are trying to maintain or by the aging property that they are trying to stabilize. For example, a specific type of stabilizer known as an ultraviolet stabilizer is designed to absorb ultraviolet rays and prevent them from attacking the plastic.

See also antioxidant; heat stabilizer; ultraviolet stabilizer.

stacked mold It is possible to feed two molds at one time from a single sprue. Such a combination mold is termed a stacked mold. It is also called a two-tier, two-level, tandem, or sandwich mold. Stacked molds are usually runnerless molds.

In this type of mold, production can be theoretically doubled providing that the machine capacity is high enough to fill both sets of cavities. The stacked mold consists of two sets of cavities, one on top of another. In this way high clamping pressure, which would normally be required with a mold having an increased number of cavities, is also minimized.

stampable thermoplastics Stampable thermoplastics are suitable for fabrication in metal stamping or compression presses. These materials are exemplified by nylon-based, mineral-filled thermoplastics.

stamp printing Stamp printing produces code or lettering by using a metal or rubber die exposed to an ink. Letterpress, letterflex, gravure, and flexography are methods of applying ink via various types of dies. For lay-flat film products gravure and flexographic printing are most commonly used.

See also printing on plastics.

standard dimension ratio (SDR) SDR or standard dimension ratio is a ratio used for dimensioning of plastic pipe. It is the ratio of the outside diameter or inside diameter to the wall thickness.

standards Many standards have been developed for reinforced plastics, laminates, and composites. In the United States, the most active bodies have been:

- American National Standards Institute (ANSI)
- Institute for Interconnecting and Packaging Electronic Circuits (IPC)
- American Society for Testing and Materials (ASTM)
- National Electrical Manufacturers Association (NEMA)
- Underwriters' Laboratories (UL)
- U.S. Federal Government

Federal specifications are defined in the Department of Defense's Index of Specifications and Standards (DODDISS) D7.14:981 and Index of Federal Specifications and Standards and Commercial Item Descriptions GS2.8/2:981. These are available from the U.S. Government. Many of the federal and military standards are gradually being abandoned as the Department of Defense replaces these with ASTM standards.

Plastic standards exist in many countries other than the United States. Many of these standards can be obtained from the American National Standards Institute (ANSI). The most active of these foreign standard bodies are:

- British Standard Institute
- French Association of Standardization
- Canadian Standards Association
- European Association of Aerospace Manufacturers
- German Institutes for Standards
- Japanese Standards Association

A complete listing of specifications and standards for plastics and composites can be found in Appendix J.

staple A staple fiber is a fiber of short lengths, usually 1/2–2 in. long and 1–5 denier. Staple fibers are generally manufactured from spinable length fibers by various cutting processes. Staple fibers are often used as reinforcement in molding compounds to improve physical properties such as modulus and impact strength.

starved area The starved area is the part of a laminate or reinforced plastic structure in which resin has not completely wetted the fabric or reinforcement.

static electricity
See electrostatic discharge.

stationary platen The stationary platen is the plate of a molding machine to which the front plate of the mold is secured during the operation. This platen is so-named because it does not move during the normal operation.

steam molding Steam molding is a process used to mold parts from preexpanded beads of polystyrene by using steam as a source of heat to expand the blowing agent in the material. The steam is contacted directly with the beads in most cases, or the steam may be used indirectly to heat mold surfaces that are in contact with the beads.

step cure A step cure is a cure cycle that is started at a low temperature and gradually is brought up to the cure temperature either at a programmed rate or in a predetermined steplike fashion. The step cure cycle allows gasses to escape before solidification of the resin as in the curing of phenolic resins. The step cure cycle may also be integrated with bumping of the pressure to allow the gasses to escape more easily.
See also out-gassing.

stereospecific (stereoregular) plastics Stereospecific, or stereoregular, plastics implies a specific or definite order of arrangement of molecules in space. This ordered regularity of the molecules is in contrast to the branched or random arrangements found in other plastics. Stereospecificity permits close placing of the molecules and leads to high crystallinity, as in the case of polypropylene.

stiffness Stiffness of a plastic is measured by its modulus or the relationship of load to deformation. It may also be expressed as the ratio between the applied stress and resulting strain. Stiffness is a term often used when the relationship of stress to strain does not conform to the definition of Young's modulus.

stitching Stitching is the progressive welding of thermoplastic materials by successive applications of two small mechanically operated electrodes, connected to the output terminals of a radio frequency generator, using a mechanism similar to that of a normal sewing machine.

stops Stops are metal pieces that are inserted between die halves used to control the thickness of a press-molded part. The use of stops is generally not recommended in practice, because the resin will receive less pressure than if the stops were not used and this can result in voids and a less dense product.

storage life

See shelf life.

strain Strain is the deformation resulting from a stress. It is measured by the ratio of the change to the total value of the dimension in which the change occurred. It is simply the change in length per unit of original length. Strain is nondimensional but frequently expressed in percentage, inches per inch, or centimeters per centimeter.

strength, dry and wet *Dry strength* is the strength of an adhesive joint determined immediately after drying under specified conditions or after a period of conditioning in a standard laboratory atmosphere. *Wet strength* is the strength of an adhesive joint determined immediately after removal from a liquid in which it has been immersed under specified conditions of time, temperature, and pressure.

stress Stress is the unit force or component of force at a point in a body acting on a plane through the point. It is simply the ratio of applied load to the original cross-sectional area of a specimen. Stress is usually expressed in pounds per square inch or in dynes per square centimeter.

stress crack A stress crack is an external or internal crack in a plastic caused by tensile stresses. The stresses that cause cracking may be present internally or externally or may be combinations of these stresses. Two basic conditions must be present for a stress crack related failure: (1) a stress and (2) an external initiating agent. For plastics the nature and structure of the material and its process history can influence the extent of stress cracking.

The development of such cracks is frequently accelerated by the environment to which the plastic is exposed. The initiating agent can be chemical exposure, heat exposure, surface-active agents, oils, greases, solvents (particularly those that cause softening or swelling of the plastic's surface), and oxidation. The stress crack can manifest itself as a series of fine surface cracks called *crazing* at one extreme, and to catastrophic rupture at the other extreme.

stress relaxation Stress relaxation is the time-dependent decrease in stress for a specimen constrained in a constant strain condition. It is the loss in stress that remains after a polymeric material has been held at constant strain over a period of time.

stress-strain diagram The stress-strain diagram (Fig. S.8) is the graph of stress as a function of strain. It is constructed from the data obtained in any mechanical test in which the load is applied to a material and continuous measurements of stress and strain are made simultaneously.

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Figure S.8 Generalized tensile stress-strain curve for plastics. . (Ref: Billmeyer, F.W., *Textbook of Polymer Science*, Interscience, New York, 1965, p. 109)

stretch forming Stretch forming is a forming process in which the heated thermoplastic sheet is stretched over a mold and subsequently cooled.

stripper plate mold A stripper plate is a plate that strips a molded piece from core pins or force plugs. The stripper plate is set into operation by the opening of the mold. The stripper plate mold uses the stripper plate and is similar in some respect to the loading-shoe mold and the removable-plate mold. It is functionally operated in the same manner as the loading-shoe mold. The stripper plate fits the core at the inside of the molded part. (See Fig. S.9)

The primary purpose of a stripper plate is to eject the part from the mold without distorting it or without the presence of objectionable ejector pin marks. The stripper plate is usually used for parts with thin wall sections (0.010–0.040 in.) when the part

Figure S.9 Diagram showing construction used for a stripper plate mold. The stripper plated is pushed down by auxiliary press equipment causing molded parts to be "stripped" from the plunger. (Ref: Buckleitner, E.V., ed., "Basic Mold Types and Features", *Plastics Mold Engineering Handbook*, 5th ed., Chapman & Hall, New York)

cannot be ejected by means of ejector pins. Stripper plate molds are not often required for thermosetting materials because the finished piece is hard and, consequently, ejector pins serve satisfactorily for ejection of the parts.

Molding by this method should be confined to units that contain only a small number of cavities, as temperature differentials may cause binding of the plates. Conversely, large numbers of cavities would require special attention to minimize expansion problems.

stripping agents It is sometimes desirable to remove a plastic coating or embedding compound in order to recover the component to which the plastic was applied. In many cases, it is desirable to soften the plastic with heat and to remove it with mechanical means. Sharp impacts, thermal shock, etc. also often facilitate the removal of unwanted plastics. However, it is not always possible to remove such plastic without the use of *chemical strippers*. There are suppliers who offer proprietary chemical strippers that work on selected polymers.

Most of the less inert thermoplastics respond well to attack by oxygen-containing solvents such as cyclohexanone or ketones. Chlorinated solvents are usually even more effective and do not cause the flammability hazards associated with the other solvents. Solutions of acetic acid or acetic acid in combinations with solvents are also used.

The best of the strippers for the thermosetting compounds are based on chlorinated solvents, usually methylene dichloride in combination with a small amount of an acid or base and perhaps in a blend with other solvents such as chlorobenzene. However, many thermoset resin formulations are virtually inert to the action of strippers.

structural adhesive A structural adhesive is an adhesive used for transferring required loads between adherends exposed to service environments that are typical for the structure involved. Structural adhesives are generally considered to be those having tensile strengths greater than 1000 psi and having other properties that are sufficient to resist the end use environment.

structural foam molding The part produced by structural foam molding is not homogenious like the part produced by thermoforming or injection molding. Within the outer skin, there is a cellular structure with the cell size increasing toward the center. The part must have a wall thickness of 0.0187 in. for any significant amount of foaming to take place. Thus the structural foam part may actually require more resin than the equivalent part made by either thermoforming or injection molding if the wall thickness must be increased to accommodate the foaming processes.

In addition, the molding process for structural foam molding is much longer than that of injection molding because of the time required for gas expansion. For these reasons, the piece part cost will be greater for a part produced by structural foam molding than for a similar part made by injection molding.

Parts made by the structural foam molding process have a swirled surface. Gas counterpressure structural foam molding and coinjection molding are variations of the process, which can produce a solid, nonswirled surface. Depending on the application, the additional mold cost for the gas counterpressure feature reduces the tooling savings over the injection molding alternative. Coinjection molding permits a solid material to be used for the outer skin and a foamed material for the inner structure, which can also be a less expensive material. This process requires sophisticated equipment. (*See* coinjection molding.)

Parts made by structural foam molding, gas counterpressure structural foam molding, or coinjection molding use closed molds and low pressures. The low pressure keeps the tool cost significantly lower than traditional injection molding, although the rate of molding is slower. These foam molding processes often allow the design of a component in one section (e.g., a steering wheel or a vacuum cleaner handle). The foam molding processes eliminate the need for assembly and the cost of fasteners. This results in a lower product cost even though the injection molding process has faster cycle times.

styrene

See polystyrene.

styrene acrylonitrile copolymers (SAN) Styrene acrylonitrile polymers are copolymers prepared from styrene and acrylonitrile monomers. The polymerization can be done under emulsion, bulk, or suspension conditions. The polymers generally contain between 20 and 30 percent acrylonitrile. The acrylonitrile content of the polymer influences the final properties, with tensile strength, elongation, and heat-distortion temperature increasing as the amount of acrylonitrile in the copolymer increases.

SAN copolymers are linear, amorphous materials with improved heat resistance over pure polystyrene. The polymer is transparent but may have a yellow color as the acrylonitrile content increases. The addition of a polar monomer, acrylonitrile, to the backbone gives these polymers better resistance to oils, greases, and hydrocarbons compared to polystyrene. Glass-reinforced grades of SAN are available for applications requiring higher modulus combined with lower mold shrinkage and lower coefficient of thermal expansion.

Because the polymer is polar, it should be dried before processing. It can be processed by injection molding into a variety of parts. SAN can also be processed by blow molding, extrusion, casting, and thermoforming.

SAN competes with polystyrene, cellulose acetate, and polymethyl methacrylate. Applications for SAN include injection-molded parts for medical devices, polyvinyl chloride (PVC) tubing connectors, dishwasher-safe products, and refrigerator shelving. Other applications include packaging for the pharmaceutical and cosmetics markets, automotive equipment, and industrial uses.

SAN can be modified with olefins, resulting in a polymer that can be extruded and injection molded. The polymer has good weatherability and is often used as a capstock to provide weatherability to less expensive parts such as swimming pools, spas, and boats.

SAN copolymers are commercially available in extrusion and injection molding grades. There are many suppliers of each. Major suppliers of SAN copolymer molding compounds are BASF (*Luran*), Bayer (*Lustran*), ComAlloy, Dow Chemical (*Tyril*), DSM Engineering, LG Chemical, LNP, RTP and Spartech.

styrene butadiene polymer Styrene butadiene polymers are *block copolymers* prepared from styrene and butadiene monomers. The copolymers are better known as *thermoplastic elastomers* (*TPEs*) and often referred to as *styrene butadiene rubbers* (*SBR*). However, copolymers with high styrene contents can be treated as thermoplastics.

The polymerization is performed with sequential anionic polymerization. The polymers can be prepared as either a star block form or as a linear, multiblock polymer. The butadiene exists as a separate dispersed phase in a continuous matrix of polystyrene. The size of the butadiene phase is controlled to be less than the wavelength of light resulting in clear materials.

The resulting amorphous polymer is tough with good flex life and low mold shrinkage. The copolymer can be ultrasonically welded, solvent welded, or vibration welded. The copolymers are available in injection molding, blow molding, extrusion, and thermoforming grades. The injection molding grades generally contain a higher styrene content in the block copolymer. Thermoforming grades are usually mixed with pure polystyrene.

Compared with similar *natural rubber* compositions of the same hardness, styrene butadiene rubber (SBR) formulations are characterized by lower tensile strength, elongation, and resilience, lower resistance to tear, flexing, abrasion, ozone, and sunlight, and higher permanent set. The freeze resistance and permeability to gases of styrene butadiene are equivalent to those of comparable natural rubber, and so are the electrical characteristics.

The polymer does not need to be dried before use. Major suppliers of these compounds include Fina Oil and Chemical (*Finaclear*), Phillips Chemical (*K-Resin*), BASF, and Firestone (*Stereon*).

Typical applications of styrene butadiene rubber include practically all products for which natural rubber is suitable except where high resilience is required. Styrene butadiene copolymers are used in toys, houseware, and medical applications. Thermoformed products include disposable food packaging such as cups, bowls, deli containers, and lids. Blister packs and other display packaging also use styrene butadiene copolymers. Other packaging applications include shrink wrap and vegetable wrap.

subcavity gang mold The subcavity gang mold consists of a group or "gang" of cavities located below a common loading well, and it is used in compression molding. A hundred or more cavities may be contained in each gang of a mold designed for small pieces. Such molds are frequently built with from 3 to 6 gangs, each gang containing 50 to 100 cavities.

As the mold closes, the compound is plasticized by the heat and pressure so that it flows into the cavities, leaving a thin layer of flash connecting all the pieces. The flash enables the press operator to pick up the load from each gang as a unit instead of picking up the individual pieces. The flash is then removed by tumbling or some other finishing operation.

submarine gate The submarine gate is a type of edge gate where the opening from the runner into the mold is located below the parting line or mold surface as opposed to conventional edge gating, where the opening is machined into the surface of the mold. (See Fig. S.10.) With submarine gates, the item is broken from the runner system on ejection from the mold.

See also tunnel gate.

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Figure S.10 Tunnel or submarine gate for automatic part-gate separation of the mold. (Ref: Schwartz, S.S. and Goodwin, S.H., *Plastics Materials and Process*, van Nostrand Reinhold, New York, 1982, p. 545)

substrate The substrate is the material on the surface of which an adhesive-containing substance is spread for any purpose, such as bonding or coating. Substrate is a broader term than *adherend*, which usually refers to an adhesively bonded substrate only. In electronics, a substrate is also the material on which a circuit is formed.

sulfone resin Sulfone-based resins are polymers containing —SO_2 groups along the backbone. The other groups are generally aromatic. The polymers are usually yellowish, transparent, amorphous materials and are known for their high stiffness, strength, and thermal stability. The polymers have low creep over a large temperature range. Sulfones can compete against some thermoset materials in performance, and their ability to be injection molded offers an advantage.

See polysulfone; polyaryl sulfone; polyether sulfone.

surface-active agent

See surfactant.

surface analysis Close examination of surfaces from fractured specimens or failed joints can sometimes lead to an explanation of why the specimen failed. With visual or microscopic examination of adhesive joints, it is sometimes evident that adhesive failure occurred at the original interface because of improper wetting or at some new interface, leaving behind a thin layer of adhesive. In comparing surface features after bond failure with the original adherend surface, the maximum resolution of about 1×10^{-8} m (100 Å) for scanning electron microscopes may not always be sufficient to detect a thin film of adhesive closely reproducing the original surface profile. Optical and staining methods to determine the presence of such films are mainly applicable to fairly thick films because optical techniques use interference phenomenon. Films a few angstroms thick are still largely undetected.

In recent years the use of highly specialized surface characterization tools has greatly improved the opportunity for deducing the surface composition. These tools have been developed for the purpose of analyzing both the adherend and the adhesive. For adherends, analytical examination generally centers on either (1) the surface chemistry for prepared surfaces by elemental analysis, chemical species, or analysis of contaminates and boundary layers or (2) analysis of failed surface for evidence of interfacial failure, failure within the adherend (e.g., metal oxide, composite matrix or fiber, etc.), or failure within a primer or other boundary layer. Analysis of the adhesive generally consists of characterizing the cured film, curing agents, and failed specimen surface chemistry.

The sciences of microphotography and holography have been used for NDT of adhesive bonds. Magnification and photography of the failed substrate will often lead to useful clues to the cause of failure. Holography is a method of producing photographic images of flaws and voids with coherent light such as that produced by a laser. The major advantage of holography is that it photographs successive "slices" through the scene volume. A true three-dimensional image of a defect or void can then be reconstructed.

Over the last 20 years, analytical tools have become available that allow for the characterization of the elemental and chemical composition of solid surfaces. The application of these analytical tools has increased our understanding of surface

Table S.3 Techniques for Studying Surface Structure and Composition (Ref: Dillard, J.G., "Microscopic Spectroscopic Studies in Adhesion", *Adhesion Principles and Practice,* Course Material Kent State University, May 1998)

	Technique	Probe Species	Description
ESCA	Electron Spectroscopy for Chemical Analysis	X-rays	Chemical information through line shape analysis. Useful for insulators and conductors. Widely used on polymers. Sample may be damaged due to X-rays.
SIMS	Secondary Ion Mass Spectrometry	Ions	Semi-quantitative elemental analysis. Useful only for conductors or Ionic insulators. Sample is severely damaged.
AES	Auger Electron Spectroscopy	Electrons	Quantitative elemental analysis tool for determining surface composition of semiconductors and conductors. Limited to non-insulators.
ATR-FTIR	Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy	Infrared light	Detailed chemical information. Non-vacuum method. Specimens must be flat and capable of intimate contact with the necessary crystal.
ISS	Ion Scattering Spectroscopy	Ions	Information gained on surface composition. Elemental analysis with single layer atomic resolution.
XES	X-Ray Emission Spectroscopy	X-rays	Information on energy levels and chemical state of adsorbed molecules; surface composition.

properties and successfully characterized surface layers. Table S.3 shows a comparison of analytical characteristics of some surface-sensitive analytical tools. The most popular of these are secondary ion mass spectroscopy (SIMS), ion scattering spectroscopy (ISS), and Auger electron spectroscopy (AES). These tools have proven practical even when the surface films are only on the order of atomic dimensions or when the failure occurs near the original interface and includes parts of both the adhesive and the adherend.

By itself, SIMS has been shown to be a powerful tool for elemental surface characterization; however, uncertain or rapidly changing secondary ion yield due to changes in chemical bonding makes quantitative analysis virtually impossible with SIMS alone. SIMS is most helpful when combined with other techniques, such as ISS and AES, which use a beam of ions of correct energy for combined use with SIMS.

The greatest strength of ESCA (electron spectroscopy for chemical analysis) lies in its ability to provide information on the surface chemistry of polymers or organics. The excitation is relatively nondestructive. AES is a useful high-spatial-resolution technique for the analysis of metals, alloys, and inorganic materials. Polymer and organic surfaces pose problems because of beam damage and sample charging. ISS is an elemental analysis technique with single-atomic-layer resolution. ISS is often used in conjunction with other surface techniques.

surface-modifying agent

See coupling agent.

surface resistivity Surface resistivity is the resistance of a material between two opposite sides over a unit square of its surface. Surface resistivity may vary widely with the conditions of measurement. It is commonly expressed in ohms per square. Surface resistivity is measured per ASTM D257.

See resistance (electrical).

surface tension In both solids and liquids the forces associated with interior molecules are balanced because each molecule is surrounded by like molecules. On the other hand, molecules at the surface are not completely surrounded by the same type of molecules, and this causes unbalanced forces. At the surface these molecules show additional free surface energy. Interfacial energy and surface energy in polymeric materials control adhesion, wetting, printing, surface treatment, and fogging.

The intensity of the free energy is proportional to the intermolecular forces of the material. The free surface energy of liquids and solids is called surface tension. It can be expressed in MJ/m^2 or dyn/cm. Values of surface tension in polymers range from 20 dyn/cm for fluorocarbons to 46 dyn/cm for nylon.

ASTM D2578 covers the measurement of surface tension by contact angle measurement. Several independent methods are also available for measuring surface tensions of polymeric systems.

See also wetting.

surface treatment The main purpose of surface preparation is to ensure that adhesion develops to the extent that the weakest link in the joint is either in the adhesive, sealant, or coating or else it is in the adherend. With optimum surface treatment, failure should not occur at the interface because of a weak boundary layer or insufficient wetting. As a general rule, all substrates must be treated in some manner before bonding, if not to remove or prevent the formation of weak boundary layers then to provide a consistent and repeatable surface. Certain low-energy surfaces must be modified chemically or physically before bonding so that the adhesive or sealant can adequately wet the surface and provide the attractive forces necessary for good adhesion. Surface preparation can range from simple solvent wiping to a combination of mechanical abrading, chemical cleaning, and acid etching.

For reliable bonding, the surface preparation method can provide several principal functions:

- Remove weak boundary layers that (1) impede wetting of the substrate and (2) create "weak links" at the interface. Common weak boundary layers are greases, oils, scale, rust, tarnish, and other oxides.
- Protect the substrate surface so that weak boundary layers do not develop during processing of the joint or during aging in service.
- Influence the surface energy of the substrate so as to reduce the contact angle between the adhesive and substrate.

To make an economical and practical joint, the surface preparation methods must also meet several other requirements. They must be safe to handle and should not be flammable or toxic. They should be inexpensive and provide fast processing times. The prebond processes should be easy to monitor and control in a production situation. In addition, the process should not in itself leave a weak boundary layer. If chemical solutions are used, they should rinse off easily and not continue to react with the surface past the time when the bond is made. The surface preparation process should allow for practical working time between preparation and application of the adhesive or sealant. Finally, the surface provided by the treatment should not change once the assembled joint is made and placed into service.

ASTM D2651 describes practices that have proved satisfactory for preparing various metal surfaces for adhesive bonding or coating. Surface preparations for aluminum alloys, titanium alloys, and copper and copper alloys are included in this standard. ASTM D2093 describes recommended surface preparations for plastic adherends.

See also adhesive bonding; wetting.

surfacing mat A surfacing mat is a very thin mat, usually 7–20 mil thick, of highly filamentized fiberglass. It is used primarily to produce a smooth surface on a reinforced plastic laminate. It is also used for precise machining or grinding because of the ease at which a resin that is reinforced with a surfacing mat can be machined.

surfactant Surfactants, or *surface-active agents*, are materials that are active at surfaces, principally functioning to reduce surface tensions in liquids. There are three basic types: nonionic (polyethylene oxides), anionic (sodium lauryl sulfates), and cationic (cetyl pyridinium chloride).

The term *surfactant*, as used in the plastics industry, also refers to cell stabilizers for polyurethane foams. Here, the surfactants function by lowering surface tension and providing stability for the expanding foam cells during polyurethane foam manufacturing. This stability is maintained until polymer growth has progressed sufficiently to be self-supporting. Surfactants also help control cell size and uniformity. Silicone surfactants are popular in this area, although several nonsilicones have also been made available and found acceptance.

There are many manufacturers of surfactants. Major manufacturers include Air Products and Chemicals Inc., American Cyanamid Co., Dow Corning Corp., C.P. Hall Co., Hoechst Celanese Corp., Shell Chemical Co., Union Carbide Chemicals and Plastics Co., and Witco Corp.

See also emulsifier; coupling agent.

surging In blow molding, surging is an unstable pressure buildup in an extruder leading to variable throughput and waviness of the *parison*.

suspension A suspension is the mixture of fine particles of any solid with a liquid or gas. The particles are called the *dispersed phase*; the suspending medium is called the *continuous phase*. A suspension is significantly different than a *solution*, in which materials of one type are dissolved in a liquid.

sweating Sweating is the exudation of small drops of liquid, usually plasticizer or softener, on the surface of a plastic part.

syndiotactic Syndiotactic is one of three classifications of polymer configuration. (*See* Fig. T.2 under tacticity.) The other two are isotactic and atactic. Syndiotactic refers to a chain of molecules in which the substituted groups alternate regularly on opposite sides of the chain.

Polymethylmethacrylate and polybutadiene are examples of polymers that can be prepared in the syndiotactic configuration.

See isotactic; atactic.

syntactic foam A syntactic foam is a lightweight material obtained by the incorporation of prefoamed or low-density fillers into a polymeric system. These fillers are generally hollow microspheres made from glass, epoxy, phenolic, or other materials. The properties of the syntactic foam are very much determined by the resin matrix that is used.

Syntactic foam is generally a closed-cell type of foam that has greater resistance to liquids than conventional foams. Syntactic foams do not swell or change size when immersed in liquids. Syntactic foams are also generally not as compressible as other foam materials. A popular example of syntactic foam is an epoxy resin filled with glass microballoons. This type of syntactic foam is generally used as a casting compound or coating.

synthetic rubber Elastomers are usually classified as natural rubber or synthetic rubber. Synthetic rubbers are made industrially via a chemical route. Elastomers in this group are:

- Acrylonitrile butadiene copolymers (NBR)
- Butadiene rubber (BR)
- Butyl rubber (IIR)
- Chlorosulfonated polyethylene (CSM)
- Epichlorohydrin (ECH, ECO)
- Ethylene propylene diene monomer (EPDM)
- Ethylene propylene monomer (EPM)
- Fluoroelastomers (FKM)
- Polybutadiene (PB)
- Polychloroprene (CR)
- Polyisoprene (IR)
- Polysulfide rubber (PSR)
- Silicone rubber (SiR)
- Styrene butadiene rubber (SBR)

Synthetic rubber is milled and cured before processing, such as with injection molding. Special processing machinery is designed specifically for synthetic rubber.

Worldwide consumption of synthetic rubber is about 11–12 million metric tons. New synthetic rubber polymerization technologies replacing older plants and increasing world consumption are reasons for new production facilities being built.

See also specific synthetic rubbers.

T

tab gate A tab gate, also called the *overlap gate*, is a small, removable tab of approximately the same thickness as the mold item. It is usually located perpendicular to the item being molded. It overlaps the cavity with a small tab in such a way that the melt jet must impinge on the cavity wall. The tab gate is used as a site for edge gate location, usually on items with large flat areas.

Figure T.1 Tab gate. (Ref: Schwartz, S.S. and Goodwin, S.H., *Plastics Materials and Process*, van Nostrand Reinhold, New York, 1982, p. 249)

Taber abrasion Taber abrasion is an abrasion resistance test that is widely used on plastic materials. It uses a Taber abrasion wheel with a specified abrasive, pressure, and rotational speed. Measurements are made to determine the weight loss of a sample during the test. ASTM D1044 specifies the use of the equipment.

See also abrasion resistance.

tack Tack is a property of an adhesive that enables it to form a bond of measurable strength immediately after adhesive and adherend are brought into contact

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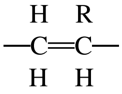
under low pressure. It is the "stickiness" of the adhesive while in the fluid state. This is also known as *green strength*. Tack is an important property for many pressure-sensitive adhesives and preformed sealants.

Tack is generally determined with a tensile testing machine and test blocks. The blocks are pulled apart immediately after the adhesive is applied and the blocks are joined. The result is reported in force required per square inch of bonded area to separate the blocks. Various instruments have also been developed to measure tack for specific applications. ASTM test methods include D2979 (Probe Tack) and D3121 (Rolling Ball Tack).

Other important characteristics related to tack and commonly measured are dry tack and tack range. *Dry tack* is the property of certain adhesives to stick to one another even though they seem dry to the touch. *Tack range* is the time that an adhesive will remain in a tacky condition after application to the adherend.

tack primer A tack primer is sticky, tacky thermoset resin that is used to hold dry or nontacky prepreg together during a laminating or bonding operation. This is often useful in applying prepreg to the vertical sides of molds.

tacticity With a monomer of the general type,



$$\begin{matrix} & \mathrm{H} & & \mathrm{R} & \\ - & \mathrm{C} & = & \mathrm{C} & - \\ & \mathrm{H} & & \mathrm{H} & \end{matrix}$$

one can generate three types of polymer structure as shown in Fig. T.2. In most cases, polymerization will yield a random arrangement of the R group along the chain. Such a polymer is *atactic*. When, however, stereospecific catalyst and reaction conditions are chosen, one can generate a polymer where the R groups are all on one side of the chain. Such a polymer is *isotactic*. One can also generate a polymer where the R group regularly alternates on either side of the chain. Such a polymer is *syndiotactic*.

Thus polymers can be classified according to their configurations or tacticity. In this nomenclature, they are either *isotactic*, *atactic* or *syndiotactic*.

Karl Zielger developed the catalysts used to promote specific tacticity in Germany around 1953. Dr. Giulio Nattta in Italy shared a Nobel Prize with Ziegler for his pioneering work in stereospecific polymerization of polypropylene with Ziegler catalysts. The synthesis of isotactic and syndiotactic polymers has now become almost commonplace, and many examples of each type are known.

See also atactic; isotactic; syndiotactic.

talc Talc is generally used as a filler for plastics. It is hydrated magnesium silicate with a theoretical composition of 31.7 percent MgO, 63.5 percent SiO_2, and 4.8 percent H_2O. Actual chemical composition varies greatly with commercial mining site. Talc has a specific gravity ranging from 2.7 to 2.8. Talc is a nonconductor of electricity and is used in the manufacture of high-frequency electrical insulators.

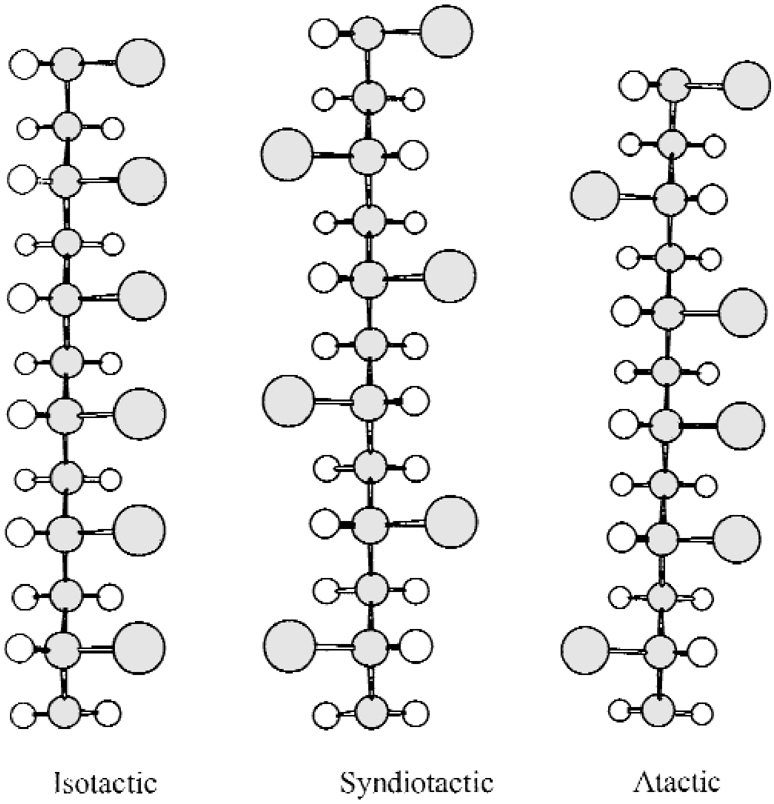


Figure T.2 Isotactic, syndiotactic, and atactic polymer chains. (Ref: Baker, A.M.M., and Mead, J., "Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

Talc exhibits heat stability up to temperatures as high as 900°C. In all plastics applications, it can be considered inert, unaffected by processing conditions. Talc also has low thermal conductivity and high resistance to heat shock. The combined water in talc is not driven off until temperatures in excess of 800°C are encountered.

Talc is inert to almost all chemical reagents and does not decompose when in contact with various acids. Pure talc is a very soft material and has a slippery texture. Natural talc may be white, gray, yellow, pale blue, or pale green with a characteristically silver or pearllike luster. Most commercial talcs used as fillers are finely ground. The finest grinds usually have an average size of 1 μm; coarser sizes are in the region of 10–75 μm.

For plastic applications, the best balance of properties, price, handling and processing ease, and oven aging stability is usually obtained with an intermediate-size talc product with an average particle size between 35 and 45 μm. In certain resins, going to a finer particle size increases specific properties; however, these property increases must to be measured against a higher price, more handling and processing requirements, and higher stabilizer levels needed for a very fine talc grade.

Commercial grades of talc used for plastics applications are fine-ground products consisting of thin platelets, preferably white in color. Because of their platelike structure, these grades are considered reinforcing fillers, as distinguished from particulate mineral extender fillers.

Talc's low cost qualifies it as a extender, for lowering the cost of the compound and extending the resin with minimal sacrifice in physical properties. Its aspect ratio qualifies it as a reinforcing filler, for enhancing performance properties of the compound. Polymers filled with platelike talc exhibit higher stiffness, tensile strength, and creep resistance at ambient as well as elevated temperatures. For example, when polypropylene homopolymer is filled with a 40 percent loading of talc, its flexural modulus is tripled from about 200,000 psi to about 600,000 psi.

Talc is used in polypropylene-filled resins, but it is also experiencing rapid growth in polyethylene and polystyrene compositions. Major uses are in automotive and appliance applications in which talc imparts increased stiffness and high-temperature creep resistance. Acting as a flow promoter, talc gives good surface quality, lower mold shrinkage, and easier processing.

Major suppliers of talc include Ashland Chemical Inc.; Canada Talc Ltd.; Pfizer Inc.; R.T. Vanderbilt Co.; and Whittaker, Clark & Daniels.

tangent delta (tan delta)
See dissipation factor

tapes Tapes are films slit to some acceptable width. They are often used by themselves for various purposes, but they are also frequently coated with adhesives.

The adhesives used on tapes are either thermosetting or thermoplastic. The thermoset adhesives consist of rubber, acrylic, silicones, and epoxies, whereas the thermoplastic adhesives are generally acrylic or rubber. Tackifying resins are generally added to increase the adhesion.

Tapes with a pressure-sensitive adhesive (such as standard office tape) are called pressure-sensitive tapes. The adhesives all deteriorate with storage. The deterioration is marked by loss of tack or bond strength and can be inhibited by storage at low temperature.

tapping and thread cutting Many different threaded fasteners can be used with plastics. Sometimes threads must be machined into the part after molding to provide for fasteners. Tapping is a process of cutting threads in the walls of a circular hole. Sometimes threads must be tapped or machined into plastic parts to provide for fasteners. Threads can be cut in thermoplastics and thermosets by the same methods used with metals and generally with the same ease of operation. Plastics may also be tapped and threaded on conventional lathes and screw machines.

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In cutting threads, either by tapping with serial taps or threading with die and die stock, frequent stops should be made. The tap or die should be backed off occasionally to clear the thread and remove the chips. A coolant or lubricant is not essential, but if available, its use is recommended to minimize heat and to flush away chips.

Because of the elastic recovery of most plastics, oversized taps should be used. Oversized taps are commercially available. Taps with slightly negative rake and with two or three flutes are preferred. Solid carbide taps and standard taps of high-speed steel with flash chrome-plated or nitrided surfaces are necessary. The cutting speed for machine tapping should be less than 50 ft/min. Tapping of filled materials is done at 25 ft/min. These speeds should be further reduced for deep or blind holes, and when the percentage of thread is greater than 65–75 percent. Sharp V-threads are not recommended.

For tapping plastic materials, solid carbide taps and standard taps of high-speed steel with flash chrome plated or nitrided surface are necessary. During tapping, the tap should be backed out of the hole periodically to clear the thread chips

For tapping thermoplastics, taps with a slightly negative rake and with two or three flutes are preferred. Some plastics such as nylon may require slightly oversized taps because the resiliency of the plastic may cause it to compress during cutting, leading to swelling after the tap is removed. For thermosets taps should be oversized by 0.002–0.003 in. and have two or three flutes. Water-soluble lubricants and coolants are preferred.

T-die A T-die is a term used to denote a center-fed slot extrusion die for film. It is used in combinations with the *die adapter* and resembles an inverted T.

tear ply A tear ply is an outer ply of a laminate or composite that is designed for easy removal after cure, generally by manually tearing the tear ply away from the laminate. This is done to provide a clean, rough, bondable surface for a secondary adhesive bonding operation. (See Fig. T.3.)

Tear plies are usually constructed out of densely woven glass fabric. It is placed on the top or bottom of a laminate construction before molding. The tear ply is removed immediately before bonding. Tear plies are commonly used when manufacturing and bonding composites in the aerospace industry.

tear resistance The tear resistance of a plastic film is the measure of the stress needed to continue rupturing a sheet of the material, usually after an initiating cut. *Tear propagation force* is the force to maintain the propagation of a tear initiated in a plastic film or thin sheet. *Tear propagation resistance* is the tear propagation force per unit thickness of material.

Several methods are commonly used to determine the tear resistance of films, elastomers, and thin plastics. ASTM D624 deals with determination of tear strength of conventional vulcanized rubber and thermoplastic elastomers. ASTM D1004 measures tear at very low rates of loading (primarily concerned with measuring tear initiation force). ASTM D2582 is a test to determine resistance to puncture and propagation of tear that is initiated by puncture. ASTM D1922 (the Elmendorf test

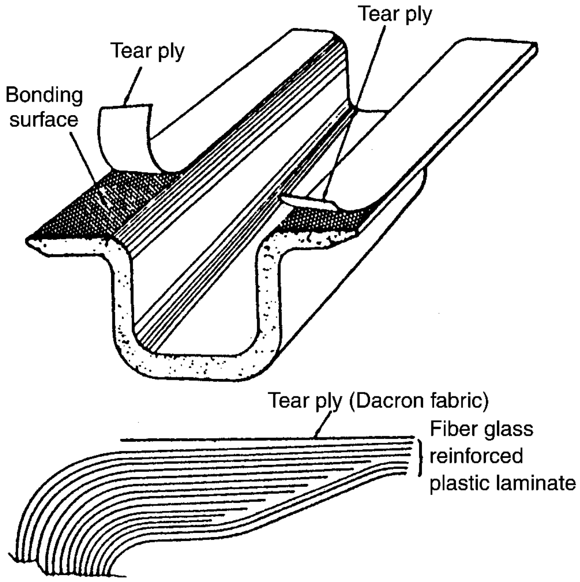

Figure T.3 Structural reinforced plastic laminate with a tear ply to produce fresh bonding surface. (Ref: Snogren, R.C., *Handbook of Surface Preparation*, Palmerton Publishing, New York, 1974)

method) and ASTM D1938 (the trouser tear method) are specific methods that may be well suited to particular applications.

telomer A telomer is a polymer composed of molecules having terminal groups incapable of reacting with additional monomers, under the conditions of the synthesis, to form larger polymer molecules of the same chemical type.

tenacity Tenacity is a term generally used in yarn manufacture and textile engineering to denote the strength of a yarn or of a filament for its given size. Numerically it is the grams of breaking force per denier unit, gpd. [Tenacity equals breaking strength (gms) divided by denier.] The yarn is usually pulled at the rate of 12 in./min.

tensile strength Tensile strength is the maximum tensile stress that a material is capable of sustaining. The first mechanical property most product designers look for in evaluating a potential material is its strength, and by this is meant tensile strength or yield at break. Tensile strength of thermoplastics are shown in Fig. T.4.

The principal test for tensile strength is ASTM D638, which calls for a dog bone-shaped specimen 8.50 in. long by 0.50 in. wide. The gripping surfaces at the ends of the specimen are 0.55 in. wide, giving it its characteristic shape. The test specimen thickness can range from 0.12 to 0.55 in. and the rate at which the stress is applied can range from 0.5 to 20 in./min. The test is also used to determine the percentage *elongation* at break and to produce the *stress-strain* curve from which the *modulus of elasticity* is derived.

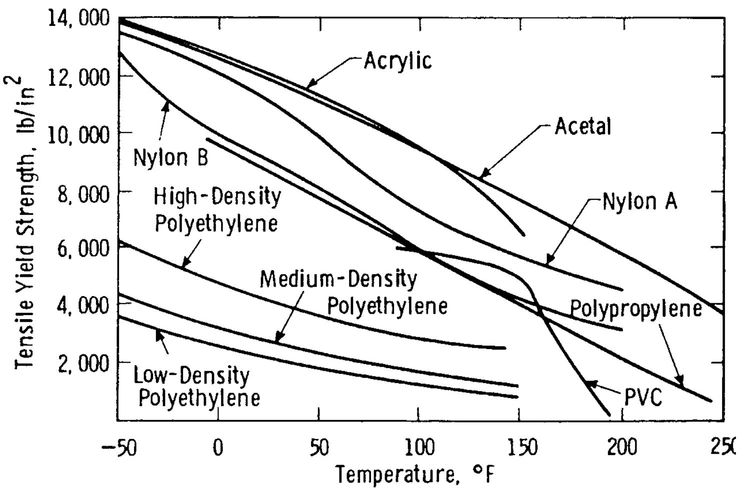

Figure T.4 Tensile yield strength of several thermoplastic materials as a function of temperature. (Ref: Barken H.E., and Javitz, A.E., "Plastics Molding Materials for Structural and Mechanical Applications", *Electrical Manufacturing*, May 1962)

Tensile strength is calculated from a maximum load during a tension test carried to rupture and the original cross-sectional area of the specimen. Tensile strength is usually expressed in force per cross-sectional area (i.e., pounds per square inch or dynes per square centimeter).

Often tensile strength is not really an important property in itself, because many products are rarely used in a pure tensile application. However, it is an indication of other qualities that correlate with tensile strength. Properties that generally improve with tensile strength are wear and tear resistance, creep, and flex fatigue. In insulation, it could indicate better cut and abrasion resistance and, generally, a tougher and more durable conductor covering.

terephthalate A terephthalate is a compound used in the manufacture of linear crystalline polyester resins, fibers, and films in combination with glycols.

termination Termination is the final step in the free radical polymerization process. After *initiation* and *propagation* of the chain radicals, the termination step stops the chain growth. Generally, this occurs because of the strong tendency of radicals to react in pairs to form a paired-electron covalent bond with loss of radical activity.

See also free radical polymerization.

terpolymer A terpolymer is a polymer that contains three monomeric units. For example, the terpolymer ABS (acylonitrile butadiene styrene) is made from acylonitrile, butadiene, and styrene monomers.

T_g (glass transition temperature) T_g is the symbol for glass transition temperature.

See glass transition temperature.

thermal analysis Thermal analysis is a series of analytical tests designed to characterize polymeric materials. These test methods are commonly used in research and development as well as quality control. In addition to characterizing the polymeric sample, the thermal analysis processes provide information regarding the effect of temperature on a compound's physical properties.

Differential scanning calorimetry (*DSC*) measures heat uptake or heat release of a compound as the temperature is raised and also the heat effects associated with material transitions such as melting and curing.

Thermal mechanical analysis (*TMA*) measures the variation in length of a sample as temperature is increased. These data can be used as a measure of the sample's coefficient of thermal expansion. TMA is good for comparing samples. TMA also measures thermal transition points by predicting the point and rate at which a compound will melt or change phase as well as determining the temperature at which blistering will occur if a molded part has not been properly post baked.

Dynamic mechanical analysis (*DMA*) measures a compound's modulus (stiffness) as its temperature is raised. This instrument has provided interesting insights into the properties of phenolics as well as those of DAPs, thermoset polyesters, silicones, and epoxies, by indicating the ability of thermosets to retain their modulus at elevated temperatures. DMA can also be used to determine thermal transition temperatures of the sample.

Thermogravimetric analysis (*TGA*) measures weight changes in a sample as the temperature is varied. This provides a useful means to determine degradative processes and heat resistance of polymeric compounds. It also can be used to determine the absorbed moisture in a sample or the temperature at which a sample begins to out-gas low-molecular-weight species.

thermal conductivity Thermal conductivity is the property of a material that represents its ability to conduct heat. It is the physical constant for the quantity of heat that passes through a unit cube of the material in a unit of time when the difference in temperatures of two faces is 1°C. Methods for measuring thermal conductivity are given in ASTM D4351, C518, and C177.

In the SI system of units the thermal conductivity is expressed in W/(m °K), and in the frequently used metric system of units the thermal conductivity is expressed in cal/(cm s °C). In British units (BU) the thermal conductivity is expressed as (BTU in)/(ft^2 h °F). The thermal conductivity is usually expressed as k.

Plastics have thermal conductivity much lower than metals and therefore are poorer heat conductors. Thermal conductivity for plastics ranges from 3×10^{-4} cal/(cm s °C) for polypropylene to 12×10^{-4} cal/(cm s °C) for HDPE. For aluminum the thermal conductivity is 0.3 cal/(cm s °C), and for steel it is 0.08 cal/(cm s °C). For closed-cell plastic foams, values of thermal conductivity are much lower than those of the unfoamed plastic because gases, and air in particular, have a lower thermal conductivity than polymers. Plastic fillers may increase the thermal conductivity of plastics. Semicrystalline plastics generally have a higher thermal conductivity than do amorphous plastics.

The numeric value of the thermal conductivity expressed in British units is sometimes referred to as the *K-factor*, and its inverse (1/K) as the *R-factor*.

See also K-factor.

thermal degradation Thermal degradation is deterioration by heat. In plastics thermal degradation is usually oxidation or pyrolysis. Oxidation is the general reduction in properties by reactions taking place with oxygen and accelerated by the presence of high temperatures. Pyrolysis is reaction of the polymer purely with heat. With pyrolysis, degradation occurs by breakage of the polymer chain called chain scission and resulting reduction in molecular weight.

thermal expansion coefficient The coefficient of linear (or volume) thermal expansion is the change of length (volume) per unit of length (volume) per degree of temperature change at a constant pressure. Compared to other materials, polymers have high values of thermal expansion coefficients. whereas metals and glass have values in the range of 0.9 to 2.2 /°K, polymers range from 5.0 to 12.4 /°K.

Thermal expansion coefficients can be measured by *thermomechanical analysis* (*TMA*). ASTM D696 describes a method of using a quartz dilatometer, and ASTM E831 describes the determination of the linear thermal expansion of solid materials.

thermal expansion molding Thermal expansion molding is a process in which elastomeric tooling details are constrained within a rigid frame to generate consolidation pressure by thermal expansion during the curing cycle. Thermal expansion molding is generally used as part of the autoclave molding process.

thermally stable plastic Thermally stable plastics are those plastics whose properties exhibit minimal change up to the operational temperature of the system in which they are used. Nearly all plastics exhibit some degree of mechanical and electrical property degradation as temperatures increase. Because many high-performance systems operate at temperatures as high as 125–200°C or higher, property changes can be significant. Properties of high temperature thermoplastics are shown in Table T.1.

Most plastics undergo dramatic property changes above their glass transition temperature. Property changes of less than 20–25 percent are usually considered minimal, although the acceptable or allowable property changes are determined by the specifications for the individual system in which the plastic is used.

See also electronic plastic; glass transition temperature; heat distortion point; IEEE thermal ratings; continuous-use temperature.

thermal stress cracking Thermal stress cracking is the *crazing* and cracking of some thermoplastic resins resulting from overexposure to elevated temperatures.

See also crazing; environmental stress cracking.

thermal transmission inspection Thermal transmission methods are relatively new techniques for the nondestructive inspection of laminates, composites, adhesive

Table T.1 Properties of Representative High Temperature Thermoplastics (Ref: English, L.K., "Raising the Ceiling of High Temperature Thermoplastics", *Materials Engineering*, 1988)

Polymer	Common Designation	Morphology*	Glass Transition, °F	Tensile Strength, ksi	Tensile Modulus, ksi	Elongation, %	Fracture Toughness G_{IC}, in·lb/in^2	Notched Izod, ft·lb/in	Major Suppliers
Polyimide	N†	A	700	16.0	580	6	—	—	E. I. du Pont
Polyimide	LARC-TPI	A	507	17.3	540	4.8	—	1.0	Rogers, Mitsui Toatsu
Polyimide	K-III†	A	484	14.8	546	14	11	—	E. I. du Pont
Polyetherimide	PEI	A	423–518	15.2	430	60	19	1.0	GE Plastics
Polyamide-imide	PAI	A	527	9.2–13.0	400–667	1.4–30	19.4	2.7	Amoco, Dow Chemical
Polyarylimide	J-2†	A	320	15.0	460	25	—	—	E. I. du Pont
Polyimidesulfone	PISO$_2$	A	523	9.1	719	1.3	8	—	Hoechst-Celanese
Polysulfone	PSF	A	374	10.2	360	>50	14	1.2	Amoco, BASF
Polyarylsulfone	PASF	A	428	10.4	310	60	20	1.2	Amoco
Polyarylene sulfide	PAS	SC	419	14.5	470	7.3	—	0.8	Phillips 66

Polyphenylene sulfide	PPS	SC	194	12.0	630	5	—	3.0	Phillips 66, Hoechst-Celanese, Mobay, GE Plastics
Polyether sulfone	PES, HTA‡	A	446–500	12.2	380	>40	11	1.6	ICI, BASF
Polyetherketone	PEK	SC	329	16.0	580	—	—	1.52	ICI, BASF
Polyetherketoneketone	PEKK	SC	311	—	—	—	—	—	E. I. du Pont
Polyetheretherketone	PEEK	SC	289	14.5	450	>40	>23	1.6	ICI
Poly(EKEKK)	PEKEKK	SC	343	—	—	—	—	—	BASF
Polyarylene ketone	PAK, HTX‡	SC	509	12.7	360	13	—	—	ICI, BASF
Liquid crystal polymer	LCP, SRP‡	C	662	20.0	2400	4.9	6.9	2.4	Dartco (Amoco), Hoechst-Celanese, ICI

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*A—amorphous; SC—semicrystalline; C—crystalline.

†Trade name of F. I. du Pont.

‡Trade name of ICI.

joints, etc. Heat flow is determined by monitoring the surface temperature of a test piece a short time after external heating or cooling has been applied. Subsurface anomalies will alter the heat flow pattern and thereby affect the surface temperature. The surface temperature difference can be detected by thermometers, thermocouples, or heat-sensitive coatings. Liquid crystals applied to the joint can make voids visible if the substrate is heated.

Thermal transmission testing is an excellent way for detecting various types of anomalies such as surface corrosion under paint before the corrosion becomes visually evident. Thin single-layer structures, such as aircraft skin panels, can be inspected for surface and subsurface discontinuities. This test is simple and inexpensive, although materials with poor heat transfer properties are difficult to test and the joint must be accessible from both sides.

For nonmetallic materials, the defect diameter must be on the order of four times its depth below the surface to obtain a reliable thermal indication. For metals, the defect diameter must be approximately eight times its depth. Some bright surfaces, such as bare copper and aluminum, do not emit sufficient infrared radiation and may require a darkening coating on their surface.

With thermal surface impedance testing, heat is injected into the test object's surface from a hot gas pulse. The resulting surface temperature transient is analyzed to determine the part's quality in nearly real time. The surface temperature transients are sensed using an innovative noncontacting, emissivity independent infrared sensor. This method is not adversely affected by surface blemishes or roughness.

thermal welding Welding by application of heat or thermal welding provides an advantageous method of joining many thermoplastics that do not degrade rapidly at their melt temperature. It is a method of providing fast, relatively easy, and economical bonds that are generally 80–100 percent the strength of the parent plastic.

Thermal welding process can be of two kinds: direct and indirect. With *direct welding*, the heat is applied directly to the substrate in the form of either a heated tool or hot gas. *Indirect heating* occurs when some form of energy other than thermal is applied to the joint. The applied energy, which causes heating at the interface or in the plastic as a whole, is generally in the form of friction, high-frequency electrical fields, electromagnetic fields, or ultrasonic vibration. Because the heating is localized at the bonding surface, indirect heating processes are very energy efficient, generally resulting in bonds that are stress free and of higher strength than those made by direct welding methods.

See also heated tool welding; hot gas welding; spin welding; induction welding; ultrasonic welding; vibration welding; and dielectric heat sealing/welding.

thermoforming Thermoforming is the process of creating a formed article from a flat sheet by combinations of heat and pressure. This process first softens the sheet by application of heat and then forms the sheet into some three-dimensional shape. *Thermoforms* are the products that result from a thermoforming operation.

Thermoforming is one of the simplest, most economical plastic-forming processes. There are numerous variations of the thermoforming process, but most involve heating the plastic sheet and making it conform to the contour of a male or female form, either by air pressure or a matching set of male and female molds. (See Fig. T.5.)

By this processing technique, thermoplastic sheets can be converted rapidly and efficiently to a myriad of shapes, the thickness of which depends on the thickness of the film being used and the processing details of the individual operations.

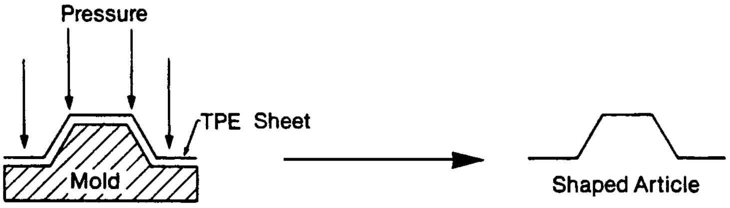

Figure T.5 Schematic depiction of thermoforming. (Ref: Rader, C.P., "Thermoplastic Elastomers", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1998)

The thermoforming process generally consists of five steps: (1) the material is usually held in a frame of some kind; (2) the material is heated to the desired temperature for forming; (3) forming is done by vacuum, pressure, and/or a mechanical assist of some kind; (4) the part is cooled sufficiently to be removed without distortion; and (5) excess material, usually the areas in the clamps, is removed.

There are a number of advantages to the thermoforming process. One of the most significant is that the tooling, in comparison to other methods of making plastics parts, is relatively inexpensive. Because the technique is particularly suited to the production of very large parts, cost savings can be impressive. Many parts with very thin walls can be made only by this method. The process is also ideal for the production of a small number of parts (samples, prototypes, etc.)

There are also several principal limitations of thermoforming. The process is confined to the use of sheet material. Therefore, all parts must have fairly uniform wall thicknesses. Thick ribs or mounting bosses cannot be obtained.

Thermoforming is used in the production of refrigerator door liners, automobile dashboard panels, cheese containers, soft drink cups, signs, packaging, and many similar items of uniform wall thickness.

Thermoforming and adhesive bonding or double-sheet forming can be used to make hollow or tubular shapes in many configurations. *Twin-sheet thermoforming* is a process that is generally used to produce large, flat, double-walled parts.

Virtually any thermoplastic sheet material can be thermoformed. However, the bulk of the parts made by this process are usually polystyrene or ABS. The highest-temperature plastic thermoformed in any significant amount is polycarbonate.

Most sheet material used in thermoforming is made by the extrusion process; however, calendered and cast sheet are also used. Successful thermoforming material must have the ability to be deep-drawn into a cavity over a female mold without tearing or excessively thinning in one area. It is also desirable for a good thermoforming material to become soft and rubbery over a wide range, rather than having a sharp melting point. The material must also have good hot strength and hot elongation.

thermogravimetric analysis (TGA) Thermogravimetric analysis (TGA) is a testing procedure in which changes in the weight of a specimen are recorded as the specimen is progressively heated. It is a useful indication of the relative temperature resistance of plastics and elastomers. It also measures low-molecular-weight constituents within a sample that volatilize before the bulk sample does.

See also thermal analysis.

thermogravimetry Similar to thermogravimetric analysis, thermogravimetry is a method for measuring changes in the mass of small specimens as these are being heated or cooled at a controlled rate by an appropriate temperature program. The results of the measurement are recorded in terms of mass as a function of temperature or time. Thermogravimetric analysis (TGA) generally refers to a specific type of instrument designed for performing thermogravimetric measurements. Thermogravimetry is the generic process.

Thermogravimetric measurements are recorded in the form of the thermogravimetric curve, in which the mass is plotted on the ordinate and the temperature or time on the abscissa. Thermogravimetry of polymers and plastics is subject to ASTM D3850.

thermomechanical analysis (TMA) Thermomechanical analysis (TMA) is a thermal analysis technique consisting of measuring physical expansion or contraction of a material as a function of temperature. TMA is a well-accepted technique for determining the glass transition temperatures in a solid sample material. TMA has also been used to determine changes in modulus or viscosity with temperature.

See also thermal analysis.

thermoplastic Plastics can be separated into two broad classifications: thermoplastics and *thermosets*. Themosetting plastics are *crosslinked*, and thermoplastic plastics are not. The different types of structures are shown in Fig. T.6.

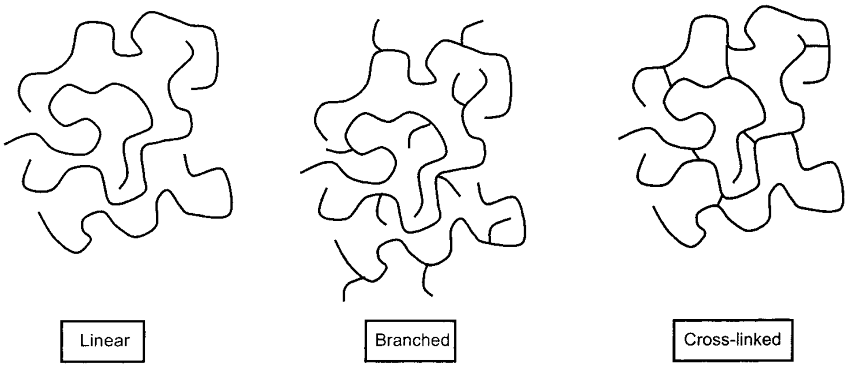

Figure T.6 Linear, branched, and crosslinked polymer structures. (Ref: Baker, A.M.M., and Mead, J., "Thermoplastics", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

Thermoplastics are polymeric materials capable of being repeatedly softened or melted by increases in temperature and hardened by decreases in temperatures. These changes are physical rather than chemical. The changes can be made because there is no crosslinking within the polymer.

A thermoplastic material can exist in a *linear* or *branched structure*. On heating a thermoplastic, a highly viscous liquid is formed that can be shaped with plastic processing equipment.

See also thermoset.

thermoplastic elastomers A thermoplastic elastomer (TPE) is a rubbery material with properties and functional performance very similar to those of a conventional thermoset rubber, yet it can be fabricated in the molten state as a thermoplastic. Thus, thermoplastic elastomers are rubberlike materials that can be processed and recycled like thermoplastic materials.

Virtually all TPEs consist of at least two polymeric phases: a hard thermoplastic phase and a soft elastomeric phase. The properties of the resulting TPE will be derived from the properties of each of the two phases and their mutual interaction. The performance characteristics of a TPE depend on the melting temperature (T_m) of the hard thermoplastic phase and the glass transition temperature (T_g) of the soft elastomeric phase. The temperature range for the TPE where the material displays elastomeric properties is between the T_m and the T_g.

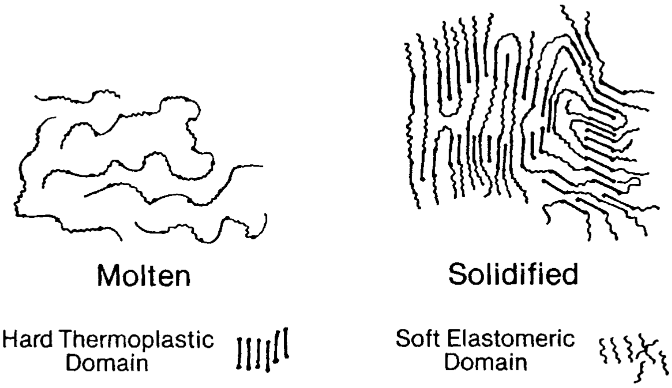

Figure T.7 Morphology of block copolymer thermoplastic elastomers (TPEs). (Ref: Rader, C.P., "Thermoplastic Elastomers", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1998)

For optimum performance, most TPEs benefit from drying before processing. TPE-based products can be manufactured by injection molding, blow molding, and extrusion. TPEs can also be thermoformed and thermally welded like typical thermoplastics. These production processes give TPEs a significant economic advantage over thermoset elastomers.

TPE grades are often characterized by their hardness, resistance to abrasion, cutting, scratching, local strain (deformation), and wear. The generic types of TPE are styrenics, thermoplastic polyolefins (TPO), polyurethane thermoplastic elastomers

Table T.2 Key Properties of Generic Classes of TPEs. (Ref: Rader, C.P., "Thermoplastic Elastomers", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1998)

Property	Styrenic	TEO	TPV	Copolyester	Polyurethane	Polyamide
Specific gravity†	0.90–1.20	0.89–1.00	0.94–1.00	1.10–1.40	1.10–1.30	1.00–1.20
Shore hardness	20A–60D	60A–65D	35A–50D	35D–72D	60A–55D	60A–65D
Low temperature limit, °C	−70	−60	−60	−65	−50	−40
High temperature limit, °C (continuous)	100	100	135	125	120	170
Compression set resistance, at 100°C	P	P	G/E	F	F/G	F/G
Resistance to aqueous fluids	G/E	G/E	G/E	P/G	F/G	F/G
Resistance to hydrocarbon fluids	P	P	F/E	G/E	F/E	G/E

* P = Poor; F = Fair; 6 = Good; E = Excellent.

† Does not include grades containing a special flame-retardant package, which generally raises the specific gravity 20 to 30 percent.

(TPU), copolyesters, polyamide, and thermoplastic vulcanizate (TPV). Key properties of these classes of TPEs are shown in Table T.2.

Styrene block copolymers are the most widely used TPEs. Styrenic TPEs are usually styrene butadiene styrene (SBS), styrene ethylene butadiene styrene (SEBS), and styrene isoprene styrene (SIS). Styrenic TPEs usually have about 30–40 percent bound styrene. Principal styrenic TPE markets are molded shoe soles and other footwear, extruded film/sheet and wire/cable covering, and pressure-sensitive and hot-melt adhesives. They are also popular as grips for bike handles, kitchen utensils, clear medical products, and personal care products. Styrenic block copolymer thermoplastic elastomers are produced by Shell Chemical (*Kraton*), Firestone Synthetic Rubber and Latex, Division of Bridgestone/Firestone (*Stereon*), Dexco Polymers (*Vector*), EniChem Elastomers (*Europrene*), and other companies.

Thermoplastic polyolefin (TPO) elastomers are typically composed of ethylene propylene rubber (EPR) or ethylene propylene diene (EPDM) as the elastomeric segment and polypropylene thermoplastic segment. LDPE; HDPE; and LLDPE; copolymers of ethylene vinyl acetate (EVA), ethylene ethylacrylate (EEA), ethylene methyl acrylate (EMA); and polybutene-1 can be used in TPOs. TPO elastomers are the second most used TPEs on a tonnage basis. Typical applications are flexible products such as boots, bellows, drive belts, conveyor belts, keypads, connectors, gaskets, grommets, lip seals, O-rings, plugs, bumper components, bushings, motor mounts, sound-deadening products, casters, handle grips, rollers, and step pads. Producers of

TPO elastomers include Montell (*Catalloy*), Dow Chemical (*Attane*), DuPont (*Engage*), and Union Carbide.

The two principal types of *thermoplastic polyurethane elastomers* (*TPUs*) are polyether and polyester. Polyethers have good low-temperature properties and resistance to fungi. Polyesters have good resistance to fuel, oil, and hydrocarbon solvents. Producers include BASF (*Elastollan*), Dow Chemical (*Pellethane*), Bayer (*Bayflex* and *Texin*), and Morton International (*Morthane*). Molded and extruded TPUs have a wide range of applications including automotive (body panels, doors, bumpers, fascia, and window encapsulations); belting; caster wheels, covering for wire and cable, film/sheet, footwear; seals and gaskets, and tubing.

Thermoplastic copolyester elastomers are segmented block copolymers with a polyester hard crystalline segment and a flexible soft amorphous segment with a very low T_g. Producers include DuPont (*Hytrel*) Ticona (*Ritefex*), and DSM (*Arnitel*). Applications include bellows, hydraulic tubing, seals, wire coating and jacketing, molded air dams, automotive exterior panel components, fascia and fascia coverings, radiator panels, extruded holes, and spark plug and ignition boots. Thermoplastic copolyester elastomers are noted by their resistance to hydrocarbon fluids.

Polyamide TPEs are usually polyester-amides, polyetherester-amide block copolymers, or polyether block amides. Polyamide TPEs are characterized by their high service temperature under load, good heat aging, and solvent resistance. The copolymers are used for waterproof/breathable outerwear, air conditioning hose, under-hood wire covering, automotive bellows, flexible keypads, decorative watch faces, rotationally molded sports balls, and athletic footwear soles. Producers include Elf Atochem (*Pebax*).

Thermoplastic vulcanizates (*TPVs*) are composed of a vulcanized rubber component, such as EPDM, nitrile rubber, and butyl rubber in a thermoplastic olefinic matrix. TPVs have a continuous thermoplastic phase and a discontinuous vulcanized rubber phase. The most common TPV polymer system is PP/EPDM rubber; however, a number of other polymer systems have been commercially developed. These include PP/NBR, PP/butyl and PP/halobutyl, PP/NR, and PP/EVA/EPDM. Producers include Advanced Elastomers Systems (*Santoprene*, *Geolast*, and *Trefsin*). The highly rubberlike properties of TPV have enabled them to perform as engineered thermoplastic rubbers. In numerous application areas they have directly replaced premium-performance thermoset rubber compounds. Prominent among these are demanding automotive applications, electrical insulation and connectors, compression seals, appliance parts, medical devices, and food and beverage contact applications.

thermoset Plastics can be separated into two broad classifications: thermosets and *thermoplastics*. Thermosets are polymeric materials that undergo, or have undergone, a chemical reaction by the action of heat, catalyst, UV light, and the like, leading to a relatively infusible state that will not remelt after setting. This infusible state is the direct result of cross-linking within the polymer. (See Fig. T.6.)

A thermoset has all of the chains tied together with covalent bonds in a network of crosslinks. A thermoset cannot be reprocessed once it is crosslinked, but a thermoplastic material can be reprocessed by heating to the appropriate temperatures.

Thermosetting is the classification of resin that cures by chemical reaction when heated and, once cured, cannot be remelted by heating.

See also thermoplastic.

thermoset injection molding Because of the chemical nature of thermoplastic materials, injection molding has traditionally been the primary molding method for thermoplastics, and compression and transfer molding have been the primary molding methods for thermosetting plastics. Because of the greater molding cycle speeds and lower molding costs in injection molding, thermoplastics have had a substantial molding cost advantage over thermosets.

Advances in equipment and in thermosetting molding compounds, however, have resulted in a rapid transition to screw-injection, in-line molding. This has been especially prominent with phenolics, but other thermosets are also included to varying degrees. The growth in screw-injection molding of phenolics has been extremely rapid. The development of this technique allows the molder to automate further, reduce labor costs, improve quality, reduce rejects, and gain substantial overall molding cycle efficiency.

thermoset molding compound Thermosetting resin systems comprise a large, versatile, and important family of molding compounds, which provide the industrial, military and commercial markets with plastic molding materials exhibiting exceptional electrical, mechanical, thermal, and chemical properties. Several different resin systems commonly are used in the manufacture of thermosetting molding compounds. These are generally compounded with minerals, glass, and other additives to provide properties required during processing and in the end application.

Diallyl orthophthalate (*DAP*) and *diallyl isophthalate* (*DAIP*) are unsaturated polyesters that are the condensation products of unsaturated dicarboxylic acids and dihydroxy alcohols. These freely copolymerize with monomers, which contain double-bond unsaturation, yielding rigid thermosetting resins. They have exceptional electrical, mechanical, thermal, and chemical properties. Molding compounds using either the DAP or the DAIP resin systems are available in free-flowing granular form and also in high-bulk-factor flake form. Suppliers include Rogers Corporation and Cosmic Plastics Inc. (*See* allyls.)

Urea molding compounds consist of urea and melamine as the base resin. Urea molding compounds are best known by the early *Plaskon* resins manufactured by Allied Chemical Co. *Melamine* and *melamine formaldehyde* molding compounds are similar to phenolics. The colorability and surface hardness led to its use in molded dinnerware along with some very important military and electrical applications. The urea molding compounds are available as free-flowing granular products that are readily preformable and can be preheated and preplasticated before molding. The melamine compounds are available both as free-flowing-granular products and as high-strength, high-bulk-factor materials. The bulky materials require auxiliary equipment for preforming or preplasticating. Suppliers include American Cyanamide, ICI/Fiberite, and Plenco Engineering Company. (*See* urea.)

Epoxy molding compounds are available in a wide range of properties. They are available in extreme soft flows and long gelation times, which make them very adaptable for encapsulation molding techniques in the encapsulation of electronic components such as integrated circuits, resistor, diode capacitor, relays, and bobbins. The compounds have found a market in the commercial and military industrial areas for connector bodies, potting shells, printed circuit boards, coils, and bobbins with their strength and high filler loadings. Several compounds can compete with the phenolics and DAPs. These molding compounds are available in free-flowing granular form suitable for automatic preforming or preplasticating and are readily moldable in all thermosetting molding techniques. The higher-impact, bulkier compounds mold readily but require special auxiliary equipment for either preforming or preplasticating. Suppliers include Cytec Fiberite, Dexter Electronics, and Morton Chemical. (*See* epoxy resins.)

Phenolic resins were the foundation of the entire thermosetting molding compound industry. Several families of phenolic thermosetting resins and compounds have been developed. Phenolic molding compounds have become the primary insulating material for a wide and diversified range of application for industrial, commercial, and military applications. The novolac-based molding compounds are available as free-flowing granular powders or pellets and flakes in the high-strength, bulky grades. The general-purpose grades are easily preformed and preplasticated, whereas the bulky products often require auxiliary equipment for such operations. Resole-based molding compounds are generally only available as granular powder or small pellets. Suppliers include Cytec Fiberite, Occidental Chemical, Plastics Engineering Company, Plaslok Corporation, and Rogers Corporation. (*See* phenolic.)

Thermoset polyester molding compounds have low cost, color availability, and high strength-to-weight ratios. Molding equipment is available that is capable of injection molding these bulky, doughlike compounds by using stuffing mechanisms that augment the passage of the compound from the hopper into the barrel for delivery to the mold. Lower molding costs and reduced finishing costs are among the benefits derived with the use of these versatile molding compounds with the injection molding process. Thermoset polyester molding compounds are available in several physical forms including free-flowing granules, pelletized, putty- or rope-type extrudates, sheet molding compound, high-build molding compound, and thick molding compound form. The molding compounds, regardless of reinforcement type, are also readily moldable in all thermosetting processes. Suppliers include American Cyanamid and BMC Inc. [*See* polyester (thermosetting).]

Silicone resins and elastomers have been used for many years. The molding compound consists of 20–25 percent resin, 75 percent filler (glass and fused silica mix), a lead-based catalyst, pigment, and lubricants. The compounds are free-flowing granular in form and are available in opaque colors (mostly red). They are readily moldable in compression, transfer, and injection molding processes. The silicones are nonconductors of either heat or electricity; have good resistance to oxidization, ozone and UV radiation, and are generally inert. They have consistent physical properties in a temperature range of 16–199°C. They also have a low glass transition temperature of −120°C. Encapsulation of semiconductor devices such as microcircuits, capacitors, and resistor, electrical connectors, seals, gaskets, O-rings and terminal and plug covers are all good applications for silicone molding compounds. Suppliers include Dow Corning, Cytec Fiberite, and General Electric. (*See* silicone.)

thickening agent Thickening agents or antisag agents increase the viscosity of fluid dispersion or solutions. Examples include bentonite, calcium carbonate with high oil absorption, crysotile asbestos, hydrated siliceous minerals, magnesium oxide, soap, stearates, and special organic waxes. The most common thickening agents used for viscosity control of resins are fumed silica, carbon, talc, and diatomaceous earth. Thickening agents differ from thixotropes in that they do not exhibit dual rehological behavior (i.e., low system viscosity under high shear, high viscosity under low shear). Thickeners exhibit high system viscosity under all shearing conditions.

Major suppliers of thickening agents include American Fillers & Abrasives, DuPont, Morton International Inc., Raschig Corp., Union Carbide Chemicals, and Witco Corp. The suppliers of thixotropic agents also generally supply thickening agents.

See also thixotropic.

thick molding compound (TMC) Thick molding compound (TMC) is a relatively new form of sheet molding compound. Thick molding compounds can be made in sheets, similar to sheet molding compound (SMC) but considerably thicker (up to 2 in.). Because it can be made in substantial thickness, it has many of the characteristics of bulk molding compound (BMC) but with improved physical properties and the advantage of being a continuous process instead of the batch process.

The formulations used for SMC and TMC can be the same and are almost the same as BMC. However, TMC is processed in a special machine in which impregnation occurs rapidly by counterrotating rolls whose spacing can be varied to provide controlled, thorough fiber saturation.

See also sheet molding compound; bulk molding compound.

Table T.3 Comparisons of TMC, SMC, and BMC Processes. (Schwartz, S.S., and Goodman, S.H., *Plastic Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 720)

Factors	TMC	SMC	BMC
Compound form, thickness and weight	Unlimited; continuous	Limited; continuous	Batch; bulk form usually
Productivity	Over 3000 lb./hr. per ft. width of machine	2000 lb./hr. per ft. width of machine	Batch; process usually
Filler concentration	High	Limited	High
Mechanical properties	High	High	Low
Glass fiber degradation	Low	Low	High
Scrap, waste, handling	Minimum; less PE film	Higher; multilayers	Higher
Molding versatility	Compression; injection	Compression	Compression: injection
Glass impregnation	Instantaneous; controlled; no kneading area	Poor control; long kneading areas	Poor; blade mixing causes fiber degradation

thinner A thinner is a volatile liquid added to an resin to modify its consistency or other properties.

See also solvent.

thixotropic A thixotropic material is one that is gellike at rest but fluid when agitated. Liquids containing suspended solids of a certain type are apt to be thixotropic. The rheological property of such a material is termed *thixotropy*. Thixotropy is desired in paints, adhesives, and sealants so that the material does not "run" down a vertical substrate surface.

Thixotropic fillers are those that when added to a polymer formulation increase the viscosity of the formulation when it is under rest. They are also known as thixotropes or antisag agents. Therefore, thixotropic agents provide sag resistance and the ability for a material to remain in place on a vertical substrate. However, when a slight force is applied, such as in the act of stirring or extruding the resins, the system acts as if it had a lower viscosity and flows with relative ease. Thixotropes work by forming a three-dimensional structure in the system via hydrogen bonding. When stressed, the structure breaks down, but it recovers after the stress is removed.

The addition of *asbestos* at one time provided excellent thixotropic formulations, but health and environmental regulations have severely limited the use of this material. Today, *fumed silica*, *precipitated calcium carbonate*, certain *clays*, and *cellulose* and other fibers offer thixotropic properties at relatively low levels of loading.

Fumed silicas (e.g., *Cab-O-Sil*, Cabot Corp.) are the dominant thixotrope. Many liquids can be turned into paste with the addition of only a few percent of fumed silica. The hydrophilic silica is most effective in nonpolar and medium polarity media, and performance is often improved by adding a polar substance such as ethylene glycol. Among the competing materials are precipitated silicas (less expensive but requiring high loading), very fine-particle organophilic clays, and a few organics (poly-substituted sorbitols, calciumorganic complexes).

Major suppliers of thixotropic agents include Ashland Chemical Inc., Cab-O-Sil Div. Of Cabot Corp., Degussa Corp., J. M. Huber Corp., Lubrizol Corp., Pluess-Staufer International Inc., and PPG Industries Inc.

See also thickening agents.

thread count In woven fabrics, the thread count is the number of yarns or threads per inch in either the lengthwise (warp) direction or crosswise (fill or weft) direction.

thread plug The thread plug is a part of a mold that shapes an internal thread in the molded part. The thread plug must be unscrewed from the finished piece after it is molded.

three-plate mold A three-plate mold is used in injection molds to permit center or offset gating of each cavity. In a three-plate mold a third or intermediate movable plate is used.

tie bars Tie bars are bars that provide structural rigidity to the clamping mechanism. Tie bars are often used to guide platen movement in molds.

titanate coupling agent
See coupling agent.

top blow Top blow is a specific type of blow molding machine. It forms hollow articles by injecting the blowing air pressure into the parison at the top of the mold.

torpedo
See injection molding machine.

torsion Torsion is stress caused by twisting of a material. *Torsional stress* is the shear stress on a transverse cross section caused by a twisting action.

torsion pendulum test The torsion pendulum test is a form of dynamic mechanical analysis (DMA). This test directly measures two dynamic properties of plastics as a function of temperature: shear or torsion modulus and damping factor. When these two properties are plotted against changing temperature, they reveal the polymer transitions, particularly glass transition of plastics. The shear modulus also indicates the relative change in rigidity due to transitions.

The mechanical damping of a polymer is related to impact, vibration, and similar dynamic stresses. Although mechanical damping has been correlated with fatigue performance, neither it nor torsion modulus can be used to determine design data, because creep effects are not included in the test.

See also thermal analysis.

toughness Toughness is the capacity of a material for absorbing mechanical energy without failure. In this sense, it may be regarded as the opposite of brittleness. In an appropriate mechanical test, a tough plastic material is characterized by a high strain at break and a large area under the stress-strain curve as well as by low notch sensitivity.

tow Tow is an untwisted bundle of continuous fibers. A tow designated as 12K has 12,000 filaments. It is commonly used in reference to synthetic fiber, particularly carbon and graphite. However, it is also used for glass and aramid fiber.

toxicity With the expanding use of plastics, attention has been focused on the potential toxic liability of these manmade materials. Although many monomers are harmful chemicals, the polymers synthesized from them are usually harmless macromolecules. However, one must take into account the possibility that the polymers may still contain small amounts of residual monomer and catalyst. Moreover, polymers are very seldom used without compounding with fillers and additives.

Being relatively smaller in molecular size, these additives can migrate from the plastic body to the environment if they are not totally bound in the plastic material. They may eventually migrate into food products packed in plastic containers, or they may interact with humans in other ways.

The toxic potential of thermodegradation and combustion products of plastics, when these materials are burned either deliberately or by accident, is also an important consideration in view of the widening use of plastics as structural and decorative lining material in buildings, vehicles, and aircraft. The polymer supplier must thoroughly disclose the toxic ingredients in a plastic formulation and any toxic products that may be released on burning. This is accomplished in the Materials Safety Data Sheet (MSDS), which must be made available on request.

track A track is a conductive carbon path formed on the surface of a plastic during electrical *arcing*. *Tracking* is the phenomenon in which a high-voltage source current creates a leakage or fault path across the surface of an insulating material by slowly but steadily forming a carbonized path (track).

See also track resistance.

track resistance Track resistance (ASTM D495) or *arc resistance* is a property that reflects the resistance of a plastic material to degradation or decomposition to form a carbon path or track between two electrodes during arcing in a high-voltage system. Arcing is the electrical condition, and tracking is the degradation resulting from that condition. Track resistance is measured in time to formation of a conductive carbon track.

Most plastics track very easily at sufficiently high voltage levels. Plastics whose base polymers contain a high percentage of noncarbon atoms (such as silicones, fluorocarbons, and certain nitrogen-containing polymers) are more resistant to carbon tracking. Also, additives such as hydrated alumina can be formulated into the plastic to block carbon tracking to varying degrees.

See also arc- and track-resistant plastics.

transfer molding Transfer molding is a method of molding thermosetting materials in which the plastic is first softened by heat and pressure in a transfer chamber and then forced or transferred by high pressure through suitable sprues, runners, and gates into a closed mold for final curing. (See Fig. T.8.)

Transfer, or plunger molding, is a process in which high-flow B-stage resins, such as epoxies, are liquefied under heat and pressure in a transfer pot, after which the resultant liquid resin is transferred under pressure into mold cavities. The transferred resin is then heated to form cured, final parts that are then removed from the mold. Although compression and transfer molding are used principally with thermosetting compounds, the processes are occasionally used with thermoplastic material, often thermoplastic composites.

The advantage of transfer molding lies in the fact that the mold proper is closed at the time the material enters. Parting lines that might give trouble in finishing are held to a minimum. Inserts are positioned, and delicate steel parts of the mold are not subject to movement. Vertical dimensions are more stable than in straight compression. Also, delicate inserts can often be molded by transfer molding, especially with the low-pressure molding compounds.

Transfer molding is often used when inserts are to be molded into the finished part (e.g., contacts in automotive distributor caps or rotors or solenoid coils); whereas, in compression molding, such inserts might be displaced during the flow of the viscous plastic. In transfer molding the inserts are gently surrounded by a liquid flowing into the cavity at controlled rates and pressures and generally at a relatively low viscosity.

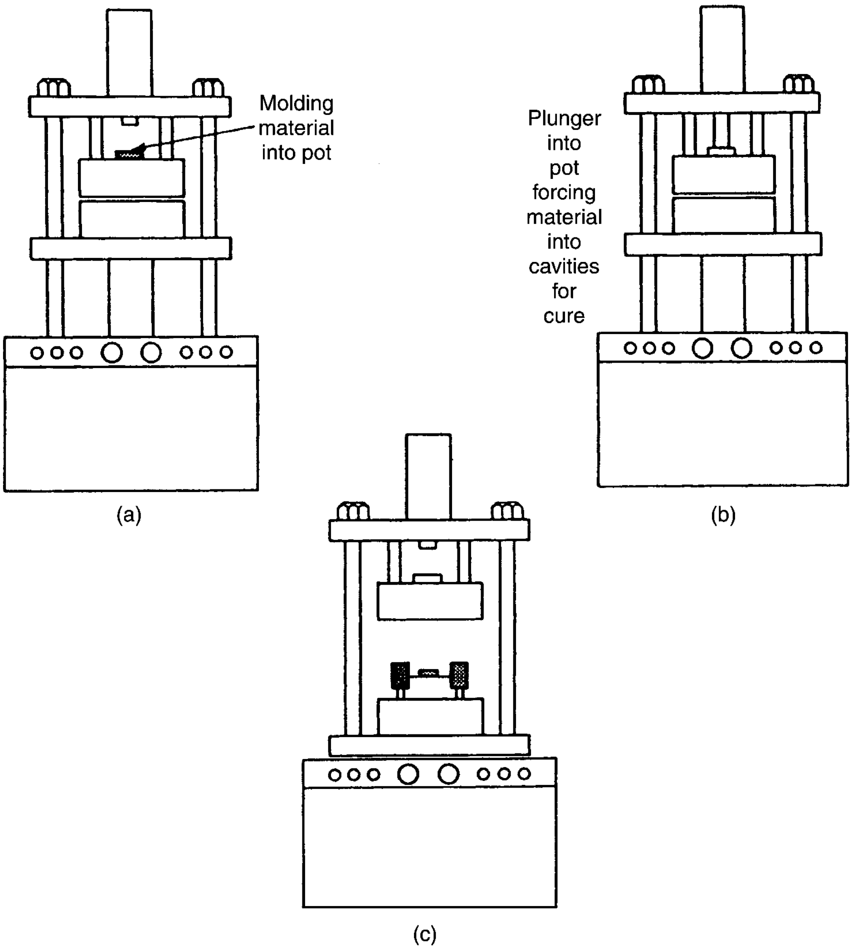

Figure T.8 Transfer molding process: (a) the mold is closed and material is placed in the pot, (b) the plunger descends into the pot, causing material to melt and flow through runners into cavities, (c) after cure, the press opens, the plunger retracts and the parts are ejected with cull and runners. (Ref: Hull, J.L., "Processing of Thermosets", *Modern Plastics Handbook*, C.A. Harper, ed., McGraw-Hill, New York, 2000)

Transfer presses and molds generally cost 5–10 percent more than compression presses and molds, but preheaters and preformers are the same as used in compression molding. Transfer cycle times are often slightly shorter than cycle times for compression molding. The motion of the compound through the small runners and gates before entering the cavity raises the compound temperature by frictional heat and mechanical shear, thereby accelerating the cure.

One highly significant application of transfer molding is the direct encapsulation of electronic components and semiconductor devices. The transfer molding process has the capability, with the correct low-viscosity resin, to successfully mold around incredibly fragile devices and whisker wires.

See also B-stage; high-flow resin.

transmittance Transmittance is the percentage of incident light that passes through a sample of material. It is determined by the intensity of the absorption and scattering effects. The absorption in polymers is insignificant, so if the scattering is zero, the sample will be transparent.

Transmittance can be determined according to ASTM D1003. This standard deals with two concepts associated with light transmission (i.e., *haze* and *luminous transmittance*). Many applications of plastics as clear materials (e.g., glazing) require low haze and correspondingly high specular or luminous transmittance. For some applications (diffusers in lighting fixtures or panels of internally lighted signs) a combination of high total luminous transmittance and haze is desirable.

The transmission of light across a clear and colorless test specimen within a very narrow angle is the subject of test standard ASTM D1746. This defines a *specular transmittance*, a term used only with the most transparent of polymeric materials. The specular transmittance is directly associated with the image-forming characteristics of the test specimens. Expressions such as transparency, clarity, see-through clarity, and image resolution are used in this context.

See also haze.

transparency, translucency, and opacity A *transparent* material has a transmittance value above 90 percent. Transparency may be defined as the ability of a material to transmit light readily with negligible scattering. A test method for the transparency of plastic sheet is ASTM D1746.

Translucency is the property of a material whereby the majority of visible light transmitted through it is scattered. Thus it is difficult or even impossible to distinguish objects viewed through a *translucent* material.

An *opaque* material has low transmittance and therefore large scattering power. The scattering power of a polymer results from morphological inhomogeneities and/or the presence of crystals. An amorphous homogeneous polymer, such as crystal polystyrene, will have little or no scattering power and therefore will be transparent. A highly crystalline polymer such as HDPE will be mostly opaque.

Amorphous polymers often allow high levels of light transmission and can thus be referred to as transparent polymers. They may include many styrenics, acrylics, cellulosics, as well as the engineering plastics such as polycarbonate and polysulfone. Also some thermosets, such as unsaturated polyester, epoxy, and urethane resins and unfilled, specially compounded elastomers (polyisoprene, silicone, urethane, etc.), can be made to be transparent.

The presence of crystalline regions tends to reduce the level of light transmission, and pure semicrystalline polymers in moderate thickness are generally translucent. They include the polyolefins, polyamides, and thermoplastic polyesters. However, several crystallizing polymers can be made into highly transparent, relatively thick products. They are polymethylpentene and polyethyleneterepthalate. Films of many crystallizing polymers, particularly oriented films, can also be transparent

See also optical properties.

transverse isotropy A material having transverse isotropy essentially has identical mechanical properties in two directions, but not in the third.

transverse properties Transverse properties are properties perpendicular to the axial (x, 1, or 1, 1) direction. Transverse properties may be designated as properties in the y or z, 2 or 3 directions.

trapped-air process The trapped-air process is used for blow molding closed objects. The bottom pinch is conventionally made, and after blowing the parison, sliding pinchers nip the top, thus forming a sealed air-inflated product.

tumbling Tumbling is a finishing procedure for thermosetting parts in which the pieces are exposed to an abrasive material while tumbling to remove gates, flash, fins, etc. When abrasive particles such as walnut shell granules and sand are used as the abrasive material, this process is often known as *tumble blasting*. Tumbling can also be used for smoothing or polishing plastic parts by rotating them in a barrel together with softer particles such as wooden pegs, sawdust, and polishing compounds. (See Fig. T.9.)

Tumbling is a simple, high-volume process to deflash rigid plastics. The tumbler is usually a metal drum or cylinder that is perforated in such a way that the plastic parts will not fall through the perforations. The tumbler is then placed on a rotating mechanism. The plastic parts are loaded in the tumbler so that at least half of the tumbler space is empty. The tumbler is set in motion, allowing the parts to slowly roll and impact against one other. The constant impacting removes the brittle, external flash in a relatively fast time (10–15 min). The limitations of tumbling are that the parts must be robust, they must be molded with rigid material, and only external flash will be removed. Tumbling can also be used to round corners and apply a surface finish to plastic parts. Tumbling does not produce as high a finish as polishing, but for many articles a very high polish is not necessary and is not worth the higher costs involved.

For more thorough flash removal, moderately abrasive material is added to the tumbling method described above. This *media deflashing* allows both internal and external flash to be removed. The parts to be deflashed are loaded into a sealed container. Once the tumbling starts an abrasive media material (ground walnuts, hard nylon, polycarbonate pellets, etc.) is directed at the parts under air pressure and at high velocity. Modern deflashers recycle the blast media and use dust collectors to minimize air pollution.

Cryogenic deflashing uses cold temperatures to make the plastic rigid and brittle. It uses essentially a sealed tumbler with either liquid nitrogen or expanding carbon dioxide (−40 to −73°C) to cool the parts. At these temperatures, even elastomers will become rigid, thus allowing the flash to be removed in a conventional tumbling process.

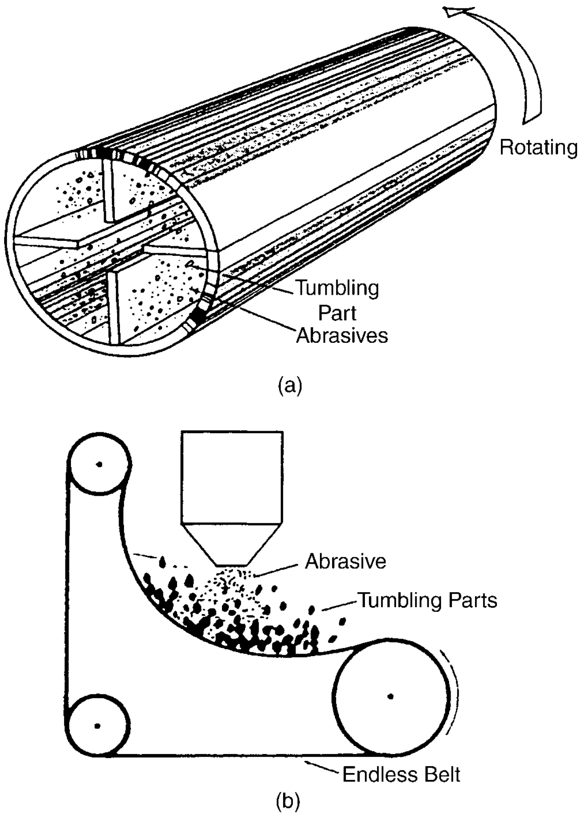

Figure T.9 Two tumbling methods: (a) parts being tumbled in a revolving drum and (b) parts being tumbled on an endless revolving belt. (Ref: Richardson, T.A., "Machining and Finishing" *Modern Industrial Plastics*, Howard W. Sams & Co., New York, 1974)

tunnel fire test The tunnel test, or *Steiner tunnel test* (ASTM E84) is intended to provide a comparative assessment of the surface-burning characteristic of materials on a relatively large scale. The fire test chamber is a long, insulated, horizontal duct with a removable lid. The fire end features an air intake and a gas burner. The chamber is equipped with observation windows along its length and various sensors.

Test specimens about 20 in. wide and 24 ft. long are held horizontally between the lid and the chamber walls. After the gas burner is turned on, the propagation of the flame front is monitored for the duration of the test (10 min maximum). A *flame spread index* is determined.

See also flammability.

tunnel gate A tunnel gate, also called a *submarine gate*, is used when automatic degating is desired. In this gate, the melt is introduced into the cavity at a point below the parting line of the cavity. During the ejection cycle the gate is sheared off. (See Fig. T.10.)

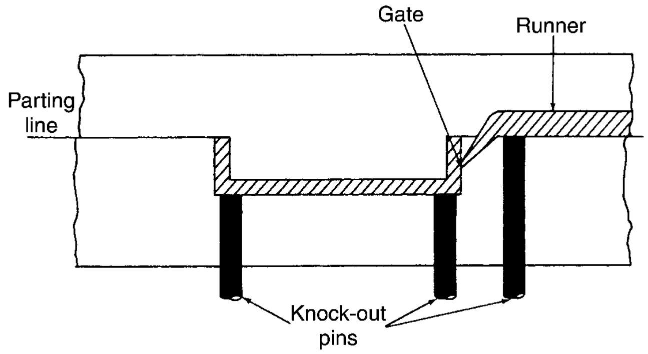

Figure T.10 Tunnel gate. (Ref: Schwartz, S.S. and Goodwin, S. H., *Plastics Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 545)

tup impact test The tup impact test is a falling weight (tup) impact test developed specifically for pipe and fittings. There are several variables that can be selected for this test method.

turning and milling For turning and milling of plastic materials, tungsten carbide- or diamond-tipped tools with negative back rake and front clearance should be used. Milling cutters and end mills will remove undesired material, such as product gate scars, on a molded article.

See also milling, turning, and routing.

twill weave
See weave.

twin-screw extrusion In contrast to the single-screw extruder, the design, principles of operation, and applications of twin-screw extruders vary widely. Although the two screws are usually arranged side by side, the introduction of two screws produces different conveyance mechanisms, varied degrees of mixing, and controllable shear.

The low head pressure generated by twin-screw extruders initially limited their use to processing of shear-sensitive material, such as PVC, and to compounding.

Although changes in design have permitted higher speeds and pressure, the primary use of twin-screw extruders is still compounding. Twin screws are used in approximately 10 percent of all extrusion processes.

See also extrusion; single-screw extruder.

twin-sheet thermoforming Twin-sheet thermoforming is a process for thermoforming hollow objects by introducing high-pressure air between two sheets and blowing the sheets into the mold halves. In this process a vacuum is also applied to assist in the formation of the hollow shape.

twist In fiber construction, the twist is the number of spiral turns about its axis per unit length for a textile stand. It is expressed as turns per inch.

In pultruded parts, this term describes an undesirable condition of longitudinal, progressive rotation that can easily be detected for a noncircular cross section by placing the pultrusion on a plane surface.

two-level mold A two-level mold comprises the placement of one cavity of a mold above another instead of side by side. This reduces clamping force. Two-level molds are often used for large area parts such as picture frames.

U

ultimate strength Ultimate strength is a term used to describe the maximum unit stress a material will withstand when subjected to an applied load in a compression, tension, or shear test. For example, *ultimate tension* is the highest stress sustained by a specimen in a tension test. *Ultimate elongation* is the elongation at rupture.

ultrasonic inspection Ultrasonic methods are at present the most popular nondestructive testing (NDT) technique for use on adhesive joints. Ultrasonic testing measures the response of the bonded joint (adhesive, laminate, composite, etc.) to loading by low-power ultrasonic energy. Short pulses of ultrasonic energy can be introduced on one side of the structure and detected on the other side. This is called *through-transmission testing*. A void or high-damped adhesive (undercured or filled with air) also prevents the ultrasonic energy from passing efficiently through the structure.

A number of different types of ultrasonic inspection techniques using pulsed ultrasound waves from 2.25 to 10 MHz can be applied to laminates and bonded structures. The most common methods are:

- *Contact pulse echo*—The ultrasonic signal is transmitted and received by a single unit.
- *Contact through transmission*—The transmitting search unit is on one side of the bonded structure and the receiving unit is on the other.

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- *Immersion method*—The assembly is immersed in a tank of water; the water acts as a coupling mechanism for the ultrasonic signal.

Figure U.1 illustrates these ultrasonic inspection processes.

Figure U.1 Ultrasonic inspection techniques. (a) Contact pulse echo with a search unit combining a transmitter and receivers. (b) Contact through transmission. Transmitting search unit on top and receiving search unit on the bottom. (c) Immersion pulse echo with search unit (transmitter and receiver) and part inspected under water. (d) Immersion through transmission with both search units (transmitter and receiver) and part under water. (e) Immersion reflector plate. Same as (c) but each unit requires a reflector plate below the part being inspected. (Ref: Hagemaier, D.J., "End Product Nondestructive Evaluation of Adhesive Bonded Metal Joints", *Adhesives and Sealants*, vol. 3, *Engineered Materials Handbook*, ASM International, Materials Park, OH, 1990)

Pulse echo techniques are perhaps the easiest to use in production. The sound is transmitted through the part, and reflections are obtained from voids at the bond interface. The result is generally considered only qualitative in nature because a poorly bonded joint will show as a good joint as long as it is acoustically coupled. A thin layer of oil or water at the interface may also act as a coupling and disguise an unbonded area. Shear waves can also be introduced into the structure with a wedge-shaped transducer. This technique is effective in analyzing sandwich structures.

Bonded structures that are ultrasonically tested by the immersion methods often use a *C-scan* recorder to record the test. This recorder is an electrical device that accepts signals from the pulser/receiver and prints out a plan view of the part. The ultrasonic search unit is automatically scanned over the part. The ultrasonic signals for bond or unbond are detected from built-in reference standards. C-scan NDT techniques are used extensively by aircraft manufacturers to inspect bonded parts.

One of the oldest and best-known ultrasonic testing systems for NDT is the *Fokker bond tester*. This method uses a sweep frequency resonance method of ultrasonic inspection. Some degree of quantitative analysis is claimed with the Fokker bond tester in the aircraft industry.

Acoustic emission is the burst of ultrasound emitted by a material under stress, detectable in practice with the aid of a piezoelectric transducer suitably attached to the article under test. Acoustic emissions from some composites, including fiber-reinforced plastics, are sometimes measured to detect the onset of yielding or permanent damage that may occur on repeated stressing.

See also nondestructive testing.

ultrasonic welding Ultrasonic welding is a frictional process that can be used to join many thermoplastic parts. Frictional heat in this form of welding is generated by high-frequency vibration. The basic parts of a standard ultrasonic welding device are shown in Fig. U.2. During ultrasonic welding, a high-frequency electrodynamic field is generated that resonates a metal horn that is in contact with one substrate. The horn vibrates the substrate sufficiently fast relative to a fixed substrate that significant heat is generated at the interface. With pressure and subsequent cooling, a strong bond can be obtained.

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Figure U.2 Equipment used in a standard ultrasonic welding process. (Ref: Grim, R.A., "Welding Process for Plastics", *Advanced Materials and Processes*, March 1995)

The frequency generally used in ultrasonic assembly is 20 kHz because the vibration amplitude and power necessary to melt thermoplastics are easy to achieve. However, this power can produce a great deal of mechanical vibration that is difficult to control, and tooling becomes large. Higher frequencies (40 kHz) that produce less vibration are possible and are generally used for welding the engineering thermoplastics and reinforced polymers. Higher frequencies are also more appropriate for smaller parts and for parts where less material degradation is required.

Ultrasonic welding is clean and fast (20–30 parts per minute) and usually results in a joint that is as strong as the parent material. The method can provide hermetically sealed components if the entire joint can be welded at one time. Large parts generally are too massive to be joined with one continuous bond so that spot welding is necessary. It is difficult to obtain a completely sealed joint with spot welding. Materials-handling equipment can be easily interfaced with the ultrasonic system to further improve rapid assembly.

Rigid plastics with a high modulus of elasticity are best. Rigid plastics readily transmit the ultrasonic energy, whereas softer plastics tend to dampen the energy before it reaches the critical joint area. Excellent results generally are obtainable with polystyrene, SAN, ABS, polycarbonate, and acrylic plastics. PVC and the cellulosics tend to attenuate energy and deform or degrade at their surfaces. Dissimilar plastics may be joined if they have similar melt temperatures and are chemically compatible. Materials such as polycarbonate and nylon must be dried before welding, otherwise their high level of internal moisture will cause foaming and interfere with the joint.

Ultrasonic welding can also be used to stake plastics to other substrates and for inserting metal parts. It can also be used for spot-welding two plastic components. Figure U.3 illustrates ultrasonic insertion, swaging, stacking, and spot-welding operations. In ultrasonic spot-welding, the horn tip passes through the top sheet to be welded. The molten plastic forms a neat raised ring on the surface that is shaped by the horn tip. Energy is also released at the interface of the two sheets, producing frictional heat. As the tip penetrates the bottom substrate, displaced molten plastic flows between the sheets into the preheated area and forms a permanent bond.

ultraviolet (UV) Ultraviolet (UV) light is light that comprises only the shorter wavelengths of invisible radiation. It is a zone of invisible radiations beyond the violet end of the spectrum of visible radiations. Because the wavelengths are shorter than visible radiations, their photons have more energy. This energy is enough to initiate some chemical reactions and degrade many plastics. Thus UV light is more damaging than visible light to most plastics.

Most plastics transmit at UV wavelengths, and these same plastics are often affected by UV-caused degradation. This degradation almost always manifests itself in color deterioration. However, in many plastics, the deterioration can extend to a significant loss of mechanical and other properties.

ultraviolet degradation Exposure to ultraviolet (UV) light will degrade many plastics, particularly polyolefins. The result will be discoloration, embittlement, and

Figure U.3 Ultrasonic joining operations. (a) Swaging: the plastic is melted and reshaped (left) by ultrasonic vibrations in order to lock another part into place. (b) Staking: ultrasonic vibrations melt and reform a plastic stud (left) in order to lock a dissimilar component into place (right). (c) Insertion: a metal insert (left) is embedded in a preformed hole in a plastic part by ultrasonic vibration (right). (d) Spot welding: two plastic components (left) are jointed at localized points (right). (Ref: Mainolfi, S.J., "Designing Component Parts for Ultrasonic Assembly", *Plastics Engineering*, December 1984) eventual degradation of physical properties. The basic culprit is a *chromophore*, a chemical group that absorbs UV light. Such a group may be part of the polymer structure (a double bond) or it may be present because of residual monomer or catalyst, aromatic or other double-bond containments in any of the ingredients, or hydroperoxide or carbonyl groups resulting from thermal oxidation during processing.

If the UV energy absorbed is not rapidly dissipated, it will begin to break the chemical bonds in the polymer's molecular chain. The lower-molecular-weight chain fragments will no longer exhibit the properties of the original polymer. It also generates free radicals, initiating and propagating a chain degradation reaction.

The reaction follows this sequence. The UV energy breaks a bond, creating an excited molecule that forms a free radical. The free radical reacts with atmospheric oxygen to form a peroxy radical. This radical then attacks at another point to form a hydroperoxide (ROOH) and another free radical, which repeats the sequence. The unstable hydroperoxide ROOH can also form new radicals to accelerate the chain reaction and lead to chain scission.

Stabilization interrupts this sequence. Mechanisms include inhibition of sequence initiation by incorporating additives to screen UV energy, to preferentially absorb it, or to quench the excited state. Mechanisms also include inhibition of the propagation process by incorporating additives that will react chemically with the free radicals and hydroperoxides as soon as they are formed to render them harmless.

See also ultraviolet resistance.

ultraviolet resistance (or light resistance) Ultraviolet (UV) resistance is the ability of a plastic to resist degradation (color fading, loss of mechanical strength, etc.) after exposure to sunlight or uv light. Stabilization is required of many polymers in applications that will require exposure to sunlight. The largest consumption of light stabilizers is for polyolefins. However, UV resistance is an important consideration with many thermoplastics and thermosets.

See also light stabilizer; ultraviolet stabilizer.

ultraviolet stabilizer A variety of additives are available for the protection of plastics from degradation by ultraviolet (UV) light. The choice of UV stabilizer depends on such factors as the application, the polymer's characteristics (particularly its absorption spectrum), the stabilizer's effect on color, and the product's expected life. Another factor that should be considered is toxicity, because most organic UV stabilizers tend to migrate to the surface.

There are several types of UV stabilizers. One group develops UV stabilization by screening out the light to restrict UV penetration into the polymer. Another group interrupts the chemical chain reactions resulting from free radicals. Several other groups operate in different mechanisms and at different times during the UV degradation process.

UV screeners are actually pigments. They render the polymer translucent or opaque and absorb or reflect UV light, thus protecting the polymer. *Carbon black*

(1–2% by weight), *titanium dioxide* at relatively high loadings, and other pigments are effective UV screeners.

UV absorbers are the oldest and largest category of UV stabilizers. They inhibit initiation of the degradation process. Materials in this class compete with the polymer for UV energy and win because their absorptivity is orders of magnitude greater than that of the polymer. *Benzophenones* are used in polyolefins, unsaturated polyesters, PVC, thermoplastic polyesters, and acrylics. This UV absorber may cause objectionable color to develop during compounding, processing, or weathering. *Benzotriazoles* are used in polystyrene, ABS, polycarbonate, and thermoset polyester. They show good initial color and long-term color stability. *Aryl esters* are used in cellulosics and some polyolefin applications. They have FDA acceptance and show good initial color, although some types may cause discoloration. *Oxanilides* exhibit very low color and low volatility and are suitable for high-temperature processing applications.

UV quenchers also inhibit initiation, although they function later in the degradation sequence than do absorbers. Quenchers are organic nickel compounds. They are typically used in polyolefins. Unlike absorbers, quenchers are effective in thin sections. They are often used along with UV absorbers. Quenchers usually impart color.

Scavengers or *decomposers* are UV stabilizers that operate later in the UV degradation sequence, inhibiting propagation rather than initiation. *Hindered amines* function as quenchers or peroxide decomposers. Their main function is free radical scavenging and termination. Advantages include effectiveness at low concentrations (as low as 0.1%), reduced volatility, and high temperature stability. They are suitable in a range of resins. They, however, are not recommended with base-sensitive resins.

There are many producers of each type of UV stabilizer. The following list includes only a few of the major suppliers:

- Benzophenones—American Cyanamid Co., BASF Corp., Ferro Crop., Witco Corp.
- Benzotriazoles—American Cyanamid Co., Ciba-Giegy Corp., Hoechst Celanese Corp.
- Carbon black—Akochem Corp., Cabot Corp., Degussa Corp., J.M. Huber Corp.
- Hindered amines—American Cyanamid Co., BF Goodrich Co., Hoechst Celanese Corp, PMC Specialties Group
- Nickel quenchers—American Cyanamid Co., Ciba-Giegy Corp., DuPont; Ferro Corp., Hoechst Celanese Corp.
- Zinc compounds—Ferro Corp., Santech Inc., RT Vanderbilt Co., Zinc Corp. of America

See also light stabilizer.

unbond An unbond is an area within a bonded interface between two aherends in which the intended bonding action failed to take place. In laminates the term unbond refers to an area in which two layers of prepreg in a cured component do not adhere. The term is also used to denote specific areas deliberately prevented from bonding to simulate a defective bond for the purpose of calibrating inspection techniques and quality control processes.

undercure Undercure is a state of a molded article that has not been adequately polymerized or hardened in the molding process. Undercure is usually due to inadequate control of time or temperature in the molding process. Undercured products can be determined by a variety of processes. The most common, however, is an indentation test, which could be as simple as a fingernail indention into the surface of the part. Standard hardness tests are often used to detect undercure. Generally, undercured parts have not achieved the full physical properties of the fully cured part and are in a softer, even gellike condition.

undercut An undercut is a protuberance or indentation that impedes withdrawal from a two-piece rigid mold. Rigid plastic parts with undercuts are difficult to remove from a standard mold. Flexible materials can be ejected intact even with slight undercuts.

Care must be used when designing a mold so as not to create undercuts that would make removal of the part impossible without damage to the part or mold or both. Molds can be made with movable features to assist with removal.

Molds that must include deep undercuts because of part configuration can be made with water-soluble plaster. This is more often done on molds for low-pressure lamination of reinforced thermosetting plastic and when the production volumes are relatively low. When the part is cured, the plaster mold is simply washed away with water. Hollow articles such as air ducts can also made with water-soluble plaster.

underfill compound Underfill compounds are low-viscosity, resinous formulations (e.g., epoxies) that will flow uniformly under the fine, small spaces of microelectronic devices that are mounted on substrates, such as printed circuit boards,

Formulation of these compounds is very critical, because filling under these tightly spaced devices with their fine leads requires tightly controlled viscosity and flow properties. In addition, fast cure is required for high productivity rates, low and controlled thermal expansion is required to avoid lead breakage due to thermal stresses in system operation, and high thermal stability is often required to ensure stable mechanical and electrical properties. These high-performance underfill compounds are among those plastics known as electronic plastics.

See electronic plastic; viscosity.

Underwriters' Laboratories The Underwriters' Laboratories (UL) is a nonprofit organization, sponsored by the National Board of Fire Underwriters, to which manufacturers voluntarily submit their devices, systems, and materials for examination and test with reference to fire, accident, and crime hazards. Products that are found to meet the necessary requirements appear in the Laboratories' Lists of Inspected Appliances, Equipment, and Materials. They also may carry an inspection label or the initials "UL" in a circle, which users regard as a guarantee of safe performance of the products. Plastic materials are usually tested as parts or components within a product or a device.

uniaxially oriented film Uniaxially oriented film is film that in the course of its production has been deliberately stretched in one of the two principal directions (machine direction or transverse direction). This technique is used to significantly improve the crystallinity and orientation of the polymer molecules in the direction the film is stretched. Uniaxial orientation results in improvement of physical properties.

unicellular A unicellular foamed plastic is one where each cell is an isolated unit. Unicellular plastics are also *closed-cell* structures.

See cellular plastics.

unidirectional laminate A unidirectional laminate is one in which substantially all of the fibers are oriented in the same direction.

unsaturated compound An unsaturated compound is any compound having more than one bond between two adjacent atoms, usually carbon atoms, and capable of adding other atoms at that point to reduce it to a single bond. The term is usually applied to organic compounds with a double or triple bond between two carbon atoms (e.g., acetylene). The compound becomes saturated by direct addition of hydrogen, halogens, and other compounds.

See also saturated compounds.

unsaturated polyester Unsaturated polyesters are a family of polyesters characterized by vinyl unsaturation in the polyester backbone. An unsaturated polyester is a thermosetting polyester that is cross-linkable by reaction with an unsaturated monomer or prepolymer by virtue of the presence of carbon-to-carbon double bonds in its polymer chain. Generally, the unsaturated polyester is dissolved in the reactive monomer.

Unsaturated polyesters find their widest use in laminates, composites such as tanks, boat bodies, lampposts, storage products, etc. Some unsaturated polyesters are used in dough molding compounds, sheet molding compounds, and molding compound in pellet form. Applications include those requiring good electrical properties and where heat resistance is beneficial.

See also polyester (thermosetting).

urea Urea is a white crystalline compound used in the synthesis of urea formaldehyde resins. It is itself synthesized from carbon dioxide and ammonia reacted under high pressure.

urea formaldehyde resin Urea formaldehyde resins (urea) are synthetic resins derived from the reaction of urea (carbamide) with formaldehyde or its polymers.

See amino resin.

urethane

See polyurethane.

urethane foam catalyst

See polyurethane foam catalyst.

V

V-bar mold A V-bar mold is a molding configuration commonly used for injection and transfer molding. It is characterized by two mold halves shaped in the form of a "V" that clamp when pressed into a V-opening.

vacuum bag molding Vacuum bag molding is a process for molding reinforced plastics. Vacuum bag molding is one of the most popular methods of making prototype or short run parts. Either wet resins or prepregs can be used. (See Fig. V.1.)

The first step in the vacuum bag molding process is to place a *release sheet* over the mold surface. The reinforcement is placed onto the release film and impregnated by brushing or spraying if prepregs are not being used. Next, *bleeders* are installed along the top of the mold. These are made of burlap, muslin, cloth, or felt and are intended to provide a space from which the air in the mold can be evacuated. The impregnated reinforcement is sometimes covered with a perforated release film. Special relief fabrics are also used. A sheet of flexible transparent material is placed over the layup on the mold and sealed. A vacuum is then applied between sheet and layup. A form-fitting bag called a *vacuum bag* can also be used on the outer surface of the part, and a vacuum is drawn so that the layup is pressurized to atmospheric pressure (approximately 15 psi). The entrapped air is mechanically worked out of the layup and removed by the vacuum, and the part is finally cured.

Heat curing can be readily done in the vacuum bag molding process because the resin content is low and the pressure can be used to inhibit the flow of resin. Because

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of the heat, however, the bag must be of a material that is heat resistant. It should also not be affected by the resin and should not affect the resin cure.

The *vacuum bag* is the impermeable film that is generally applied to the outside of the layup to facilitate conformability to the mold form and air removal during cure. Polyvinyl chloride (PVC) bags are useful up to 66°C and are less expensive than polyvinyl alcohol (PVA). Certain PVC polymers, however, inhibit polyester resins and prevent a tack-free cure. When high curing temperatures or steam-autoclave curing is required, the bag should be made of neoprene rubber or some similar elastomer. Film materials suitable for bag manufacture also include cellophane, polypropylene, nylon, and fluorocarbons. Silicone and butyl rubbers are also used to make vacuum bags. To make the best parts, the bag should be tailored to the part so that wrinkles will be at a minimum.

Advantages of the vacuum bag process are:

1. The molds are relatively inexpensive.
2. The process is faster than hand layup.
3. Prepregs can be used.
4. The product is not as rich in resin as those produced by the hand layup process, and its properties are better.
5. The process does not require highly skilled personnel.

The disadvantages of the process are:

1. Only the surface adjacent to the mold surface is smooth. The other surface may be duller and show folds and marks from the bag.
2. The part still contains more resin than those made by high-pressure techniques, and hence its properties are not optimal.
3. Certain shapes with complicated surfaces or sharp corners are difficult to form.
4. Dry spots and voids are fairly common.

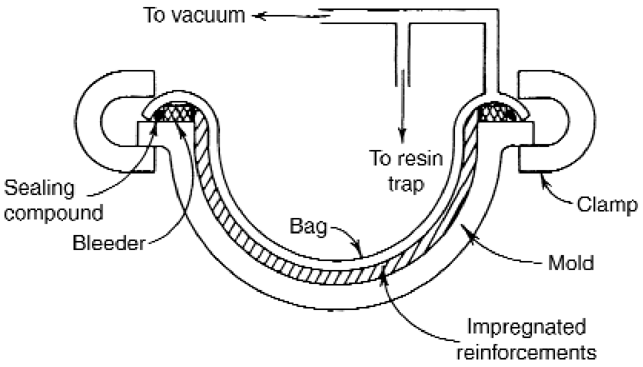


Figure V.1 Vacuum bag molding (Ref: Harper, C.A., "Laminates and Reinforced Plastics Materials and Processes"; *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C.A. Harper, ed., McGraw-Hill, New York, 1998)

A modification of the vacuum bag process is *pressure bag molding*. In this process, a lid is placed over the mold and clamped down to contain about 50 psi. Steam is sometimes used to accelerate cure of the resin. The resulting parts, when made at higher pressures, are considerably denser and of a higher reinforcement content than parts made by vacuum bag methods. This technique, however, is mainly applicable to female molds. Bags used on male molds have a tendency to pucker and develop folds. In actual practice, the pressure bag technique is combined with the use of a vacuum to aid in removing most of the entrapped air.

vacuum forming Vacuum forming is a variation of the thermoforming process in which pressure can be brought about by a vacuum on one side of the sheet. The sheet is clamped in a stationary frame, heated, and drawn down by a vacuum into a mold. In other variations of the thermoforming process, air pressure, clamping, or other methods are used to form the hot thermoplastic sheet to the shape of the mold.

See thermoforming.

vacuum hot pressing Vacuum hot pressing is a method of processing materials (especially powders) into preformed shapes at elevated temperatures, consolidation pressures, and low atmospheric pressures.

vacuum impregnating

See impregnating resin.

vacuum injection molding Vacuum injection molding is a molding process in which, with a male and a female mold, reinforcements are placed in the mold, a vacuum is applied, and a liquid resin is introduced that saturates the reinforcement.

vacuum metallizing Vacuum metalizing is a process in which the surfaces of a plastic part are thinly coated with metal by exposing them to the vapor of the metal that has been evaporated under vacuum. Vacuum metalizing is a physical rather than a chemical process for depositing metal coatings on prepared surfaces.

In vacuum metalizing, plastics or films are thoroughly cleaned and/or etched and given a base coat of lacquer to eliminate surface defects. The parts are then placed in a vacuum chamber with small pieces of coating metal (e.g., chromium, gold, silver, zinc, or aluminum) placed on special heating filaments. Once sealed and under about 0.5 μm of vacuum, the heating filaments are energized until the metal melts and vaporizes. The vaporized metal coats everything it contacts in the chamber, condensing on the cooler surfaces. Parts must be rotated for full coverage, because the metal vapor travels in a line of sight from its origin. Once the coating is accomplished the vacuum is released, the parts are removed, and generally coated with lacquer to help protect its surface.

The metal thickness on a vacuum metalized plastic part is generally 3–4 Å ($1–4 \times 10^{-6}$ in.), which is significantly less that the 1-mil thickness for conventional electroplating. Vacuum metalizing is a batch-type process and does not have the continuous-flow attributes that electrolytic plating has. However, there are several cost savings associated with vacuum metalizing. Because vacuum metallizing inherently has a thinner coating, less metal is used and there are no toxic chemicals involved.

valve gating Valve gating is the process of controlling the flow of polymer at the gate. It can be accomplished by several different techniques. In general, all the methods use a probe at the gate, which either automatically or electronically shuts the flow. When the pressure diminishes, because of the screw retraction, the spring in the probe forces the valve to seal the gate. An automatically trimmed gate is the result.

Another gate valve is the *spear* system in which the probe, using electronic controls, alternately melts and freezes the gate as required by the cycle. Both techniques, and other similar ones, are particularly suitable for use in runnerless molding.

van der Waals forces van der Waals forces are secondary bond forces that act to hold molecules together. These are more generally known as secondary valence or intermolecular forces. The first quantitative statements about them were made by van der Waals in his studies of the equation of state of real gases.

vapor curing Generally used for curing coatings and finishes, vapor curing is a catalyzation or crosslinking conversion method for two-component coatings. The product is coated with one component of the coating in a conventional manner. It is then placed in an enclosure that is filled with the other component, the curing agent, in vapor form. It is in this enclosure that the reaction occurs.

varnish Varnish is a general and somewhat antiquated term referring to combinations of resins, oils, and driers that can be used as finishes or coatings. They also contain thinners or solvents to reduce their viscosity and thus permit a thin, smooth coating to be applied. On curing with the aid of heat or a catalyst, they form a tough, resistant film.

Phenolic, melamine, and silicone varnishes are used to impregnate reinforcement in high-pressure laminates. Polyester varnishes are used in continuous low-pressure laminates. The first group is also used in insulating varnishes for electrical coils and other equipment.

vehicle The vehicle is the liquid medium in which the pigments, particles, etc., are dispersed in coatings such as paint. A vehicle enables the coating to be applied.

veil A veil is an ultrathin mat similar to a *surface mat*, often composed of organic fibers as well as glass fibers.

See also surface mat.

vent Vents are small openings placed in a mold to allow air to exit the mold as molding material enters. (See Fig. V.2.) *Venting* is extremely important for successful parts production. This eliminates air holes, voids, or bubbles in the molded part.

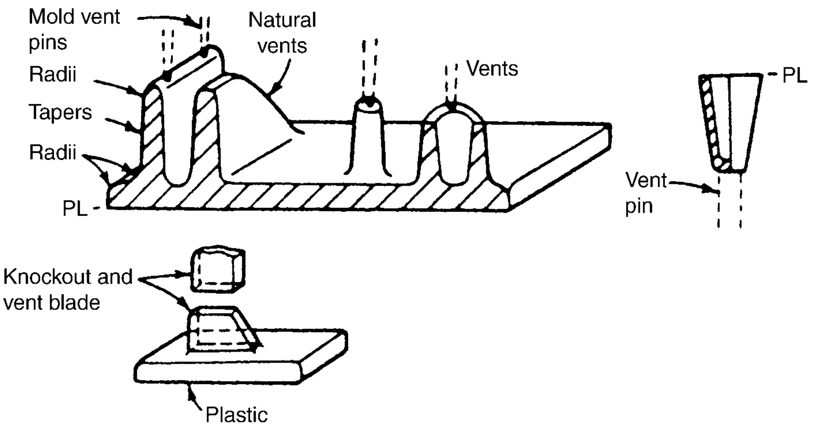


Figure V.2 Ejector pins and vents. (Ref: Hull, J.L.., "Design and Processing of Plastics Parts", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., McGraw-Hill, New York, 1996)

Compression of the entrapped air by the rapidly entering resin can cause discoloration or charring of the resin front, particularly at the last corner filled. Voids or apparent sink marks, due to air bubbles, may also be noted because of insufficient venting.

The vent should be located, if possible, directly opposite a gate, or at least at the point of a corner, etc. Typical vents on one mold half are 0.25–0.50 in. wide and 0.002–0.005 in. deep. In some cases the vent need be no more than a scratch made on the parting line surface of the mold using a diamond-pointed tool.

Vents in the mold's cavities and runners permit air in the cavities to leave the mold ahead of the melt front. The absence, poor location, or clogging of vents can produce short shots (incomplete filling of the cavity) accompanied by char marks from burning of the trapped air (commonly referred to as dieseling). Because thin wall molds are filled very rapidly, vacuum is applied to the vents to improve removal of air in the mold.

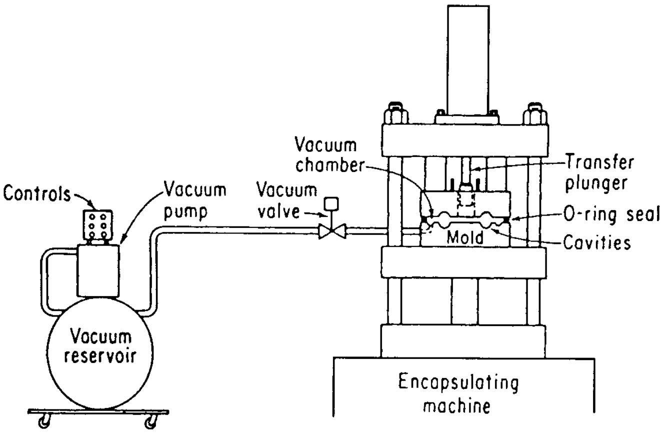


Figure V.3 Schematic diagram showing principle of vacuum venting with transfer molding. (Courtesy Hull Corporation)

Other techniques used for venting include very shallow, flat areas machined on the surface of several ejection pins or, for extreme cases, the use of vacuum to exhaust the air just before injection (See Fig. V.3.). If vent holes or channels are made in the mold they should not be over a few thousandths of an inch in diameter, or in depth, to prevent the resin from entering and clogging the vent.

vent cloth A vent cloth, or *breather cloth*, is a layer or layers of open-weave cloths used to provide a path for vacuum to reach the area over a laminate being cured. Volatiles and air can be easily removed through the veil cloth. The vent cloth also causes the pressure differential that results in the application of pressure to the part being cured.

venting In autoclave curing of a part or assembly, venting refers to the turning off of the vacuum source and venting the vacuum bag to the atmosphere. In this manner the pressure on the part is then the difference between the pressure in the autoclave and atmospheric pressure.

Venturi dispersion plug The Venturi dispersion plug is a plate having an orifice with a conical relief drilled into it. This is fitted into the nozzle of an injection molding machine to aid in the dispersion of colorants in the resin.

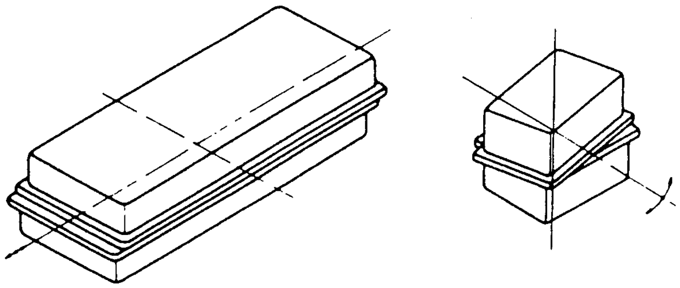
vermiculite Vermiculite is a foliated mineral mixed with resin to form a filler of relatively high compressive strength. The mineral is a processed product of *biotite* and other *micas*. Vermiculite is more commonly used for an extender in aluminum paints and as a conditioner for soils.

See also mica.

vertical flash ring The vertical flash ring is the clearance between the force plug and the vertical wall of the cavity in a positive or semipositive mold. Vertical flash ring is also a term given to the ring of excess material that escapes from the cavity into this clearance space.

vibration welding Vibration welding is similar to ultrasonic welding in that it uses the heat generated at the surface of two parts rubbing together. This frictional heating produces melting in the interfacial area of the joint. Vibration welding is different from ultrasonic welding, however, in that it uses lower frequencies of vibration, 120–240 Hz, rather than the 20–40 kHz that is used for ultrasonic welding. With lower frequencies, much larger parts can be bonded because of less reliance on the power supply. (See Fig. V.4.)

There are two types of vibration welding: linear and axial. *Linear vibration welding* is most commonly used. Friction is generated by a linear, back and forth motion. *Axial or orbital vibration welding* allows irregularly shaped plastic parts to be vibration welded. In axial welding one component is clamped to a stationary structure; the other component is vibrated with orbital motion.



Linear vibration (left) is employed where the length to width ratio precludes the use of axial welding (right) where the axial shift is still within the width of the welded edge.

Figure V.4 Linear and axial vibration welding of a two-part container. (Ref: Scherer, R., "Vibration Welding Could Make the Impossible Design Possible", *Plastics World*, September 1976)

Vibration welding fills a gap in the spectrum of thermoplastic welding in that it is suitable for large, irregularly shaped parts. Vibration welding has been used successfully on large thermoplastic parts such as canisters, pipe sections, and other parts that are too large to be excited with an ultrasonic generator and ultrasonically welded. Vibration welding is also capable of producing strong, pressure-tight joints at rapid rates. The major advantage is its application to large parts and to noncircular joints, provided that a small relative motion between the parts in the welding plane is possible.

Usually, the same manufacturers of ultrasonic welding equipment will also provide vibration welding equipment. Vibration welding equipment can be either electrically driven (variable frequency) or hydraulically driven (constant frequency). Capital cost is generally higher than with ultrasonic welding.

Process parameters to control in vibration welding are the amplitude and frequency of motion, weld pressure, and weld time. Joint pressure is held in the range of 200–250 psi, although at times much higher pressures are required. High mechanical strength can usually be obtained at shorter weld times by decreasing the pressure during the welding cycle. Vibration welding times depend on the melt temperature of the resin and range from 1 to 10 s. with solidification times of less than 1 s. Total cycle times typically range from 6 to 15 s. This is slightly longer than typical spin welding and ultrasonic welding cycles but much shorter than hot plate welding and solvent cementing.

Vibration welding is applicable to a variety of thermoplastic parts with planar or slightly curved surfaces. The basic joint is a butt joint, but unless parts have thick walls, a heavy flange is generally required to provide rigidity and an adequate welding surface.

Vibration welding is ideally suited to parts injection molded or extruded in engineering thermoplastics as well as acetal, nylon, polyethylene, ionomer, and acrylic resins. Almost any thermoplastic can be vibration welded. Unlike other welding methods, vibration welding is applicable to crystalline or amorphous or filled, reinforced, or pigmented materials. Vibration welding also can be utilized with melt-processable fluoropolymers and polyester elastomers, none of which can be joined by ultrasonic welding.

Vibration welding techniques have found several applications in the automobile industry including emission control canisters, fuel pumps and tanks, head and tail light assemblies, heater valves, air intake filters, water pump housings, and bumper assemblies. They have also been used for joining pressure vessels and for batteries, motor housings, and butane gas lighter tanks.

Vicat softening point The Vicat softening point is a standard test for measuring the temperature at which a thermoplastic will soften. Thus it is useful to characterize polymers that have no definite melting point.

It involves the penetration of a flat-ended needle into the plastic under controlled conditions. A fixed load (1000 gm) is applied to the needle with a 0.0015-in^2. circular or square cross section, and the plastic is heated at a uniform rate. The softening point is defined as the temperature at which the penetration reaches a standard value (1 mm). ASTM D1525 defines the process used in measuring the Vicat softening point.

Vicat softening points are usually higher than heat-distortion temperatures and are used primarily on thermoplastics. Vicat readings are not affected by sample size and molded-in stresses as some other melting or softening point test processes are.

vinyl acetate Vinyl acetate plastics are those based on polymers of vinyl acetate or copolymer of vinyl acetate with other monomers.

See polyvinyl acetate.

vinyl chloride Vinyl chloride plastics are those based on polymers of vinyl chloride or copolymers of vinyl chloride with other monomers.

See polyvinyl chloride.

vinyl ester Vinyl ester resins are thermosetting resins that are crosslinkable through reaction of their vinyl groups. They are commonly used as resin matrix in reinforced parts because they easily wet and bond to reinforcing fibers such as glass, carbon, and aramid.

They have easy processing properties, much like a polyester resin. In their uncured state vinyl ester resins also have physical properties similar to those of polyesters, but once crosslinked, vinyl esters have much greater strength, stiffness, and toughness than conventional polyester resins, particularly when exposed to corrosive chemicals. Vinyl esters are noted for their resistance to water and chemicals at both room and elevated temperature.

Vinyl ester resins are made from the esterification of epoxy resins via their terminal epoxy group with an unsaturated acid such as methacrylic acid derived from epoxy resin. The resultant polymer is typically dissolved in a reactive monomer such as styrene.

Three types of vinyl ester resins are commercially available: (1) conventional or resilient grades based on bisphenol A-type epoxies; (2) fire-retardant grades based on tetrabromobisphenol-A epoxies; and (3) high-heat grades based on novolac epoxies.

A brominated vinyl ester resin will have enhanced flame-retardant properties. Bisphenol epoxy vinyl esters provide toughness to filament-wound parts (4% tensile elongation) and resistance to acid, alkaline, and oxidizing conditions. Heat-deflection temperatures range from 93 to 260°C depending on the cure agents and processes. Vinyl ester resins are sometimes modified with urethane for high-performance laminates that resist high-temperature alkaline environments.

Vinyl ester parts are usually formed by most composite manufacturing processes such as *filament winding*, *lamination*, and *pultrusion*. They are often used in construction applications in chemical plants or other environments calling for great resistance to chemicals. The largest use for vinyl ester resins has been in reinforced plastics equipment such as scrubbers, pipe and tanks, and chemical-resistant coatings such as tank and flue stack linings. Conventional trade names of vinyl ester resins and molding compounds (along with their suppliers) are *Atlac* (Reichold), *Derakane* (Dow Plastics), *Dion* (Firestone), *Varimat* (Interplastic Corp.) and *Cyglas* (Cytec Fiberite).

vinylidene chloride Vinylidene chloride is one of the very inert thermoplastics with excellent drug and meat packaging properties. It provides very low transmission of water vapor, odor, and food flavoring. Vinylidene chloride plastics are those based on the polymerization of vinylidene chloride or copolymerization of vinylidene chloride with other unsaturated compounds.

See also polyvinylidene chloride.

vinylidene fluoride Vinylidene fluoride is a thermoplastic chemical- and ultraviolet (UV) light-resistant material with a thermal range from −62 to 149°C. Its flammability properties are classified as nondrip, self-extinguishing. It can be molded by all processes. Vinylidene fluoride is generally used as the basis for 30-year paints.

See polyvinylidene fluoride.

vinyl phenolic Vinyl phenolic compounds are generally alloys or mixtures of phenolic resin with polyvinyl formal or polyvinyl butyral resins. They are mostly used as adhesives. Because of their excellent shear and peel strength, vinyl phenolic adhesives are one of the most successful early structural adhesives for metal.

Room-temperature shear strength as high as 5,000 psi is available in commercial products. Maximum operating temperature, however, is only 93°C because of the thermoplastic constituent softens at elevated temperatures. Chemical resistance and impact strength are outstanding. Vinyl phenolic adhesives are supplied in solvent solutions and as supported and unsupported film. The adhesive cures rapidly at elevated temperatures under pressure.

They are generally used to bond metals, rubbers, and plastics to themselves or to each other. A major application of vinyl phenolic adhesive is the bonding of copper sheet to plastic laminate in printed circuit board manufacture.

vinyl resin Vinyls are structurally based on the ethylene molecule through substitution of hydrogen atom with a halogen or other group. The vinyl family is comprised of seven major types. These are polyvinyl acetals, polyvinyl acetate, polyvinyl alcohol, polyvinyl carbazole, polyvinyl chloride, polyvinyl chloride acetate, and polvinylidene chloride.

Vinyls are basically tough and strong. They resist water and abrasion and are excellent electrical insulators. Special tougher types provide high wear resistance. Excluding some nonrigid types, vinyls are not degraded by prolonged contact with water, oils, foods, common chemicals, or cleaning fluids such as gasoline or naphtha. Vinyls are, however, affected by chlorinated solvents.

Generally, vinyls will withstand continuous exposure to temperatures ranging up to 54°C. Flexible types, filaments, and some rigid vinyls are unaffected by even higher temperatures. Some of these materials in certain conditions (e.g., burning) may be health hazards. These materials also are slow burning, and certain types are self-extinguishing. However, direct contact with an open flame or extreme heat must be avoided.

See also specific vinyl compounds.

virgin material Virgin material is plastic material in a form suitable as feedstock in the relevant processing of products but yet used or processed other than in the course of its own production. It is usually available as pellets, prills, powders, flakes, liquid, etc.

viscoelastic Viscoelastic is a term used to characterize the mechanical behavior of some materials that exhibit a combination of viscous and elastic behaviors. Viscoelastic materials have a time-dependent response to deformation or recovery from load. A material having this property is considered to combine the features of a perfect elastic solid and a perfect fluid.

viscosity Viscosity is the property of a fluid that manifests itself as resistance to flow. Viscosity is the internal friction or resistance to flow of a liquid. Viscosity is a function of the constant ratio of shearing stress to the rate of shear. In the cgs system of units, the unit of viscosity is the poise. This is the force of one dyne per area of one centimeter, per velocity gradient of one centimeter per second per centimeter, which reduces to g/cm-s. The usual symbol is P or η. In the SI of units the unit of viscosity is the Pa s with water as the standard having a viscosity of 1.0 Pa s. The higher the number, the less flow.

In liquids for which the ratio of shearing stress to the rate of shear is a function of stress, the term *apparent viscosity* is defined as this ratio. Liquids in which the shearing stress is directly proportional to the shear rate are called “Newtonian” liquids.

Inherent viscosity is the logarithmic viscosity number determined by dividing the natural logarithm of the relative viscosity (sometimes called the viscosity ratio) by the concentration in grams per 100 ml of solution.

Relative viscosity or *viscosity ratio* is determined by dividing the average efflux time of the solution by the average efflux time of the pure solvent.

There are various methods for measuring viscosity. ASTM D2857 provides a standard practice for the determination of dilute-solution viscosity of polymers. ASTM D1601 is a similar type test method for the viscosity of ethylene polymers. ASTM D789 is for dilute-solution viscosity of vinyl chloride polymers.

viscosity depressant Viscosity depressants are materials that are added in small amounts to a liquid to lower its viscosity. Their major application in the plastics industry is to lower viscosity in vinyl plastisols, so that the processor/formulator does not have to achieve this goal by increasing the plasticizer level.

Viscosity depressants also compensate for the increase in plastisol viscosity that can result from prolonged storage. They can be used to maintain a constant viscosity level in a plastisol that has a tendency to build up viscosity rapidly, by regular additions of small amounts of depressant.

Although many products are available, some of the more popular viscosity depressants are ethoxylated fatty acids. These can be varied in composition over a broad range to obtain desired wetting characteristics.

Major suppliers of viscosity depressants include Albright & Wilson Americas, Dow Corning Corp., Eastman Chemical, C.P. Hall Co., Henkel Corp., ICI Americas, Lubrizol Corp., and Union Carbide.

volatile matter Volatile matter is the amount, commonly expressed as a percentage by weight, of gaseous and vaporized matter given off, and lost, by a material under specified test conditions. ASTM D1203 offers a method of measuring volatile loss from plastics via activated carbon. ASTM D4526 measures volatile loss by headspace gas chromatography. There are also several ASTM specifications for measuring the volatile loss of specific polymers.

VOC or *volatile organic concentration* has become a standard term for the concentration of volatile organce matter in resins, coatings, and adhesives. It is often used in regulatory standards on emissions.

volume resistivity Volume resistivity is the electrical resistance between opposite faces of a 1-cm cube of insulation material. The volume resistivity is commonly expressed in ohm-centimeters. The recommended test is ASTM D257. Volume resistivity is also called *specific insulation resistance*.

See also dielectric properties.

vulcanization Vulcanization is the chemical reaction in which the physical properties of an elastomer are changed by causing it to react with sulfur or other cross-linking agents. Because crosslinking occurs, vulcanization provides a resistance to deformation and flow above the melting point of the elastomer.

The changes in physical properties include decreased plastic flow, reduced surface tackiness, increased elasticity, much greater tensile strength, and considerably less solubility. More recently, certain thermoplastics (e.g., polyethylene) have been formulated to be vulcanizable.

vulcanized fiber A vulcanized fiber is a cellulosic material (wood, paper, or other cellulose fiberboard) that has been partially gelatinized by action of a chemical (usually zinc chloride but also sulfuric acid and cuproammonium solution) and then heavily compressed or rolled to the required thickness, leached free from the gelatinizing agent, and dried.

Vulcanized fiber is produced in the form of sheets, coils, tubes, and rods. Sheets are made in thicknesses of 0.0025–2 in. and approximately 48 × 80 in. in size. Outside diameters of tubes range from 0.1875 to 4.375 in. Rods are produced at 0.09–2 in. in diameter.

Vulcanized fiber is one of the strongest, most rigid, and lightweight materials available (about one-half as heavy as aluminum). It is oil proof but will absorb 20–60% water on long immersion. It has high impact resistance and good machineabilty. Standard grades are available for punching and forming for dielectric applications. These are described by NEMA standards. Bone grade has greater hardness and stiffness, and semiflexible grades are made for use as gaskets and packing. An intermediate grade serves for manufacture of items such as suitcases.

Major limitations of vulcanized fiber include lack of flexibility, dimensional instability caused by poor resistance to water absorption, and exceptionally long processing time (zinc chloride extraction).

vulcanized oils Vulcanized oils are vegetable oils vulcanized with sulfur and used for compounding with rubber for rubber goods or as a rubber substitute. Castor oil, corn oil, rapeseed oil, and soybean oil are used. *Mineral rubber* was a name applied to vulcanized oils mixed with bitumens, especially gilsonite.

W

warp In fabric construction, warp is a term given to fibers that run lengthwise throughout a woven fabric. In cured laminates, warp is an undesirable change in shape from the part's original shape.

water absorption Water absorption is the ratio of the weight of water absorbed by a material to the weight of the dry material. ASTM D570 offers a process for measuring water absorption in this manner. If a more accurate assessment of plastics' water resistance is required, mechanical and/or electrical tests may be run and compared before and after water immersion or exposure.

ASTM D570 uses a specimen size that is 0.125 in. thick and 2.00 in. in diameter for molding materials. The material is submerged in water, and the increase in weight is measured. This test can be performed with several procedures ranging from 1 h in boiling water to 24 h in water at 23°C.

Although most plastics are insoluble in water, they will absorb it. Depending on the degree of absorption, the properties of a plastic may be affected to a greater or lesser degree. The greatest deleterious effect of water on plastics is in the areas of electrical insulation and dimensional stability. There are certain plastics as well whose susceptibility to water causes significant deterioration in mechanical properties.

See also hydrolysis.

water break The water break test is a test used to determine the cleanliness of a metal surface or any surface that has a surface energy (critical surface tension)

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greater than that of water. On a clean prepared metal surface a drop of water will form a solid film. A discontinuous film or droplet remaining on the surface indicates contamination and incomplete surface preparation.

The effect of the water break test is generally due to the fact that greases, oils, and other contaminants have a low surface energy (surface tension less than water) so that a water droplet will bead up and show an incomplete film when applied to surfaces where these contaminants are present. The water break test is sometimes used after surface treatment and before adhesive bonding or coating to determine the adequacy of the surface treatment.

See also wetting.

water-extended polyester Water-extended polyester is a casting formulation in which water is suspended in the polyester resin. The polyester is a room-temperature-curing unsaturated polyester formulation. The water is beat into the polyester resin with high-speed mixers to disperse the droplets throughout the resin. The final, cured product is often used as wood simulation for furniture and other household decorative items.

water honing Water or vapor honing is a cleaning process used for small, delicate parts. When the substrate is so delicate that abrasive treatment is too rough, contaminants can be removed by water honing. This method is similar to grit blasting except that very fine abrasive particles are suspended in a high velocity-water or steam spray. Sometimes solvents are used as the liquid medium in honing operations. Thorough rinsing after honing is generally not required.

water jet cutting A water jet process is a cutting process that uses a high speed jet of water emitted from a nozzle under high pressure (10,000–60,000 psi or greater). The advantage of water jet cutting is that it does not create a burr, and it is a low-temperature process.

Water jet cutting is also capable of cutting through very tough materials such as aramid-reinforced composites. Test specimens of advanced composite laminates (e.g., aramid and graphite composites) are generally cut via water jet cutting because conventional cutting will degrade the specimen.

weak boundary layer

See adhesion theories.

wear The term wear is usually used to describe progressive damage at the interface of two sliding surfaces. The term *abrasion* is used to describe more short-term aggressive removal of matter through the action of a strong and purposeful abrading action. Wear is affected by two major factors: the relative velocity at the interface (V) and the contact pressure (P). Generally, materials can be characterized by a *PV limit* (the product of P and V).

It thus becomes possible to characterize quantitatively the resistance to wear of sliding systems. If a reference surface is used (e.g., stainless steel with a specified finish), the wear resistance of different polymers can be compared. This is commonly done for polymeric bearing systems. The PV limit for a strong engineering plastic widely used for sliding mechanisms, such as acetal or nylon, is about 1000 psi ft/min. For fluorocarbons it is about 200 psi ft/min, and for inexpensive thermosetting plastic (e.g., phenolic) it is 100 psi ft/min.

Wear tests are conducted on devices featuring a variety of modes of sliding and geometries. These test geometries include unidirectional or alternating motion, pin-cylinder, bar-cylinder, pin-disk, and thrust washer.

See also abrasion.

Weatherometer A Weatherometer is an instrument, developed by the National Bureau of Standards and sold by Atlas, that is used to subject test articles to accelerated weathering conditions. It measures the effect of thermal changes, sunlight, and rain on plastic materials and products. To accelerate the process, it applies a rich source of UV, elevated temperatures, and water spray to the surface of the parts being tested.

The Weatherometer consists of an enclosure with a high-intensity light source mounted inside a rotating cylindrical rack on which are mounted test specimens. These units are also supplied with xenon-arc lamps, which are closer in wavelength to natural sunlight. The instrument is equipped for temperature and humidity in addition to the energy source and a programmed spray of water. The effects of SO_2, ozone, or nitrous oxides can also be studied.

The Weatherometer is often used in comparing the weather resistance of paint coatings and the surface appearance of plastics parts. Although it is difficult to make a correlation to actual, real-time aging, the Weatherometer provides a useful instrument to measure the relative weather resistance of different materials.

weather resistance *Weathering* is a broad term encompassing exposure of plastics to solar or ultraviolet (UV) light, temperature, oxygen, humidity, snow, wind, pollution, and other general environmental conditions. However, in actuality the term is often used to include only ultraviolet light and oxidation.

Plastics deterioration from weathering is a process of slow oxidation in which the UV radiation furnishes the energy and the atmosphere (including moisture) furnishes the oxygen. In polymeric materials the UV energy causes scissioning of the molecules, which exposes the material to oxygen in the air and from dissolved oxygen in rain or dew.

The UV energy in sunlight varies in wavelength distribution and intensity with the time of day and year as well as latitude and elevation of exposure. The presence of water also depends on the region, time of year, etc. Therefore, predicting natural weather resistance from laboratory tests can be difficult.

Natural outdoor exposure is the oldest method of determining weather resistance. The standard procedure is to expose samples vertically, facing south. There are many standard test sites set up to do outdoor exposure tests on a variety of parts or samples. So-called accelerated tests are those that use inclined racks (5–45° from the horizontal) facing south in southern locations where sunlight is strongest and available for more hours per day. The most widely used laboratory test for accelerated aging is the Weatherometer.

See Weatherometer.

weave The weave is the pattern in which a fabric is woven. There are standard patterns usually designated by a style number. The most common fiberglass woven fabric weaves include plain or taffeta wave and satin weave. Several common types of weaves are illustrated in Fig. W.1.

The *plain weave* is the simplest and most commonly used weave in fabric construction. In the plain weave the warp and filling threads cross alternatively. The two sides of a plain weave are identical. Plain-woven fabrics are generally the least pliable, but they are also the most stable. This stability permits the fabrics to be woven with a fair degree of porosity without too much sleaziness. However, properties are significantly reduced relative to a weaving pattern with fewer crossovers.

Crowfoot weave is a three by one interlacing weave, that is, a filling thread floats over three warp thirds and then under one. This type of fabric looks different on one side than the other. Fabrics with this weave are more pliable than either the plain or basket weave and, consequently, are easier to form around curves.

An *eight-harness satin weave* is a fabric that has a seven by one weave pattern in which a filling thread floats over seven warp threads and then under one. Like the crowfoot wave, it looks different on one side than on the other. This weave is more pliable than any of the other weaves and is especially adaptable to forming around compound curves.

Four-harness satin refers to a fabric weave also named *crowfoot satin* because the weaving pattern when laid out on cloth design paper resembles the imprint of a crow's foot. In this type of weave there is a three by one interlacing, that is, a filing thread floats over the three warp threads and then under one. This type of fabric looks different on one side than on the other. Fabrics with this weave are more pliable than either the plain or basket weave and, consequently, are easier to form around curves.

The *leno weave* is a locking-type weave in which two or more warp threads cross over each other and interlace with one or more filling threads. It is used primarily to prevent the shifting of fibers in open-weave fabric designs. It is especially useful when the fabric will be exposed to the pressures of a flowing resin during the reinforced plastic molding operation.

The *mock leno weave* is an open weave that resembles a leno and is accomplished by systems of interlacings that draw a group of threads together and leave a space between the group and the next. The warp threads do not actually cross each other as in a real leno and, therefore, no special attachments are required for the loom. This type of weave is generally used when a high thread count is required for strength and the fabric must remain porous.

A *twill weave* is a basic weave characterized by a diagonal rib or twill line. Each end floats over at least two consecutive picks, allowing a greater number of yarns per unit area than in a plain weave, while not losing a great deal of fabric stability.

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Figure W.1 Types of fiberglass fabric weaves. (Ref: PPG Industries also Schwartz. S.S. and Goodman S.H., *Plastics Materials and Processes*, van Nostrand Reinhold, New York, 1982, p. 486)

Figure W.1 (*Continued*)

The *basket weave* is a specific weave used in the construction of *reinforcing fabric*. Two or more warp threads cross alternately with two or more filling threads. The basket weave is less stable than the *plain weave* but produces a flatter and stronger fabric. It is also a more pliable fabric than the plain weave, and a certain degree of porosity is maintained, although not as much as with the plain weave.

See also glass fabric.

web Web is a term given to a thin sheet that is being processed in a machine. For example, the molten web is that which issues from a die, and the substrate web is the substrate being coated.

wedge mold A wedge mold is a mold of any of the basic types in which a portion of the force or cavity is removable from the mold. It may also be attached to the mold frame in such a way that the wedge moves in the mold without being removed.

This type of mold is used to hold inserts in the side of a part, generally at right angles to the direction of draw. It is also used to mold side holes and under-cuts or projections on the molded part that are at right angles to the direction of draw. If the wedge is removed from the mold during the operation, it must be designed so that it can be returned only in the proper position.

weft Weft are fibers that run perpendicular to the *warp* fibers (i.e., they run across the machine direction of the fabric). These are sometimes also called *fill* or *woof* fibers.

See also warp.

welding (plastic) Welding is a method of joining thermoplastics by one of several processes. These processes can be most generally classified as thermal-welding processes or solvent-welding processes.

By careful application of heat or solvent to a thermoplastic substrate, one may liquefy the surface resin and use it to form the bond. With thermal or solvent welding, surface preparation is not as critical as with adhesive bonding. The bond strength is determined by diffusion of polymer from one surface into another instead of by the wetting and adsorption of an adhesive layer. However, with welding some form of pretreatment may still be necessary. Certainly, the parts should be clean, and all mold release and contaminants must be removed by standard cleaning procedures.

Welding by application of heat or *thermal welding* provides an advantageous method of joining many thermoplastics that do not degrade rapidly at their melt temperature. It is a method of providing fast, relatively easy, and economical bonds that are generally 80–100 percent the strength of the parent plastic.

Thermal welding process can be of two kinds: direct and indirect. With *direct welding*, the heat is applied directly to the substrate in the form of either a heated tool or hot gas. *Indirect heating* occurs when some form of energy other than thermal is applied to the joint. The applied energy, which causes heating at the interface or in the plastic as whole, is generally in the form of friction, high-frequency electrical fields, electromagnetic fields, or ultrasonic vibration. Because the heating is localized at the bonding surface, indirect heating processes are very energy efficient, generally resulting in bonds that are stress free and of higher strength than those made by direct welding methods.

Solvent welding or cementing is the simplest and most economical method of joining many noncrystalline thermoplastics. Solvent-cemented joints are less sensitive to thermal cycling than joints bonded with adhesives, and they are as resistant to degrading environments as their parent plastic. Bond strength equaling 85–100 percent of the parent plastic can be obtained. The major disadvantage of solvent cementing is the possibility of stress cracking or crazing of the part and the possible hazards of using low-vapor-point solvents. When two dissimilar plastics are to be joined, adhesive bonding is generally desirable because of solvent and polymer compatibility problems.

Solvent cements should be chosen with approximately the same solubility parameter as the plastic to be bonded. Table S.1 (under solvent cementing) lists typical solvents used to bond major plastics. It is common to use a mixture of fast-drying solvent with a less volatile solvent to prevent crazing. The solvent cement can be bodied to 25 percent by weight with the parent plastic to fill gaps and reduce shrinkage and internal stress during cure.

The parts to be bonded should be unstressed and, if necessary, annealed. The surfaces should mate well and have a clean, smooth surface. A V-joint or rounded butt joint is generally preferred for making a solvent butt joint. Scarf joints and flat butt joints are difficult to position and to apply pressure to during the solvent evaporation phase of the process.

The solvent cement is generally applied to the substrate with a syringe or brush. In some cases the surface can be immersed in the solvent. After the area to be bonded softens, the parts are mated and held under pressure until dry. Pressure should be low and uniform so that the finished joint will not be stressed. After the joint hardens the pressure is released, and an elevated temperature cure may be necessary, depending on the plastic and desired joint strength. The bonded part should not be packaged or stressed until the solvent has adequate time to escape from the joint.

See also types of thermal welding; solvent cementing.

weld marks Weld marks or *weld lines* are the marks on a molded plastic part caused by the meeting of two flow fronts during the molding operation. These are also sometimes called *flow lines* or *knit lines*.

wet abrasive blasting Wet abrasive blasting is similar to sandblasting or dry abrasive blasting except that an abrasive slurry is used as the blasting medium. Generally, three parts of water by volume to one part by volume of the abrasive is used. The abrasive medium is generally a 20–325 grit aluminum oxide or glass bead abrasive slurry.

The wet blasting process can be more adaptable than conventional dry blasting. Wet blasting can handle a wider range of abrasive materials, and a spray rinse automatically removes the blasting residue.

wet layup Wet layup is the process used when a reinforced plastic structure is made by applying a liquid resin to a woven or mat fabric. This is the simplest method of impregnating continuous lengths of mat, fabrics, or rovings with resin.

The reinforcement is passed through a bath and then through a squeeze roll. Such a procedure can be used to produce material with resin contents of approximately 30–50 percent that vary by approximately ± 3 percent.

This procedure is used where materials are required for immediate use or only in small or moderate amounts. The impregnated product, depending on the particular resin, is usually quite tacky and somewhat difficult to handle, particularly if stored in the rolled-up condition.

wet strength Wet strength is the strength of a part or material immediately after immersion in water for a significant period of time. For example, the wet strength of an adhesive joint is determined immediately after the joint has been removed from a liquid in which it has been immersed under specified conditions of time, temperature, and pressure.

The wet strength of paper is generally considered the strength of paper when saturated with water. This is especially used in the discussions of processes where the wet strength of the paper is increased by the addition of plastic resins.

wetting The term *wetting* refers to a liquid spreading over and intimately contacting a solid surface. The degree of wetting is determined by the surface energy of the substrate and the liquid. Figure W.2 illustrates good and poor wetting of a liquid spreading over the surface. Good wetting results when the liquid flows into the valleys and crevices on the substrate surface; poor wetting results when the liquid bridges over the valleys formed by these crevices.

Wetting is favored when the substrate surface tension or its critical surface energy is high and the surface tension of the wetting liquid is relatively low. (See Table W.1.) Low-energy polymers therefore easily wet high-energy substrates such as metal. Conversely polymeric substrates having low surface energies will not be readily wet by other materials and are useful for applications requiring nonstick, passive surfaces such as release films, antigraffiti paints, etc.

Good wetting is very important in adhesive bonding. After intimate contact is achieved between the adhesive and adherend through wetting, it is believed that permanent adhesion results primarily through forces of molecular attraction.

See surface energy, surface tension.

wetting agent

See coupling agent.

whiskers Whiskers are short single crystal fibers or filaments used as a reinforcement in a matrix. Whisker diameters range from 1 to 25 μm with aspect ratios between 100 and 15,000.

So-called ceramic “whiskers” received much attention in the 1950s and 1960s for their outstanding mechanical properties. They are generally short, fiber-shaped,

Table W.1 Critical Surface Tensions for Common Solids and Surface Tensions of Common Liquids

Materials	Critical Surface Tension, dyne/cm
Acetal	47
Acrylonitrile-butadiene-styrene	35
Cellulose	45
Epoxy	47
Fluoroethylene propylene	16
Polyamide	46
Polycarbonate	46
Polyethylene	31
Polyethylene terephthalate	43
Polyimide	40
Polymethylmethacrylate	39
Polyphenylene sulfide	38
Polystyrene	33
Polysylfone	41
Polytetrafluoroethylene	18
Polyvinyl chloride	39
Silicone	24
Aluminum	≈500
Copper	≈1000
Material	**Surface Tension, dyne/cm**
Epoxy resin	47
Fluorinated epoxy resin*	33
Glycerol	63
Petroleum lubricating oil	29
Silicone oils	21
Water	73

*Experimental resin; developed to wet low-energy surfaces. (Note low surface tension relative to most plastics.)

defect-free single crystals based on carbon and oxides, nitrides, or carbides of various metals such as aluminum, beryllium, boron, magnesium, and silicon. Sapphire, silicon carbide, silicon nitride, aluminum nitride, boron carbide, and magnesium oxides, as well as graphite and silicon are examples of ceramic whiskers. Their high price has largely kept them from significantly penetrating the plastics reinforcement field.

Wollastonite Wollastonite is a naturally occurring nonmetallic calcium metasilicate, $CaSiO_3$. It is the only commercially available pure white mineral that is wholly needlelike. The typical length-to-diameter ratios range from 3:1 to 20:1 The theoretical composition of pure Wollastonite is 48.3 percent CaO and 51.7 percent SiO_2

It is available in very fibrous to finely divided grades. Wollastonite has been used in thermosetting molding compounds, paints, and ceramics. It is also widely used in

Figure W.2 An illustration of good and poor wetting by an adhesives spreading over a surface. (Ref: Schneberger, G.L., "Chemical Aspects of Adhesives Bonding, *Adhesives Age*, March 1970)

thermoplastics such as nylon, polycarbonate, thermoplastic polyesters, polyoflefins, polystyrene, thermoplastic urethanes, and vinyl plastisols. It is also used on some elastomeric systems to provide a good balance between low cost and property advantages.

Used as a reinforcing filler, Wollastonite can reduce costs and enhance the compound by increasing flexural strength and modulus, increasing tensile strength and modulus, decreasing water absorption, and improving dimensional stability.

Major suppliers of Wollastonite include Harwick Chemical Corp., NYCO Minerals Inc., Pluess-Staufer International Inc., and R. T. Vanderbilt Co.

woof
See weft.

working life The working life is the period of time during which a liquid resin or adhesive remains stable and suitable for use after mixing with catalyst, solvent, or other compounding ingredients. The working life is the measured time from (1) when the product is ready for use (i.e., mixed and ready to apply) until the time when (2) the resin mix is no longer usable because the curing, drying, etc. mechanism has progressed to such an extent that the product is no longer workable.

ASTM D1338 establishes two procedures for determining working life. One method uses viscosity change, and the other method uses end properties as the criteria when the effective working life has expired.

See pot life.

woven fabric Woven fabric was the first type of fibrous glass reinforcement developed for reinforced composite applications. It is a high-cost reinforcement used widely because of its high strength characteristics. Breaking strength, fabric thickness, fabric weight, pliability, and finish are factors to be considered when fabric selection is made.

See also glass fabric; fabric; weave.

woven roving Woven roving is a thick reinforcement manufactured with either conventional or spun roving. It is sometimes called *roving cloth*. Woven roving is produced by weaving rovings into coarse, heavy, drapable fabrics. Woven roving is available in a variety of weaves. It costs less than conventional fabrics. It is generally used for high-strength, glass-reinforced composite applications.

See also roving.

X

X-ray inspection *Radiography* (*X-ray*) inspection can be used to detect voids or discontinuities in molded parts, adhesive bonds, laminates, composites and panel constructions. This method is more expensive and requires more skilled experience than ultrasonic methods. The product must contain some metal powder or other suitable filler to create enough contrast to make the defects visible. This method is applicable to honeycomb sandwich structures as well as metal and nonmetal joints.

***x-y* axis** The *x-y* axis indicates directions parallel to fibers in a woven fiber reinforced laminate. The *x-y* axis defines the plane of the laminate, whereas the *z-axis* defines the thickness of the laminate. Physical properties are much higher and thermal expansion is much lower in the *x-y* axis, because this expansion is more controlled by the fabric in the laminate.

Convention is that the *x-axis* is the axis in the plane of the laminate that is used as the 0° reference for designating the angle of a lamina. The *y-axis* is the axis in the plane of the laminate that is perpendicular to the *x*-axis.

See also *z*-axis.

XMC and HMC *XMC* (*extra high-strength molding compound*) and *HMC* (*high-strength molding compound*) are both thermosetting molding compounds that are made on filament winding equipment so as to contain high concentrations of glass reinforcement.

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XMC refers to a series of improved structural molding compounds by PPG Industries. They are distinguished from other *bulk molding compounds (BMCs)* by their very high percentage of fiberglass (up to 80% by width). The XMC uses filament winding techniques to incorporate continuous fiberglass strands. The polyethylene film-wrapped composite is removed from the winding mandrel for further molding to shape.

HMC is a similar product produced by PPG Industries. HMC uses chopped glass strands rather than filament reinforcement but is processed like XMC. HMC is aimed at strength rather than final part surface finish. HMC is generally produced with vinyl ester resins.

Major applications of these materials are in automotive structures where high strength-to-weight ratios are in greatest demand. Examples include door beams, transmission and radiator supports, and wheels.

See also bulk molding compound (BMC); sheet molding compound (SMC); thick molding compound (TMC).

xylenol Xylenol, $C_6H_3OH(CH_3)_2$, is one of the substituted phenols obtained from both coal tar and petroleum. Six isomeric forms are possible. It is used in producing phenolic type resins and as an organic solvent.

Y

yarn Yarns are higher-cost reinforcements produced on special textile equipment by twisting fibrous strands (generally glass) from the basic forming package. They permit a large number of yarns to be handled conveniently as a unidirectional reinforcement.

yield value The yield value or *yield point* is the lowest stress at which a material undergoes plastic deformation. Below this stress, the material is elastic; above it, the material is viscous. In a stress-strain plot this stress value is marked by the point at which the initial ascending part of the curve first levels off, or reaches a maximum.

Yield strength is the stress at the yield point. For materials whose stress-strain curve does not exhibit a yield point, yield strength is sometimes defined in terms of a specified limiting stress value of the departure of linearity. The *yield point elongation* is the difference between the elongation at the completion and at the start of discontinuous yielding.

yoke forming Yoke forming is a method of stretch forming sheet plastics.

Young's modulus Young's modulus, also called the *Young's modulus of elasticity*, is the modulus of elasticity in tension. It is the ratio of stress in a material to its deformation. Young's modulus is the ratio of normal stress to corresponding strain for tensile or compressive stresses at less than the proportional limit of the material.

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Z

z-axis The z-axis is the direction perpendicular to fibers in the woven fiber reinforced laminate, that is, through the thickness of the laminate. Physical properties are much lower and thermal expansion is much higher in the z-axis because this expansion is more controlled by the resin than the laminate.

See also x-y axis.

Zahn viscosity cup The Zahn viscosity cup is a small, U-shaped cup suspended from a looped wire, with an orifice of any one of five sizes at the base of the cup. The entire cup is submerged in the test sample and then withdrawn. The time in seconds from the moment the top of the cup emerges from the sample until the stream from the orifice first breaks is the measurement of viscosity.

Because of the simplicity of the test and its ability to be used alongside mixing equipment, the cup viscosity test is ideal for mixing resinous solutions or making adjustments of solvent to existing solutions to obtain a specified viscosity.

Ziegler-Natta catalyst In the 1950s, Ziegler and Natta's work on anionic coordination catalysts led to the development of polypropylene, high-density linear polyethylene, and other stereospecific polymers. Ziegler-Natta catalysts are capable of controlling the microstructure to produce stereospecific polymers. In the Ziegler method, catalysts made from the reaction of titanium tri- or tetrachloride with aluminum alkyls are generally used during polymerization to provide stereospecificity.

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Ziegler-Natta catalysts are used in the low-pressure process to produce polyethylenes. Various types of polyethylene, including ultrahigh-molecular-weight polyethylene can be produced with Ziegler catalysts in a low-pressure process.

These low-pressure methods (under 500 psi) were developed by Phillips and DuPont in the United States and are called Ziegler or linear processes, in contrast to the high-pressure or conventional processes. Low-pressure polymerization produces a polyethylene having remarkably different properties, because of the greater linearity of the polymer and differences in molecular weight distribution.

zirconate Zirconate coupling agents have a structure very similar to that of the titanates. Zirconium propionate is used as an adhesion promoter in printing ink formulations for polyolefins that have been treated by corona discharge. Like the titanates, zirconate coupling agents are useful in improving the dispersion characteristics of fillers in polymer systems.

See also coupling agents.

ZMC ZMC is a process based on injection molding that reduces glass fiber breakage. It requires the use of a specially formulated *bulk molding compound*. Glass orientation is random, as in SMC. This method appears to overcome most of the disadvantages (i.e., fiber breakage and orientation) regarding injection molding of thermosetting materials without losing the advantages. ZMC is a French process, and the development is ongoing.

See also bulk molding compound.

APPENDICES

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LISTING OF APPENDICES

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APPENDIX A

Some Common Abbreviations Used in the Plastics Industry*

AAGR	average annual growth rate
AS	atomic absorption spectroscopy
ABA	acrylonitrile-butadiene-acrylate
ABS	acrylonitrile-butadiene-styrene copolymer
ACM	acrylic acid ester rubber
ACS	acrylonitrile-chlorinated PE-styrene
AES	acrylonitrile-ethylene-propylene-styrene
AMMA	acrylonitrile-methyl methacrylate
AN	acrylonitrile
AO	antioxidant
APET	amorphous polyethylene terephthalate
APP	atactic polypropylene
ASA	acrylic-styrene-acrylonitrile
ASTM	American Society for Testing and Materials
ATH	aluminum trihydrate
AZ(O)	azodicarbonamide
BATF	Bureau of Alcohol, Tobacco, and Firearms
BM	blow molding
BMC	bulk molding compounds

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BMI	bismaleimide
BO	biaxially-oriented (film)
BOPP	biaxially-oriented polypropylene
BR	butadiene rubber
BS	butadiene styrene rubber
CA	cellulose acetate
CAB	cellulose acetate butyrate
CAD	computer aided design
CAE	computer aided engineering
CAM	computer aided manufacturing
CAP	cellulose acetate propionate
CAP	controlled atmosphere packaging
CBA	chemical blowing agent
CF	cresol formaldehyde
CFA	chemical foaming agent
CFC	chlorofluorocarbons
CFR	Code of Federal Regulations
CHDM	cyclohexanedimethanol
CIM	computer integrated manufacturing
CN	cellulose nitrate
COP	copolyester
COPA	copolyamide
COPE	copolyester
CP	cellulose propionate
CPE	chlorinated polyethylene
CPET	crystalline polyethylene terephthalate
CPP	cast polypropylene
CPVC	chlorinated polyvinyl chloride
CR	chloroprene rubber
CS	casein
CSD	carbonated soft drink
CTA	cellulose triacetate
CVD	chemical vapor deposition
DABCO	diazobicyclooctane
DAM	days after manufacture
DAM	diallyl maleate
DAP	diallyl phthalate
DCPD	dicyclopentadiene
DE	diotamaceous earth
DEA	dielectric analysis
DETDA	diethyltoluenediamine
DMA	dynamic mechanical analysis
DSC	differential scanning analysis
DMT	dimethyl ester of terephthalate
DWV	drain, waste, vent (pipe grade)

EAA	ethylene acrylic acid
EB	electron beam
EBA	ethylene butyl acrylate
EC	ethyl cellulose
ECTFE	ethylene-chlorotrifluoroethylene copolymer
EEA	ethylene-ethyl acrylate
EG	ethylene glycol
EMA	ethylene-methyl acrylate
EMAA	ethylene methacrylic acid
EMAC	ethylene-methyl acrylate copolymer
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EMPP	elastomer modified polypropylene
EnBA	ethylene normal butyl acrylate
EP	epoxy resin, also ethylene-propylene
EPA	Environmental Protection Agency
EPDM	ethylene-propylene terpolymer rubber
EPM	ethylene-propylene rubber
EPS	expandable polystyrene
ESCR	environmental stress crack resistance
ESI	ethylene-styrene copolymers
ETE	engineering thermoplastic elastomers
ETFE	ethylene-tetrafluoroethylene copolymer
ETP	engineering thermoplastics
EVA(C)	polyethylene-vinyl acetate
EVOH	polyethylene-vinyl alcohol copolymers
FDA	Food and Drug Administration
FEP	fluorinated ethylene propylene copolymer
FPVC	flexible polyvinyl chloride
FR	flame retardant
FRP	fiber reinforced plastic
GIM	gas injection molding
GIT	gas injection technique
GMT(P)	glass mat reinforced thermoplastics
GPC	gel permeation chromotography
GPPS	general purpose polystyrene
GRP	glass fiber reinforced plastics
GTP	group transfer polymerization
HALS	hindered amine light stabilizer
HAS	hindered amine stabilizers
HB	Brinell hardness number
HCFC	hydrochlorofluorocarbons
HCR	heat-cured rubber
HDI	hexamethylene diisocyanate
HDPE	high-density polyethylene

HDT	heat deflection temperature
HFC	hydrofluorocarbons
HIPS	high-impact polystyrene
HMDI	diisocyanato dicyclohexylmethane
HMW	high molecular weight
HNP	high nitrile polymer
IIR	butyl rubber
IM	injection molding
IMC	in-mold coating
IMD	in-mold decoration
IPI	isophorone diisocyanate
IV	intrinsic viscosity
LCP	liquid crystal polymers
LIM	liquid injection molding
LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
LP	low-profile resin
MAP	modified atmosphere packaging
MbOCA	3,3′-dichloro-4,4-diamino-diphenylmethane
MBS	methacrylate-butadiene-styrene
MC	methyl cellulose
MDI	methylene diphenylene diisocyanate
MEKP	methyl ethyl ketone peroxide
MF	melamine formaldehyde
MFI	melt flow index
MIS	management information systems
MMA	methyl methacrylate
MPE	metallocene polyethylenes
MPF	melamine-phenol-formaldehyde
MPR	melt-processable rubber
MRP	manufacturing requirement planning
MWD	molecular weight distribution
NBR	nitrile rubber
NDI	naphthalene diisocyanate
NDT	nondestructive testing
NR	natural rubber
ODP	ozone depleting potential
OFS	organofunctional silanes
OPET	oriented polyethylene terephthalate
OPP	oriented polypropylene
O-TPV	olefinic thermoplastic vulcanizate
OEM	original equipment manufacturer
OSA	olefin-modified styrene-acrylonitrile
PA	polyamide
PAEK	polyaryletherketone

PAI	polyamide imide
PAN	polyacrylonitrile
PB	polybutylene
PBA	physical blowing agent
PBAN	polybutadiene-acrylonitrile
PBI	polybenzimidazole
PBN	polybutylene naphthalate
PBS	polybutadiene styrene
PBT	polybutylene terephthalate
PC	polycarbonate
PCC	precipitated calcium carbonate
PCD	polycarbodiimide
PCR	post-consumer recyclate
PCT	polycyclohexylenedimethylene terephthalate
PCTA	copolyester of CHDM and PTA
PCTFE	polychlorotrifluoroethylene
PCTG	glycol-modified PCT copolymer
PE	polyethylene
PEBA	polyether block polyamide
PEC	chlorinated polyethylene
PEDT	3,4 polyethylene dioxithiophene
PEEK	polyetheretherketone
PEI	polyether imide
PEK	polyetherketone
PEL	permissible exposure level
PEKEKK	polyetherketoneetherketoneketone
PEN	polyethylene naphthalate
PES	polyether sulfone
PET	polyethylene terephthalate
PETG	PET modified with CHDM
PF	phenol formaldehyde
PFA	perfluoroalkoxy resin
PI	polyimide
PID	proportional, integral, derivative
PIBI	butyl rubber (also IIR)
PIM	powder injection molding
PLC	programmable logic controller
PMDI	polymeric methylene diphenylene diisocyanate
PMMA	polymethyl methacrylate
PMP	polymethylpentene
PO	polyolefins
POM	polyacetal
PP	polypropylene
PPA	polyphthalamide
PPC	chlorinated polypropylene

PPE	polyphenylene ether, modified
ppm	parts per million
PPO	polyphenylene oxide
PPS	polyphenylene sulfide
PPSU	polyphenylene sulfone
PS	polystyrene
PSU	polysulfone
PTA	purified terephthalic acid
PTFE	polytetrafluoroethylene
PU	polyurethane
PUR	polyurethane
PVC	polyvinyl chloride
PVCA	polyvinyl chloride acetate
PVDA	polyvinylidene acetate
PVDC	polyvinylidene chloride
PVDF	polyvinylidene fluoride
PVF	polyvinyl fluoride
PVOH	polyvinyl alcohol
QMC	quick mold change
RFI	radio frequency interference
RHDPE	recycled high density polyethylene
RIM	reaction injection molding
RPET	recycled polyethylene terephthalate
RTD	resistance temperature detector
RTM	resin transfer molding
RTV	room temperature vulcanizing
SI	silicone plastic
SAN	styrene acrylonitrile copolymer
SB	styrene butadiene copolymer
SBC	styrene block copolymer
SBR	styrene butadiene rubber
SMA	styrene maleic anhydride
SMC	sheet molding compound
SMC-C	SMC-continuous fibers
SMC-D	SMC-directionally oriented
SMC-R	SMC-randomly oriented
SPC	statistical process control
SQC	statistical quality control
SRIM	structural reaction injection molding
TA	terephthalic acid
TDI	toluene diisocyanate
TEO	thermoplastic elastomeric olefin
TGA	thermogravimetric analysis
TLCP	thermoplastic liquid crystal polymer
TMA	thermomechanical analysis

TMC	thick molding compound
T/N	terephthalate/naphthalate
TPA	terephthalic acid
TP	thermoplastic
TPE	thermoplastic elastomer
TPO	thermoplastic olefins
TPU	thermoplastic polyurethane
TPV	thermoplastic vulcanizate
TS	thermoset
TWA	time-weighted average
UF	urea formaldehyde
UHMW	ultrahigh molecular weight
ULDPE	ultralow-density polyethylene
UP	unsaturated polyester resin
UR	urethane
UV	ultraviolet
VA(C)	vinyl acetate
VC	vinyl chloride
VDC	vinylidene chloride
VLDPE	very low-density polyethylene
VOC	volatile organic compounds
ZNC	Ziegler-Natta catalyst

APPENDIX B

Important Properties of Plastics and Listing of Plastics Suppliers*

Important Properties for Designing with Plastics†

For most product design engineers, designing with plastics presents difficult problems, often resulting in missed opportunities or less than optimal plastic or plastic-containing products. The primary reason is that most design engineers are not experienced with plastics, since their education and training have prepared them for designing with metals. Furthermore, the chemical nature of plastics coupled with the extremely large number of plastics makes it often difficult for designers without specific training to properly understand and differentiate between kinds of plastics. The myriad grades and formulations only complicate the problem.

Based on this fundamental industry problem, the requirement exists for a well-categorized listing of plastic resins and compounds and their important properties for use by design engineers. This table, adapted from *Modern Plastics Encyclopedia '98*, well meets this need. Coupled with the discussions on these materials in the text of this handbook, this comprehensive data table will provide the product design engineer with useful guidelines ranging from processing pressures and temperatures used for molding plastic materials to part shrinkage during molding and on to all of the important mechanical, thermal, and physical properties needed for part design. Also listed are the ASTM test methods used in determining these properties, for those who need further understanding of these properties and their limitations. Lastly, major suppliers are provided for each of the materials, along with a listing of addresses. This will enable source selection and help in obtaining more detailed data for each of the plastic materials listed.

Notes for the data tables and the names and addresses of suplliers listed in the tables are presented at the end of this Appendix.

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[†] The following table is reprinted from the *Modern Plastics Encyclopedia '98,* pp. B-152 to B-210, Resins and Compounds section.

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Materials				ABS						
					Flame-retarded Grades, Molding and Extrusion					Injection Molding Grades
		Properties	ASTM Test Method	Extrusion Grade	ABS	ABS/PVC	ABS/PC	ABS/Nylon	ABS/PC Injection Molding and Extrusion	Heat-resistant
Processing	1a.	Melt flow (gm./10 min.)	D1238	0.4–6.86	1.2–1.7; 6	1.9				1.1–1.8
	1.	Melting temperature, °C. T_m(crystalline)								
		T_g (amorphous)		88–120	110–125					110–125
	2.	Processing temperature range, °F. (C = compression; T = transfer I = injection; E = extrusion)		E: 350–500	C: 350–500 I: 380–500	370–410	I: 425–520	I: 460–520	I: 460–540 E: 450–500	C:325–500 I: 475–550
	3.	Molding pressure range, 10^3 p.s.i.			8–25		10–20	8–25	10–20	8–25
	4.	Compression ratio		2.5–2.7	1.1–2.0	2.0–2.5	1.1–2.5	1.1–2.0	1.1–2.5	1.1–2.0
	5.	Mold (linear) shrinkage, in./in.	D955	0.004–0.007	0.004–0.008	0.003–0.006	0.004–0.007	0.003–0.010	0.005–0.008	0.004–0.009
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	2500–8000	3300–8000	5800–6500	5800–9300	4000–6000	5800–7400	4800–7500
	7.	Elongation at break, %	D638[b]	2.9–100	1.5–80		20–70	40–300	50–125	3–45
	8.	Tensile yield strength, p.s.i.	D638[b]	4300–7250	4000–7400	4300–6600	7700–9000	4300–6300	3500–8500	4300–7000
	9.	Compressive strength (rupture or yield), p.s.i.	D695	5200–10,000	6500–7500		11,000–11,300			7200–10,000
	10.	Flexural strength (rupture or yield), p.s.i.	D790	4000–14,000	6200–14,000	7900–10,000	12,000–14,500	8800–10,900	8700–13,000	9000–13,000
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	130–420	270–400	325–380	350–455	260–320	350–380	285–360
	12.	Compressive modulus, 10^3 p.s.i.	D695	150–390	130–310		230			190–440
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	130–440	300–600	320–400	350–400	250–310	290–375	300–400
		200° F.	D790							
		250° F.	D790							
		300° F.	D790							

	14.	Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.5–12	1.4–12	3.0–18.0	4.1–14.0	15–20	6.4–12.0	2.0–6.5
	15.	Hardness	Rockwell	D785	R75–115	R100–120	R100–106	R115–119	R93–105	R95–120	R100–115
			Shore/Barcol	D2240/ D2583			Shore D-73				
Thermal	16.	Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	60–130	65–95	46–84	67	90–110	62–72	60–93
	17.	Deflection temperature under flexural load, °F.	264 p.s.i.	D648	170–220	158^{g}; 181; 190–225 annealed	169–200 annealed	180–220	130–150	210–240	220–240 annealed 181–193^{g}
			66 p.s.i.	D648	170–235	210–245 annealed		195–244	180–195	220–265	230–245 annealed
	18.	Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177							4.5–8.0
Physical	19.	Specific gravity		D792	1.02–1.08	1.16–1.21	1.13–1.25	1.17–1.23	1.06–1.07	1.07–1.15	1.05–1.08
	20.	Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.20–0.45	0.2–0.6		0.24		0.15–0.24	0.20–0.45
			Saturation	D570							
	21.	Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	350–500	350–500	500	450–760		430	350–500
				SUPPLIERS^{a}	Albis: American Polymers; Ashley Polymers; Bamberger Polymers; BASF; Bayer Corp.; Diamond Polymers; Dow Plastics; Federal Plastics; GE Plastics; LG Chemical; RSG Polymers; A. Schulman; Shuman	Albis; Ashley Polymers; BASF; Bayer Corp.; ComAlloy; Diamond Polymers; DSM; Federal Plastics GE Plastics; LG Chemical; M. A. Polymers; Polymer Resources; RSG Polymers; RTP; A. Schulman; Shuman	ComAlloy; CONDEA Vista; Novalec; A Schulman; Shuman	American Polymers; Ashley Polymers; Bayer Corp.; ComAlloy; Diamond Polymers; Dow Plastics; GE Plastics; LG Chemical; M. A. Polymers; Polymer Resources; RTP	Bayer Corp.	Ashley Polymers; Bayer Corp.; ComAlloy; Diamond Polymers; Dow Plastics; GE Plastics; LG Chemical; M. A. Polymers; Polymer Resources; RTP	American Polymers; Ashley Polymers; BASF; Bayer Corp.; Diamond Polymers; Dow Plastics; Federal Plastics; GE Plastics; LG Chemical; Polymer Resources; RSG Polymers; RTP; A. Schulman; Shuman

ABS (Cont'd)

	Injection Molding Grades (Cont'd)								EMI Shielding (Conductive)		
	Medium-Impact	High-Impact	Platable Grade	Transparent	20% Glass Fiber-reinforced	30% Glass Fiber-reinforced	20% Long Glass fiber-reinforced	40% Long Glass-fiber-reinforced	6% Stainless Steel Fiber	7% Stainless Steel Fiber	10% Stainless Steel Fiber
1a.	1.1–34.3	1.1–1.8	1.1								
1.											
	102–115	91–110	100–110	120	100–110	100–110	100–110	100–110	100–110	100–110	100–110
2.	C: 325–350 I: 390–525	C: 325–350 I: 380–525	C: 325–400 I: 350–500	455–500	C: 350–500 I: 350–500	I: 400–460	I: 400–460	I: 400–460	I: 400–460	I: 400–460	I: 400–460
3.	8–25	8–25	8–25		15–30						
4.	1.1–2.0	1.1–2.0	1.1–2.0								
5.	0.004–0.009	0.004–0.009	0.005–0.008	0.009–0.067	0.001–0.002	0.002–0.003	0.001–0.002	0.001	0.004–0.006	0.004	0.004–0.006
6.	5500–7500	4400–6300	5200–6400	5000	10,500–13,000	13,000–16,000	13,000	16,000	6300–9200	6000	7100
7.	2.2–60	3.5–75		20	2–3	1.5–1.8	2.0	1.5	3.8	3.8	2.5
8.	5000–7200	2800–6300	6700	7000							
9.	1800–12,500	4500–8000			13,000–14,000	15,000–17,000	14,000	17,000			
10.	7100–13,000	5400–11,000	10,500–11,500	10,000	14,000–17,500	17,000–19,000	20,000	25,000	8700–11,000	10,000–12,000	12,100
11.	300–400	150–350	320–380	290	740–880	1000–1200	900	1000	300–400		400
12.	200–450	140–300			800						
13.	310–400	179–375	340–390		650–800	1000	850	1100	280–410	430	500

14.	3.0–9.6	6.0–10.5	4.0–8.3	1.5–2.0	1.1–1.4	1.2–1.3	2.0	2.5	1.2–1.4	1.0–1.1	1.4
15.	R102–115	R85–106	R103–109	R94	M85–98, R107	M75–85	M85–95	M90–100			
16.	80–100	95–110	47–53	60–130	20–21						
17.	174–220 annealed	205–215 annealed; 192 unannealed	190–222 annealed	194	210–220	215–230	210	215	190	185–200	190
	192–225 annealed	210–225 annealed	215–222 annealed	207	220–230	230–240	225	225			
18.					4.8						
19.	1.03–1.06	1.01–1.05	1.04–1.07	1.08	1.18–1.22	1.29	1.23	1.36	1.10–1.28	1.12	1.14
20.	0.20–0.45	0.20–0.45		0.35	0.18–0.20	0.3	0.2	0.2	0.4	0.4	
21.	350–500	350–500	420–550		450–460						
	Albis; American Polymers; Ashley Polymers; Bamberger Polymers; BASF; Bayer Corp.; Diamond Polymers; Dow Plastics; Federal Plastics; GE Plastics; LG Chemical; Polymer Resources; RSG Polymers; RTP; A. Schulman; Shuman	Albis; American Polymers; Ashley Polymers; Bamberger Polymers; BASF; Bayer Corp.; Diamond Polymers; Dow Plastics; Federal Plastics; GE Plastics; LG Chemical; Polymer Resources; RSG Polymers; RTP; A. Schulman; Shuman	American Polymers; Ashley Polymers; Bamberger Polyumers; Bayer Corp.; Diamond Polymers; Dow Plastics; Federal Plastics; GE Plastics; LG Chemical; RSG Polymers; A. Schulman	BASF; Bayer Corp.; Diamond Polymers; GE Plastics; LG Chemical; A. Schulman	Albis; American Polymers; Ashley Polymers; ComAlloy; Diamond Polymers; DSM, Ferro; LG Chemical; LNP; M.A. Polymers; RTP; A. Schulman; Thermofil	Albis; American Polymers; Ashley Polymers; ComAlloy; Diamond Polymers; DSM Ferro; LG Chemical; LNP; M.A. Polymers; RTP	DSM	DSM	Federal Plastics; Ferro; LNP, RTP; Ticona	DSM; Ferro; LNP RTP, Ticona	RTP; Ticona

Materials			**ABS** (Cont'd)				**Acetal**		
			EMI Shielding (Conductive) (Continued)			Rubber-Modifled			
	Properties	ASTM Test Method	20% PAN Carbon Fiber	20% Graphite Fiber	40% Aluminum Flake	Injection Molding and Extrusion Grades	Homo-Polymer	Copolymer	Impact-Modified Homo-polymer
Processing	1a. Melt flow (gm./10 min.)	D1238					1–20	1–90	0.5–7.0
	1. Melting temperature, °C. T_m(crystalline)						172–184	160–175	175
	T_g (amorphous)		100–110						
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 415–500	I: 420–530	I: 400–550		I: 380–470	C: 340–400 I: 360–450	I: 380–420
	3. Molding pressure range, 10^3 p.s.i.		15–30				10–20	8–20	6–12
	4. Compression ratio						2.0–4.5	3.0–4.5	
	5. Mold (linear) shrinkage, in./in.	D955	0.0005–0.004	0.001	0.001		0.018–0.025	0.020 (Avg.)	0.012–0.019
Mechanical	6. Tensile strength at break, p.s.i.	D638^b	15,000–16,000	15,200–15,800	3300–4200	5400–7100	9700–10,000		6500–8400
	7. Elongation at break, %	D638^b	1.0–2.0	2.0–2.2	1.9–5	20–30	10–75	15–75	60–200
	8. Tensile yield strength, p.s.i.	D638^b				6100	9500–12,000	8300–10,400	5500–7900
	9. Compressive strength (rupture or yield), p.s.i.	D695	17,000	16,000–17,000	6500		15,600–18,000 @ 10%	16,000 @ 10%	7600–11,900 @10%
	10. Flexural strength (rupture or yield), p.s.i.	D790	23,000–25,000	23,000	6200	8900–13,000	13,600–16,000	13,000	5800–10,000
	11. Tensile modulus, 10^3 p.s.i.	D638^b	1800–2000	1660	370	310	400–520	377–464	190–350
	12. Compressive modulus, 10^3 p.s.i.	D695					670	450	
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	890–1800	1560	400–600	260–380	380–490	370–450	150–350
	200° F.	D790					120–135		50–100
	250° F.	D790					75–90		33–60
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.0	1.3	1.4–2.0	3.12–7.34	1.1–2.3	0.8–1.5	2.0–17
	15. Hardness	Rockwell	D785	R108		R107	90–105	M92–94, R120	M75–90	M58–79
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	18	20	40		50–112	61–110	92–117
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	215–225	216	190–212	181–212	253–277	185–250	148–185
		66 p.s.i.	D648	225–230	240	220		324–342	311–330	293–336
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	9.6				5.5	5.5	
Physical	19. Specific gravity		D792	1.13–1.14	1.17	1.54–1.61	103–119	1.42	1.40	1.32–1.39
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.17	0.15	0.23		0.25–1	0.20–0.22	0.30–0.44
		Saturation	D570					0.90–1	0.65–0.80	0.75–0.85
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149					400–500 (90 mil)	500 (90 mil)	400–480 (90 mil)
			SUPPLIERS[a]	DSM: Ferro: LNP: RTP	Albis: LNP: RTP: Thermofil	ComAlloy; Thermofil	Diamond Polymars: RSG Polymers	Ashiey Polymers; DupPont; RTP; Shuman	American Polymers; Ashley Polymers; BASF; LG Chemical; M.A. Hanna Eng.; Network Polymers; RTP; Ticona	Ashley Polymers; DuPont

Acetal (Cont'd)

	Impact-Modified Copolymer	Mineral-filled Copolymer	Extrusion and Blow Molding Grade (Terpolymer)	Copolymer with 2% Silicone Low Wear	UV Stabillzed Copolymer	20% Glass-reinforced Homo-polymer	25% Glass-Coupled Copolymer	40% Long Glass Fiber-reinforced	21% PTFE-filled homo-polymer	2–20% PTFE-filled Copolymer	1.5% PTFE-filled Homo-Polymer
1a.	5–26		1.0	9	2.5–27.0	6.0			1.0–7.0		6
1.											
	160–170	160–175	160–170	160–170	170	175–181	160–180	190	175–181	160–175	175
2.	I: 360–425	I: 360–450	E: 360–400	I: 360–450	I: 360–450	I: 350–480	I: 365–480	380–430	I: 370–410	I: 350–445 I: 325–500 E: 360–500	I: 400–440
3.	8–15	10–20		10–20	10–20	10–20	8–20	8–12	10–20	8–20	
4.	3.0–4.5	3.0–4.0	3.0–4.0	3.0–4.0	3.0–4.0		3.0–4.5	3.0–4.0		3.0–4.5	
5.	0.018–0.020	0.015–0.019	0.02	0.022	0.022	0.009–0.012	0.004 (flow) 0.018 (trans.)	0.003–0.010	0.020–0.025	0.018–0.029	
6.		6400–11,500				8500–9000	16,000–18,500	17,400	6900–7600	8300	10,000
7.	60–300	5–55	67	60	30–75	6–12	2–3	1.3	10–22	30	13
8.	3000–8000	6400–9600	8700	7400	8800–9280	7500–8250	16,000		6900–7600	8300	10,000
9.			16,000		16,000	18,000 @ 10%	17,000 @ 10%	20,400	13,000 @ 10%	11,000–12,600	
10.	7100	12,500–13,000	12,800	12,000	13,000	10,700–16,000	18,000–28,000	27,000	11,000	11,500	13,900
11.	187–319	522–780			410–910	900–1000	1250–1400	1700	410–420	250–280	450
12.					450						
13.	120–300	430–715	350	350	375–380	600–730	1100	1430	340–380	310–360	430
						300–360			110–120		150
						250–270			80–85		95

14.	1.7–4.7	0.9–1.2	1.7	1.1–1.4	1.12–1.5	0.5–1.0	1.0–1.8	6.9	0.7–1.2	0.5–1.0	1.0
15.	M35–70; R110	M83–90	M84	M75	M80–85	M90	M79–90, R110		M78, M110	M79	M93
16.	130–150	80–90				33–81	17–44		75–113	52–68	
17.	132–200	200–279	205	230	221–230	315	320–325	320	210–244	198–225	277
	306–318	302–325	318	316	316–320	345	327–331		300–334	280–325	342
18.										4.7	
19.	1.29–1.39	1.48–1.64	1.41	1.4	1.41	1.54–1.56	1.58–1.61	1.72	0.15–1.54	1.40	1.42
20.	0.31–0.41	0.20	0.22	0.21	0.22	0.25	0.22–0.29		0.20	0.15–0.26	0.19
	1.0–1.3	0.8–0.9	0.8	0.8	0.8	1.0	0.8–1.0		0.72	0.5	0.90
21.						490 (125 mil)	480–580		400–460 (125 mil)	400–410	450 (90 mils)
	Ashley Polymers; BASF; L.G. Chemical; M.A. Hanna Eng.; Network Polymers; Ticona	BASF; LG Chemical; M.A. Hanna Eng.; Network Polymers; Ticona	Network Polymers; Ticona	LGs-Chemical; M.A. Hanna Eng.; Network Polymers RTP; Ticona	BASF; LG Chemical; M.A. Hanna Eng.; Network Polymers; Ticona	ComAlloy; DSM; DuPont; Ferro; LNP; RTP	BASF; ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng.; Network Polymers; RTP Ticona	Ticona	Adell; DSM; DuPoint; Ferro; LNP; RTP	ComAlloy; DSM; Ferro; L.G. Chemical; LNP; M.A. Hanna Eng.; RTP; Ticona	DuPont

Materials				**Acetal** (Cont'd)						**Acrylic**
								EMI Shielding (Conductive)		Sheet
		Properties	ASTM Test Method	Chemically Lubricated Homo-polymer	UV Stabilized Homo-polymer	UV Stabilized 20% Glass-Filled Homo-polymer	Extrusion Grade Homo-polymer	30% Carbon Fiber	10% PAN Carbon Fiber, 10% PTFE-filled Copolymer	Cast
Processing	1a.	Melt flow (gm./10 min.)	D1238	6	1–6	6	1–6			
	1.	Melting temperature, °C.								
		T_m (crystalline)		175	175	175	175	166	163–175	
		T_g (amorphous)								90–105
	2.	Processing temperature rang, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 400–440	I: 400–440	I: 400–440	E: 380–420	I: 350–400	I: 350–410	
	3.	Molding pressure range. 10^3 p.s.i.						10–20		
	4.	Compression ratio						3–4		
	5.	Mold (linear) shrinkage, in./in.	D955					0.003–0.005	0.002	1.7
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	9500	10,000	8500	10,000	7500–11,500	12,000	66–11,000
	7.	Elongation at break, %	D638[b]	40	40–75	12	40–75	1.5–2	1.3	2–7
	8.	Tensile yield strength, p.s.i.	D638[b]	9500	10,000	8500				
	9.	Compressive strength (rupture or yield), p.s.i.	D695							11,000–19,000
	10.	Flexural strength (rupture or yield). p.s.i.	D790	13,000	14,100–14,300	10,700	14,100–14,300	12,500–16,500	14,000	12,000–17,000
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	450	400–450	900	400–450	1350	1300	310–3100
	12.	Compressive modulus, 10^3 p.s.i.	D695							390–475
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	400	420–430	730	420–430	1100–1200	1000	320–3210
		200° F.	D790	130	130–135	360	130–135			
		250° F.	D790	80	90	270	90			
		300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.4	1.5–2.3	0.8	1.5–2.3	0.7–0.8	0.7	0.3–0.4
	15. Hardness	Rockwell	D785	M90	M94	M90	M94			M80–102
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696							50–90
	17. Deflection temperature under flexural load. °F	264 p.s.i.	D648	257	257–264	316	257–264	320	320	98–215
		66 p.s.i.	D648	329	334–336	345	334–336	325	325	165–235
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177							4.0–6.0
Physical	19. Specific gravity		D792	1.42	1.42	1.56	1.42	1.43–1.53	1.49	1.17–1.20
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.27	0.25	0.25	0.25	0.22–0.26	0.25	0.2–0.4
		Saturation	D570	1.00	0.90	1.00	0.90			
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	400 (125 mils)	500 (90 mils)	490 (125 mils)	500 (90 mils)			450–550
SUPPLIERS[a]				DuPont	DuPont	DuPont	DuPont	DSM; LNP; RTP; Ticona	DSM; Ferro; LNP M.A. Hanna Eng.; RTP	Aristech; AtoHaas; Cyro; DuPont; ICI Acrylics

	Acrylic (Cont'd)							**Acrylonitrile**			**Allyl**
	Sheet (Cont'd)	Molding and Extrusion Compounds									
	Coated	Acrylic/PC Alloy	PMMA	MMA-Styrene Copolymer	Impact-Modified	Heat-resistant	Acrylic Multi-polymer	Extrusion	High-Impact Extrusion	Injection	Ally Diglycol Carbonate Cast Sheet
1a.		3–4	1.4–27	1.1–24	1–11	1.6–8.0	2–14	3	3	12	
1.										135	Thermoset
	90–110	140	85–105	100–105	80–103	100–165	80–105			95	
2.		I: 450–510 E: 430–480	C: 300–425 I: 325–500 E: 360–500	C: 300–400 I: 300–500	C: 300–400 I: 400–500 E: 380–480	C: 350–500 I: 400–625 E:360–550	I: 400–500 E: 380–470	380–420	380–410	C: 320–345 I: 410 E: 380–410	
3.		5–20	5–20	10–30	5–20	5–30	5–20	25	25	20	
4.			1.6–3.0			1.2–2.0		2–2.5	2–2.5	2–2.5	
5.		0.004–0.008	0.001–0.004 (flow) 0.002–0.006 (trans.)	0.002–0.006	0.002–0.006	0.002–0.006	0.004–0.008	0.002–0.005	0.002–0.005	0.002–0.005	
6.	10,500	8000–9000	7000–10,500	8100–10,100	5000–9000	9300–11,500	5500–8200			9000	5000–6000
7.	3	58	2–5.5	2–5	4.6–70	2–10	5–28	3–4	3–4	3–4	
8.			7800–10,600		5500–8470	10,000		9500	7500	7500–9500	
9.	18,000		10,500–18,000	11,000–15,000	4000–14,000	15,000–17,000	7500–11,500	12,000	11,500	12,000	21,000–23,000
10.	16,000	11,300–12,500	10,500–19,000	14,100–16,000	7000–14,000	12,000–18,000	9000–13,000	14,000	13,700	14,000	6000–13,000
11.	450	320–350	325–470	430–520	200–500	350–650	300–430	500–550	450–500	500–580	300
12.	450		370–480	240–370	240–370	450					300
13.	450	320–350	325–460	450–460	200–430	450–620	290–400	490	390	500–590	250–330
						150–440					
						350–420					

14.	0.3–0.4	26–30	0.2–0.4	0.3–0.4	0.40–2.5	0.2–0.4	1.0–2.5	5.0	9.0	2.5–6.5	0.2–0.4
15.	M105	46–49	M68–105	M80–85	M35–78	M94–100	22–56	M60	M45	M60–M78	M95–100
16.	40	52	50–90	60–80	48–80	40–71	44–50	66	66	66	81–143
17.	205	214	155–212	208–211	165–209	190–310	180–194	156	151	151–164	140–190
	225	253	165–225		180–205	200–315		170	160	166–172	
18.	5.0		4.0–6.0	4.0–5.0	4.0–5.0	2.0–4.5	5.3	6.1	6.1	6.1–6.2	4.8–5.0
19.		1.15	1.17–1.20	1.06–1.13	1.11–1.18	1.16–1.22	1.11–1.12	1.15	1.11	1.11–1.15	1.3–1 4
20.	<0.4	0.3	0.1–0.4	0.11–0.17	0.19–0.8	0.2–0.3	0.3			0.28	0.2
21.	500		400–500	450	380–500	400–500		220–240	220–240	220–240	380
	DuPont	Cyro	American Polymers; AtoHaas; Continental Acrylics; Cyro; DuPont; ICI Acrylics; LG Chemical; Network Polymers; Plaskolite; RTP	Network Polymers; NOVA Chemicals	AtoHaas; Continental Acrylics; Cyro; DuPont; ICI Acrylics; Network Polymers; RTP	AtoHaas; Cyro; ICI Acrylics; Network Polymers; Plaskolite; RTP	Cyro	BP Chemicals	BP Chemicals	BP Chemicals	PPG

			Allyl (Cont'd)			**Cellulosic**			
			DAP Molding Compounds			Cellulose Acetate		Cellulose Acetate Butyrate	Cellulose Acetate Propioniate
Materials	Properties	ASTM Test Method	Glass-filled	Mineral-filled	Ethyl Cellulose Molding Compound and Sheet	Sheet	Molding and Extrusion Compound	Molding and Extrusion Compound	Molding and Extrusion Compound
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C. T_m (crystalline)		Thermoset	Thermoset	135	230	230	140	190
	T_g (amorphous)								
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		C: 290–360 I: 300–350	C: 270–360	C: 250–390 I: 350–500		C: 260–420 I: 335–490	C: 265–390 I: 335–480	C: 265–400 I: 335–515
	3. Molding pressure range, 10^3 p.s.i.		2000–6000	2500–5000	8–32		8–32	8–32	8–32
	4. Compression ratio		1.9–10.0	1.2–2.3	1.8–2.4		1.8–2.6	1.8–2.4	1.8–3.4
	5. Mold (linear) shrinkage, in./in.	D955	0.0005–0.005	0.002–0.007	0.005–0.009		0.003–0.010	0.003–0.009	0.003–0.009
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	6000–11,000	5000–8000	2000–8000	4500–8000	1900–9000	2600–8100	2000–7800
	7. Elongation at break, %	D638[b]	3–5	3–5	5–40	20–50	6–70	40–88	29–100
	8. Tensile yield strength, p.s.i.	D638[b]					2500–7600	1600–7200	
	9. Compressive strength (rupture or yield), p.s.i.	D695	25,000–35,000	20,000–32,000			3000–8000	2100–7500	2400–7000
	10. Flexural strength (rupture or yield), p.s.i	D790	9000–20,000	8500–11,000	4000–12,000	6000–10,000	2000–16,000	1800–10,100	2900–11,400
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	1400–2200	1200–2200				50–200	60–215
	12. Compressive modulus, 10^3 p.s.i.	D695							
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	1200–1500	1000–1400			1000–4000	90–300	120–350
	200° F.	D790							
	250° F.	D790							
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	0.4–15.0	0.3–0.8	0.4	2.0–8.5	1.0–7.8	1.0–10.9	0.5–No break
	15. Hardness	Rockwell	D785	E80–87	E60–80E	R50–115	R85–120	R17–125	R11–116	R10–122
		Shore/Barcol	D2240/							
			D2583							
Thermal	16. Coef. of linear thermal expansion. 10^{-6} in./in./°C.		D696	10–36	10–42	100–200	100–150	80–180	110–170	110–170
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	330–550+	320–550	115–190		111–195	109–202	111–228
		66 p.s.i.	D648					120–209	130–227	147–250
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	5.0–15.0	7.0–25	3.8–7.0	4–8	4–8	4–8	4–8
Physical	19. Specific gravity		D792	1.70–1.98	1.65–1.85	1.09–1.17	1.28–1.32	1.22–1.34	1.15–1.22	1.17–1.24
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.12–0.35	0.2–0.5	0.8–1.8	2.0–7.0	1.7–6.5	0.9–2.2	1.2–2.8
		Saturation	D570							
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	400–450	400–450	350–500	250–600	250–600	250–475	300–475
			SUPPLIERS[a]	Cosmic Plastics; Rogers Corp.	Cosmic Plastics; Rogers Corp.	Dow Chem.; Federal Plastics; Rotuba	Rotuba	Albis; Eastman; Rotuba	Albis; Eastman; Rotuba	Albis; Eastman; Rotuba

Cellulosic (Cont'd)	**Chlorinated PE**	**Epoxy**								
		Bisphenol Molding Compounds			Sheet Molding Compound (SMC)		Novolak Molding Compounds		Casting Resins and Compounds	
Cellulose Nitrate	30–42% Cl Extrusion and Molding Grades	Glass Fiber-reinforced	Mineral-filled	Low Density Glass Sphere-filled	Glass Fiber-reinforced	Carbon fiber-reinforced	Mineral- and Glass-filled, Encap-sulation	Mineral- and Glass-filled, High Temperature	Unfilled	Silica-filled
1a.										
1.	125	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset
							145–155	155–195		
2. C: 185–250	E: 300–400	C: 300–330	C: 250–330	C: 250–300	C: 250–330	C: 250–330	C: 280–360	T: 340–400		
		T: 280–380	T: 250–380	I: 250–300	T: 270–330	T: 270–330	I: 290–350			
							T: 250–380			
3. 2–5		1–5	0.1–3	0.1–2	0.5–2.0	0.5–2.0	0.25–3.0	0.5–2.5		
4.		3.0–7.0	2.0–3.0	3.0–7.0	2.0	2.0		1.5–2.5		
5.		0.001–0.008	0.002–0.010	0.006–0.010	0.001	.001	0.004–0.008	0.004–0.007	0.001–0.010	0.0005–0.008
6. 7000–8000	1400–3000	5000–20,000	4000–10,800	2500–4000	20,000–35,000	40,000–50,000	5000–12,500	6000–15,500	4000–13,000	7000–13,000
7. 40–45	300–900	4			0.5–2.0	0.5–2.0			3–6	1–3
8.										
9. 2100–8000		18,000–40,000	18,000–40,000	10,000–15,000	20,000–30,000	30,000–40,000	24,000–48,000	30,000–48,000	15,000–25,000	15,000–35,000
10. 9000–11,000		8000–30,000	6000–18,000	5000–7000	50,000–70,000	75,000–95,000	10,000–21,800	10,000–21,800	13,000–21,000	8000–14,000
11. 190–220		3000	350		2000–4000	10,000	2100	2300–2400	350	
12.			650					660		
13.		2000–4500	1400–2000	500–750	2000–3000	5000	1400–2400	2300–2400		
					1500–2500					
					1200–1800					

14. 5–7		0.3–10.0	0.3–0.5	0.15–0.25	30–40	15–20	0.3–0.5	0.4–0.45	0.2–1.0	0.3–0.45
15. R95–115		M100–112	M100–M112				M115		M80–110	M85–120
	Shore A60–76				B: 55–65	B: 55–65	Barcol 70–75	Barcol 78		
16. 80–120		11–50	20–60		12	3	18–43	35	45–65	20–40
17. 140–160		225–500	225–500	200–250	550	550	300–500	500	115–550	160–550
18. 5.5		4.0–10.0	4–35	4.0–6.0	1.7–1.9	1.4–1.5	10–31	17–24	4.5	10–20
19. 1.35–1.40	1.13–1.26	1.6–2.0	1.6–2.1	0.75–1.0	0.10	0.10	1.6–2.05	1.85–1.94	1.11–1.40	1.6–2.0
20. 1.0–2.0		0.04–0.20	0.03–0.20	0.2–1.0	1.4	1.6	0.04–0.29 0.15–0.3	0.15–0.17	0.08–0.15	0.04–0.1
21. 300–600		250–400	250–420	380–420			325–450	440–450	300–500	300–550
P.D. George	Dow Plastics	Amoco Electronic; Cytec Fiberite	Amoco Electronic; Cytec Fiberite	Cytec Fiberite	Quantum Composites	Quantum Composites	Amco Electronic; Cosmic Plastics; Cytec Fiberite: Rogers	Amoco Electronic; Cosmic Plastics; Cytec Fiberite: Rogers	Ciba Specialty Chemicals; Conap; Dow Plastics; Emerson & Cuming; Epic Resins; ITW Devcon; Shell; United Mineral	Conap; Emerson & Cuming; Epic Resins; ITW Devcon

			Epoxy (Cont'd)			**Ethylene Vinyl Alcohol**	**Fluoroplastics**		
			Casting Resins and Compounds (Cont'd)					Polytetrafluoroethylene	
Materials	Properties	ASTM Test Method	Aluminum-filled	Flexibllized	Cyclo-aliphatic		Polychloro-trifluoro-ethylene	Granular	25% Glass Fiber-reinforced
Processing	1a. Melt flow (gm./10 min.)	D1238				0.8–14.0			
	1. Melting temperature, °C. T_m (crystalline)		Thermoset	Thermoset	Thermoset	142–191		327	327
	T_g(amorphous)					49–72	220		
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)					I: 365–480 E: 365–480	C: 460–580 I: 500–600 E: 360–590		
	3. Molding pressure range, 10^3 p.s.i.						1–6	2–5	3–8
	4. Compression ratio					3–4	2.6	2.5–4.5	
	5. Mold (linear) shrinkage, in./in.	D955	0.001–0.005	0.001–0.010			0.010–0.015	0.030–0.060	0.018–0.020
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	7000–12,000	2000–10,000	8000–12,000	5405–13,655	4500–6000	3000–5000	2000–2700
	7. Elongation at break, %	D638[b]	0.5–3	20–85	2–10	180–330	80–250	200–400	200–300
	8. Tensile yield strength, p.s.i	D638[b]				7385–10,365	5300		
	9. Compressive strength (rupture or yield), p.s.i.	D695	15,000–33,000	1000–14,000	15,000–20,000		4600–7400	1700	1000–1400 @1% strain
	10. Flexural strength (rupture or yield), p.s.i.	D790	8500–24,000	1000–13,000	10,000–13,000	230–285	7400–11,000		2000
	11. Tensile modulus, 10^3 p.s.i.	D638[b]						58–80	200–240
	12. Compressive modulus, 10^3 p.s.i.	D695		1–350	495	300–385	150–300	60	
	13. Flexural modulus, 10^3 p.s.i. 73 °F.	D790					170–200	80	190–235
	200 °F.	D790					180–260		
	250 °F.	D790							
	300 °F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^{1}/_{8}$-in. thick specimen)		D256A	0.4–1.6	2.3–5.0		1.0–1.7	2.5–5	3	2.7
	15. Hardness	Rockwell	D785	M55–85				R75–112		
		Shore/Barcol	D2240/ D2583		Shore D65–89			Shore D75–80	Shore D50–65	Shore D60–70
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	5.5	20–100			36–70	70–120	77–100
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	190–600	73–250	200–450			115	
		66 p.s.i.	D648					258	160–250	
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	15–25				4.7–5.3	6.0	8–10
Physical	19. Specific gravity		D792	1.4–1.8	0.96–1.35	1.16–1.21	1.12–1.20	2.06–2.2	2.14–2.20	2.2–2.3
	20. Water absorption ($^{1}/_{6}$-in. thick specimen), %	24 hr.	D570	0.1–4.0	0.27–0.5		6.7–8.6	0	<0.01	
		Saturation	D570							
	21. Dielectric strength ($^{1}/_{8}$-in. thick specimen), short time, v./mil		D149		235–400			500–600	480	320
			SUPPLIERS[a]	Conap; Emerson & Cuming; Epic Resins; ITW Devcon	Conap; Dow Plastics; Emerson & Cuming; Epic Resins; ITW Devcon	Ciba Specialty Chemicals; Union Carbide	Eval Co. of America	Ciba Specialty Chemicals; Elf Atochem N.A.	Ausimont; DuPont; Dyneon; ICI Americas	Ausimont; DuPont; Dyneon; ICI Americas; RTP

Fluoroplastics (Cont'd)

		Fluorinated Ethylene Propylene		Polyvinyl Fluoride Film		Polyvinylidene Fluoride			Modified PE-TFE		
	PFA Fluoro-plastic	Unfilled	20% Milled Glass Fiber	Unfilled	Filled	Molding and Extrusion	Wire and Cable Jacketing	EMI Shielding (Conductive); 30% PAN Carbon Fiber	Unfilled	25% Glass Fiber-reinforced	THV-200
1a.											
1.	300–310	275	262	192	192	141–178	168–170		270	270	120
						−60 to −20	−30 to −20				
2.	C: 625–700 I: 680–750	C: 600–750 I: 625–760	I: 600–700			C: 360–550 I: 375–550 E: 375–550	E: 420–525	I: 430–500	C: 575–625 I: 570–650	C: 575–625 I: 570–650	E: 450
3.	3–20	5–20	10–20			2–5	1.10		2–20	2–20	
4.	2.0	2.0				3	3				
5.	0.040	0.030–0.060	0.006–0.010			0.020–0.035	0.020–0.030	0.001	0.030–0.040	0.002–0.030	
6.	4000–4300	2700–3100	2400	6000–16,000	6000–16,000	3500–7250	7100	14,000	6500	12,000	3500
7.	300	250–330	5	100–250	75–250	12–600	300–500	0.8	100–400	8	600
8.	2100					2900–8250	4460				
9.	3500	2200				8000–16,000	6600–7100		7100	10,000	
10.			4000			9700–13,650	7000–8600	19,800	5500	10,700	
11.	70	50		300–380	300–380	200–80,000	145–190	2800	120	1200	
12.						304–420	180				
13.	95–120	80–95	250			170–120,000	145–260	2100	200	950	12
									80	450	
									60	310	
									20	200	

14.	No break	No break	3.2			2.5–80	7	1.5	No break	9.0	
15.						R79–83, 85	R77		R50	R74	
	Shore D64	Shore D60–65				Shore D80, 82 65–70	Shore D75		Shore D75		44
16.	140–210		22			70–142	121–140		59	10–32	
17.			150			183–244	129–165	318	160	410	
	166	158				280–284			220	510	
18.	6.0	6.0		0.0014–0.0017	0.0014–0.0017	2.4–3.1	2.4–3.1		5.7		
19.	2.12–2.17	2.12–2.17		1.38–1.40	1.38–1.72	1.77–1.78	1.76–1.77	174	1.7	1.8	1.95
20.	0.03	<0.01	0.01			0.03–0.06	0.03–0.06	0.12	0.03	0.02	
21.	500	500–600		2000–3300 *(D150–81)	2000–3300 *(D150–81)	260–280	260–280		400	425	
	Ausimont; DuPont; Dyneon	DuPont	RTP	DuPont	DuPont	Ausimont; Elf Atochem N.A.; Solvay Polymers	Ausimont; Elf Atochem N.A.; Solvay Polymers	RTP	DuPont	Ausimont; DuPont; RTP	Dyneon

Materials			Fluoroplastics (Cont'd)			Ionomer		Ketones	
								Polyaryletherketone	
	Properties	ASTM Test Method	THV-400	THV-500	PE-CTFE	Molding and Extrusion	Glass- and Rubber-modified; Molding and Extrusion	Unfilled	30% Glass Fiber-reinforced
Processing	1a. Melt flow (gm./10 min.)	D1238						4–7	15–25
	1. Melting temperature, °C.								
	T_m (crystalline)		150	180	220–245	81–96	81–220	323–381	329–381
	T_g (amorphous)								
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		E: 470	E: 480	C: 500 I: 525–575 E: 500–550	C: 280–350 E: 300–450	C: 300–400 I: 300–550 E: 350–525	I: 715–805	I: 715–805
	3. Molding pressure range, 10^3 p.s.i.				5–20	2–20	2–20	10–20	10–20
	4. Compression ratio					3	3	2	2
	5. Mold (linear) shrinkage, in./in.	D955			0.020–0.025	0.003–0.010	0.002–0.008	0.008–0.012	0.001–0.009
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	3400	3300	6000–7000	2500–5400	3500–7900	13,500	23,700–27,550
	7. Elongation at break, %	D638[b]	500	500	200–300	300–700	5–200	50	2.2–3.4
	8. Tensile yield strength, p.s.i.	D638[b]			4500–4900	1200–2300	1200–4500	15,000	
	9. Compressive strength (rupture or yield), p.s.i.	D695						20,000	30,000
	10. Flexural strength (rupture or yield), p.s.i.	D790			7000			18,850–24,500	34,100–36,250
	11. Tensile modulus, 10^3 p.s.i.	D638[b]			240	to 60		520–580	1410–1754
	12. Compressive modulus, 10^3 p.s.i.	D695							
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790		30	240	3–55	8–700	530	1600
	200° F.	D790						530	1520
	250° F.	D790						520	1460
	300° F.	D790						500	1390

	14. Izod impact, ft.-lb/in. of notch ($^{1}/_{8}$-in. thick specimen)		D256A			No break	7–No break	2.5–1.8 No break	1.6–2.7	1.8–1.9
	15. Hardness	Rockwell	D785			R93–95	R53		M98	M102
		Shore/Barcol	D2240/ D2583	53	54	Shore D75	Shore D25–66	Shore D43–70	Shore D86	Shore D90
Thermal	16. Coef of linear thermal expansion, 10^{-6} in./in./°C.		D696			80	100–170	50–100	41–44.2	18.5–20
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648			170	93–100		323–338	619–662
		66 p.s.i.	D648			240	113–125	131–400	482–582	644–662
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2}-°C.		C177			3.8	5.7–6.6		7.1	
Physical	19. Specific gravity		D792	1.97	1.78	1.68–1.69	0.93–0.96	0.95–1.2	1.3	1.47–1.53
	20. Water absorption ($^{1}/_{8}$-in. thick specimen), %	24 hr.	D570			0.01	0.1–0.5	0.1–0.5	0.1	0.07
		Saturation	D570						0.8	0.5
	21. Dielectric strength ($^{1}/_{8}$-in. thick specimen), short time, v./mil		D149			490–520	400–450		355	370
SUPPLIERS[a]				Dyneon	Dyneon	Ausimont	DuPont; Exxon; Network Polymers	DuPont; Network Polymers; A. Schulman	Amoco Polymers	RTP

	Ketones (Cont'd)						**Liquid Crystal Polymer**				
	Polyaryletherketone (Cont'd)			Polyetheretherketone							
	40% Glass Fiber-reinforced	Modified, 40% Glass	30% Carbon fiber	Unfilled	30% Glass Fiber-reinforced	30% Carbon Fiber-reinforced	45% Glass Fiber-reinforced, HDT	40% Glass Fiber-reinforced	30% Mineral-filled	Glass Fiber-reinforced for SMT	Unfilled Medium Melting Point
1a.	15–25	15–25	15–25								
1.	329	324	329	334	334	334					280–421
2.	I: 715–805	I: 715–765	I: 715–805	I: 660–750 E: 660–720	I: 660–750	I: 660–800	I: 660–730	I: 590–645	I: 660–690	I: 610–680	I: 540–770
3.	10–20	10–20	10–20	10–20	10–20	10–20			4–8		1–16
4.	2	2	2	3	2–3	2	2.5–3	2.5–3	2.5-3	2.5–3	2.5–4
5.	0.001–0.009	0.001–0.009	0.002–0.008	0.011	0.002–0.014	0.0005–0.014					0.001–0.006
6.	25,000	22,500	30,000	10,200–15,000	22,500–28,500	29,800–33,000	18,200	21,240	15,950	19,600	15,900–27,000
7.	2	1.5	1.5	30–150	2–3	1–4	2.1	1.5	4.0	1.6	1.3–4.5
8.				13,200							
9.	32,500	33,000	33,800	18,000	21,300–22,400	25,000–34,400	10,900				6200–19,000
10.	40,000	34,000	40,000	16,000	33,000–42,000	40,000–48,000	22,400	27,000	18,415	25,000	19,000–35,500
11.	1900	2250	2700		1250–1600	1860–3500	2170	2890		2700	1400–2800
12.							491		590		400–900
13.	2100	2100	2850	560	1260–1600	1860–2600	22.4	2280	1400	1950	1770–2700
	2010	1960	2790	435	1400	1820					1500–1700
	1910	1750	2480		1350	1750					1300–1500
	1790	1500	2100	290	1100	1400					1200–1450

14.	2	1.2	1.5	1.6	2.1–2.7	1.5–2.1	2.0	8.3	3.0	1.8	1.7–10
15.	M102	M103									M76; R60–66
16.	18	18.5	7.9	<150°C: 40–47 <150°C: 108	<150°C: 12–22 >150°C: 44	<150°C: 15–22 >150°C: 5–44	12.5–80.2		8–22		5–7
17.	619	586	634	320	550–599	550–610	572	466	455	520	356–671
	644	643	652			615					
18.	10.5	8.8			4.9	4.9	2.02				2
19.	1.55	1.6	1.45	1.30–1.32	1.49–1.54	1.42–1.44	1.75	1.70	1.63	1.6	1.35–1.84
20.	0.05	0.04	<0.2	0.1–0.14	0.06–0.12	0.06–0.12	<.1			<.1	0–<0.1
				0.5	0.11–0.12	0.06					<0.1
21.	420	385					900				800–980
	RTP	Amoco Polymers; RTP	Amoco Polymers; RTP	Victrex USA	DSM; LNP; RTP; Victrex USA	DSM; LNP; RTP; Victrex USA	RTP	Amoco Polymers; RTP	DuPont; RTP	Amoco Polymers; RTP	Ticona

Materials	Properties	ASTM Test Method	Liquid Crystal Polymer (Cont'd) 30% Carbon Fiber-reinforced	50% Mineral-Filled	30% Glass Fiber-reinforced	30% Glass Fiber-reinforced, High HDT	Unfilled Platable Grade	PTFE-filled	15% Glass Fiber-reinforced
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C. T_m (crystalline)		280	327	280–680	355		281	280
	T_g (amorphous)								
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		555–600	I: 605–770	I: 555–770	I: 625–730	I: 600–620		
	3. Molding pressure range, 10^3 p.s.i.		1–14	1–14	1–14	4–8			
	4. Compression ratio		2.5–4	2.5–4	2.5–4	2.5–4	3–4	3:1	3:1
	5. Mold (linear) shrinkage, in./in.	D955	0–0.002	0.003	0.001–0.09	−0.01		0–3	0–3
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	35,000	10,400–16,500	16,900–30,000	18,000–21,025	13,500	24,500–25,000	28,000
	7. Elongation at break, %	D638[b]	1.0	1.1–2.6	1.7–2.7	1.7–2.2	2.9	3.0–5.2	3
	8. Tensile yield strength, p.s.i.	D638[b]			19,600				
	9. Compressive strength (rupture or yield), p.s.i.	D695	34,500	6800–7500	9900–21,000	9600–12,500			
	10. Flexural strength (rupture or yield), p.s.i.	D790	46,000	14,200–23,500	21,700–25,000	24,000–25,230		18,500–29,000	30,000
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	5400	1500–2700	700–3000	2330–2600	1500	1100–1600	1100–2100
	12. Compressive modulus, 10^3 p.s.i.	D695	4800	490–2016	470–1000	447–770			
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	4800	1250–2500	1660–2100	1800–2050	1500	1000–1400	1600
	200° F.	D790							
	250° F.	D790			900	1100			
	300° F.	D790			800	1100			

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.4	0.8–1.5	2.0–3.0	2.0–4.2	0.6	2.1–3.8	5.5
	15. Hardness	Rockwell	D785	M99	82	77–87, M61	M63			
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	−2.65	9–65	4.9–77.7	14–36			
	17. Deflection temperature under flexural load, °F	264 p.s.i.	D648	440	429–554	485–655, 271°C	518–568	410	352–435	430
	.	66 p.s.i.	D648			400–530				
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C		C177		2.57	1.73	1.52			
Physical	19. Specific gravity		D792	1.49	1.84–1.89	1.60–1.67	1.6–1.66		1.50–1.62	1.5
	20. Water absorption ($^1/_8$-in. thick specimen), %	24hr.	D570	<0.1	<0.1	<0.1%, 0.002	<0.1	0.03		
		Saturation	D570			0.05				0.2
	21. Dielectric strength ($^1/_8$- in. thick specimen), short time, v./mil		D149		900–955	640–1000	900–1050	600		
			SUPPLIERS[a]	RTP; Ticona	RTP; Ticona	Amoco Polymers; Dupont; RTP; Ticona	Amoco Polymers; Dupont; RTP; Ticona	Ticona	RTP; Ticona	RTP; Ticona

	Liquid Crystal Polymer (Cont'd)	**Melamine Formaldehyde**		**Phenolic**						
				Molding Compounds, Phenol-formaldehyde						
									Impact-modified	
	Glass/Mineral-filled	Cellulose-filled	Glass Fiber-reinforced	Glass	PAN Carbon	Woodflour-filled	Woodflour- and Mineral-filled	High-Strength Glass Fiber-reinforced	Cotton-filled	Cellulose-filled
1a.										
1.	280	Thermoset	Thermoset	Termoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset
2.		C: 280–370 I: 200–340 T: 300	C: 280–350			C: 290–380 I: 330–400	C: 290–380 I: 330–390 T: 290–350	C: 300–380 I: 330–390 T: 300–350	C: 290–380 I: 330–400	C: 290–380 I: 330–400
3.		8–20	2–8			2–20	2–20	1–20	2–20	2–20
4.	3:1	2.1–3.1	5–10			1.0–1.5		2.0–10.0	1.0–1.5	1.0–1.5
5.	0–3	0.005–0.015	0.001–0.006	0.0012	0.0016	0.004–0.009	0.003–0.008	0.001–0.004	0.004–0.009	0.004–0.009
6.	21,000–25,000	5000–13,000	5000–10,500	13,500	29,750	5000–9000	6500–7500	7000–18,000	6000–10,000	3500–6500
7.	1.4–2.3	0.6–1	0.6	1.6	1.15	0.4–0.8		0.2	1–2	1–2
8.										
9.	18,000–21,000	33,000–45,000	20,000–35,000	55,600	62,700	25,000–31,000	25,000–30,000	16,000–70,000	23,000–31,000	22,000–31,000
10.	31,000–34,000	9000–16,000	14,000–23,000	31,700	49,000	7000–14,000	9000–12,000	12,000–60,000	9000–13,000	5500–11,000
11.	2400–3100	1100–1400	1600–2400	1280	2490	800–1700	1000–1800	1900–3300	1100–1400	
12.	2000–2800							2740–3500		
13.	2200–2900	1100		1570	2800	1000–1200	1200–1300	1150–3300	800–1300	900–1300

14.	1.6–3.8	0.2–0.4	0.6–18	0.3	0.4	0.2–0.6	0.29–0.35	0.5–18.0	0.3–1.9	0.4–1.1
15.	76–79	M115–125	M115			M100–115	M90–110	E54–101	M105–120	M95–115
								Barcol 72		
16.	6–8	40–45	15–28	10–51	5–50	30–45	30–40	8–34	15–22	20–31
17.	437	350–390	375–400			300–370	360–380	350–600	300–400	300–350
18.		6.5–10	10–11.5			4–8	6–10	8–14	8–10	6–9
19.	1.68–1.89	1.47–1.52	1.5–2.0	1.50–1.52	1.37–1.40	1.37–1.46	1.44–1.56	1.69–2.0	1.38–1.42	1.38–1.42
20.		0.1–0.8	0.09–1.3			0.3–1.2	0.2–0.35	0.03–1.2	0.6–0.9	0.5–0.9
	0.2							0.12–1.5		
21.	840	270–400 175–215 @ 100° C	130–370			260–400	330–375	140–400	200–360	300–380
	RTP; Ticona	Cytec Fiberite; Patent Plastics; Perstorp; Plastics Mfg.	Cytec Fiberite	Cytec Fiberite	Cytec Fiberite	Amoco Electronic; OxyChem; Plaslok; Plastics Eng; Rogers	Amoco Electronic; OxyChem; Plaslok; Plastics Eng; Rogers	Cytec Fiberite; OxyChem; Plastics Eng; Quantum Composites; Resinoid; Rogers	Bayer Corp.; Cytec Fiberite; OxyChem; Plaslok; Plastics Eng.; Resinoid; Rogers	Amoco Electronic; Cytec Fiberite; OxyChem; Plaslok; Plastics Eng.; Resinoid; Rogers

Materials				**Phenolic** (Cont'd)				**Polyamide**	
				Molding Compounds, Phenol-formaldehyde (Cont'd)		Casting Resins		Nylon Alloys	Nylon, Type 6
				Impact-modified (Cont'd)	Heat-resistant				
		Properties	ASTM Test Method	Fabric and Rag-filled	Mineral- or Mineral- and Glass-filled	Unfilled	Mineral-filled	Ceramic and Glass Fiber-reinforced	Molding and Extrusion Compound
Processing	1a.	Melt flow (gm./10 min.)	D1238	0.5–10					0.5–10
	1.	Melting temperature, °C. T_m (crystalline)		Thermoset	Thermoset	Thermoset	Thermoset		210–220
		T_g (amorphous)							
	2.	Processing temperature range, °F. (C = compression; T = transfer, I = injection; E = extrusion)		C: 290–380 I: 330–400 T: 300–350	C: 270–350 I:330–380 T: 300–350				I: 440–550 E: 440–525
	3.	Molding pressure range, 10^3 p.s.i.		2–20	2–20				1–20
	4.	Compression ratio		1.0–1.5	2.1–2.7				3.0–4.0
	5.	Mold (linear) shrinkage, in./in.	D955	0.003–0.009	0.002–0.006			0.002	0.003–0.015
Mechanical	6.	Tensile strength at break, p.s.i.	D638^{b}	6000–8000	6000–10,000	5000–9000	4000–9000	25,000–30,000	6000–24,000
	7.	Elongation at break, %	D638^{b}	1–4	0.1–0.5	1.5–2.0		3–4	30–100^{c}; 300^{d}
	8.	Tensile yield strength, p.s.i.	D638^{b}						13,100^{c}; 7400^{d}
	9.	Compressive strength (rupture or . yield), p.s.i	D695	20,000–28,000	22,500–36,000	12,000–15,000	29,000–34,000		13,000–16,000^{c}
	10.	Flexural strength (rupture or yield), p.s.i.	D790	10,000–14,000	11,000–14,000	11,000–17,000	9000–12,000	39,000–45,000	15,700^{c}; 5800^{d}
	11.	Tensile modulus, 10^3 p.s.i.	D638^{b}	900–1100	2400	400–700			380–464^{c}; 100–247^{d}
	12.	Compressive modulus, 10^3 p.s.i.	D695						250^{d}
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	700–1300	1000–2000			1800–2150	390–410^{c}; 140^{d}
		200° F.	D790						
		250° F.	D790						
		300° F.	D790						

	14.	lzod impact, ft.-lb./in. of notch ($^{1}/_{8}$-in. thick specimen)		D256A	0.8–3.5	0.26–0.6	0.25–0.4	0.36–0.5	1.6–2.0	0.6–2.2^{c}: 3.0^{d}
	15.	Hardness	Rockwell	D785	M105–115	E88	M93–120	M85–120	R–120	R119^{c}; M 100–105^{c}
			Shore/Barcol	D2240/ D2583		Barcol 70				
Thermal	16.	Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	18–24	19–38	68	75		80–83
	17.	Deflection temperature under flexural load, °F.	264 p.s.i.	D648	325–400	275–475	165–175	150–175	415–495	155–185^{c}
			66 p.s.i.	D648					420–515	347–375^{c}
	18.	Thermal conductivity, 10^{-4} cal.-cm./sec. cm.^{2}-°C.		C177	9–12	10–24	3.5			5.8
Physical	19.	Specific gravity		D792	1.37–1.45	1.42–1.84	1.24–1.32	1.68–1.70	1.59–1.81	1.12–1.14
	20.	Water absorption ($^{1}/_{8}$-in. thick specimen), %	24 hr.	D570	0.6–0.8	0.02–0.3	0.1–0.36		0.35–0.50	1.3–1.9
			Saturation	D570		0.06–0.5				8.5–10.0
	21.	Dielectric strength ($^{1}/_{8}$-in. thick specimen), short time, v./mil		D149	200–370	200–350	250–400	100–250		400^{c}
				SUPPLIERS^{a}	Cytec Fiberite; OxyChem; Resinoid; Rogers	Amoco Electronic; Cytec Fiberite; OxyChem; Plaslok; Plastics Eng.; Resinoid; Rogers	Ametek; Schenectady; Solutia; Union Carbide	Schenectady; Solutia	Network Polymers; RTP; Thermofil	Adell; Albis; AlliedSignal; ALM; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; ComAlloy; Custom Resins; DuPont; EMS; Federal Plastics; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymer Resources; Polymers Intl.; A. Schulman; Thermofil; Ticona; Wellman

Polyamide (Cont'd)

Nylon, Type 6 (Cont'd)

								Semiaromatic Semi-crystalline Copolymer	
	15% Glass Fiber-reinforced	25% Glass Fiber-reinforced	30–35% Glass Fiber-reinforced	50% Glass Fiber-reinforced	30% long Glass Fiber-reinforced	40% long Glass Fiber-reinforced	50% long Glass Fiber-reinforced	35% Glass Fiber-reinforced	45% Glass Fiber-reinforced
1a.									
1.	220	220	210–220	220	210–220	210–271	220	300	300
2.	520–555	520–555	I: 400–550	535–575	I: 460–550	I: 460–550	I: 480–540	610–625	610–625
3.				2–20		10–20	10–20	10–20	5–20 5–20
4.			3.0–4.0		3.0–4.0	3.0–4.0	3–4	3	3
5.	2–3 3 10^{23}	2 3 10^{23}	0.001–0.005	1 3 10^{23}	0.003–0.009	0.002–0.010	0.002–0.008	0.002–0.003	0.001–0.002
6.	18,900^{c}; 10,200^{d}	23,200^{c}; 14,500^{d}	24–27,600^{c}; 18,900^{d}	33,400^{c}; 23,200^{d}	25,200–26,000^{c}	30,400–31,300	35,400–36,200^{c}	31,000–30,500	35,500–33,500
7.	3.5^{c}; 6^{d}	3.5^{c}; 5^{d}	2.2–3.6^{c}	3.0^{c}; 3.5^{d}	2.3–2.5^{c}	2.2–2.3	2.0–2.1^{c}	2.4–2.2	2.2–2.2
8.									
9.			19,000–24,000^{c}		24,000–32,200^{c}	33,800–37,400	39,700–39,900^{c}	48,600	48,600
10.			34–36,000^{c}, 21,000^{d}		38,800–40,000^{c}	45,700	53,900^{c}	44,100	47,500
11.	798^{c}; 508^{d}	1160^{c}; 798^{d}	1250–1600^{c}; 1090^{d}	2320^{c}; 1740^{d}	1300	1800	2200–2270^{c}	1,750,000	2,230,000
12								550,000	560,000
13.	700^{d}; 420^{d}	910^{c}; 650^{d}	1250–1400^{c}; 800–950^{d}	1700^{c}; 1570^{d}	1200^{c}	1600	1930–2000^{c}	1,500,000	2,000,000
								1,450,000	1,770,000
								740,000	850,000

14.	1.1	2.0	2.1–3.4^{c}; 3.7–5.5^{d}		4.2^{c}	6.2–6.4	8.4–8.6^{c}	2.1	2.2
15.	M92^{c}; M74^{d}	M95^{c}; M83^{d}	M93–96^{c}; M78^{d}	M104^{c}; M93^{d}	M93–96	M93		124	124
16.	52	40	16–80	30	22^{c}			15–48	15–48
17.	374	410	392–420^{c}	419	420^{c}	405	415	500	502
	419	428	420–430^{c}	428	425^{c}				
18.			5.8–11.4						
19.	1.23	1.32	1.35–1.42	1.55	1.4	1.45	1.56	1.47	1.58
20.	2.6	2.3	0.90–1.2	1.5	1.3			0.4	0.27
	8.0	7.1	6.4–7.0	4.8				3.5	2.8
21.			400–450^{c}		400				
	Ashley Polymers; BASF; Bayer Corp.; ComAlloy; EMS; M.A. Hanna Eng.; M.A. Polymers; Network Polymers; Nyltech; Polymers Intl., RTP;A Schulman; Wellman	Ashley Polymers; BASF; Bayer Corp.; EMS; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymers Intl.; RTP; A. Schulman	Adell; Albis AlliedSignal; ALM; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; ComAlloy; DSM; EMS; Ferro; LNP; M.A. Hanna Eng.; M.A. Polymers; Network Polymers; Nyltech; Polymers Intl., RTP; A. Schulman; Thermofil, Ticona, Wellman	Ashley Polymers; BASF; Bayer Corp.; ComAlloy; EMS; M.A. Hanna Eng.; Network Polymers Nyltech; Polymers Intl.; RTP	Adell; ALM; DSM; Ferro; LNP; RTP; Ticona	Adell; ALM; DSM; Ferro; LNP; RTP; Ticona	RTP; Ticona	DuPont	DuPont

			Polyamide (Cont'd)				
			Nylon, Type 6 (Cont'd)				
			Toughened		Flame-retarded Grade		
Materials	Properties	ASTM Test Method	Unreinforced	33% Glass Fiber-reinforced	30% Glass Fiber-reinforced	40% Mineral- and Glass Fiber-reinforced	40% Mineral-reinforced
Processing	1a. Melt flow (gm./10 min.)	D1238					
	1. Melting temperature, °C.						
	T_m (crystalline)		210–220	210–220	210–220	210–220	210–220
	T_g (amorphous)						
	2. Processing temperature range, °F. (C 5 compression; T 5 transfer; I 5 injection; E 5 extrusion)		I: 520–550	I: 520–550	I: 520–560	I: 450–550	I: 450–550
	3. Molding pressure range, 10^3 p.s.i.				12–25	2–20	2–20
	4. Compression ratio				3.0–4.0	3.0–4.0	3.0–4.0
	5. Mold (linear) shrinkage, in./in.	D955	0.006–0.02	0.001–0.003	0.001	0.003–0.006	0.003–0.006
Mechanical	6. Tensile strength at break, p.s.i.	D638^{b}	6500–7900^{c}; 5400^{d}	17,800^{c}	18,800–22,000^{c}	17,400^{c}–19,000^{d}	11,000–11,300
	7. Elongation at break, %	D638^{b}	65.0–150^{c}	4.0^{c}	1.7–3.0^{c}	3^{c}; 2–6^{d}	3.0
	8. Tensile yield strength, p.s.i.	D638^{b}			22,000^{c}	19,000–20,000	
	9. Compressive strength (rupture or yield), p.s.i.	D695			23,000^{c}	14,000–18,000^{c}	
	10. Flexural strength (rupture or yield), p.s.i.	D790	9100^{c}	25,800^{c}	28,300–31,000^{c}	23,000–30,000^{c}	
	11. Tensile modulus, 10^3 p.s.i.	D638^{b}	290^{c}; 102^{d}		1200^{c}–1700	1160–1400^{c}; 725^{d}	
	12. Compressive modulus, 10^3 p.s.i.	D695					
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	250^{c}	1110^{c}	1160–1400^{c}	900–1300^{c}; 650–996^{d}	650–700
	200° F.	D790					
	250 °F.	D790					
	300 °F.	D790					

	14. Izod impact, ft.-lb./in. of notch (${}^{1}/_{8}$-in. thick specimen)		D256A	16.4^{c}	3.5^{c}	1.5^{c}–2.2	0.6–4.2^{c}; 5.0^{d}	1.8–2.0
	15. Hardness	Rockwell	D785				R118–121^{c}	
		Shore/Barcol	D2240/ D2583					
Thermal	16. Coef. of linear thermal expansion, 10^{22} in./in./°C.		D696				11–41	
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	135^{c}; 122	400^{c}	380–400^{c}	390–405^{c}	270–285
		66 p.s.i.	D648	158	430^{c}	420	410–425^{c}	
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C		C177					
Physical	19. Specific gravity		D792	1.07; 1.06	1.33	1.62–1.7	1.45–1.50	1.45
	20. Water absorption (${}^{1}/_{8}$-in. thick specimen), %	24 hr.	D570		0.86	0.5–0.6	0.6–0.9	
		Saturation	D570				4.0–6.0	
	21. Dielectric strength (${}^{1}/_{8}$-in. thick specimen), short time, v./mil		D149				490–550^{c}	
			SUPPLIERS[a]	Adell; Albis; Allied Signal; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; Custom Resins; DSM; EMS; Ferro; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymers Intl.; A. Schulman; Wellman	Adell; AlliedSignal; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; ComAlloy: DSM; EMS; Ferro; LNP; M.A. Hanna Eng.; Network Polymers; Polymers Intl.; RTP; A. Schulman; Wellman	AlliedSignal; ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymers Intl.; RTP; Ticona	Adell; Allied Signal; Ashley Polymers; BASF; Bayer Corp.; ComAlloy; DSM; EMS; Ferro; LNP; M.A. Hanna Eng.; M.A. Polymers; Network Polymers; Nyltech; Polymers Intl.; RTP; A. Schulman; Thermofil; Wellman	Albis; AlliedSignal; Ashley Polymers; Bayer Corp.; M.A. Hanna Eng.; Network Polymers; Polymers Intl.; RTP; A. Schulman; Wellman

Polyamide (Cont'd)

	Nylon, Type 6 (Cont'd)									Nylon, Type 66
	High-impact Copolymers and Rubber-modified Compounds	Unfilled with Molybdenum Disulfide	Impact-Modified; 30% Glass Fiber-Reinforced	EMI shielding (Conductive); 30% PAN Carbon Fiber	Cast	Cast, heat-stabilized	Cast, Oil-Filled	Cast, Plasticized	Cast, Type 612 Blend	Molding Compound
1a.	1.5–5.0									
1.	210–220	215	220	210–220	227–238	227–238	227–238	227–238	227–238	255–265
2.	I: 450–580 E: 450–550	I: 460–500	I: 480–550	I: 520–575						I: 500–620
3.	1–20	5–20	3–20							1–25
4.	3.0–4.0	3.0–4.0	3.0–4.0							3.0–4.0
5.	0.008–0.026	1.1	0.003–0.005	0.001–0.003						0.007–0.018
6.	6300–11,000^c	11,500^c	21,000^c;14,500^d	30,000–36,000^c	12,000–13,500	12,000–13,500	9,500–11,000	9,700–10,800	8,700–11,500	13,700^c; 11,000^d
7.	150–270^c	60–80	5^c–8^d	2–3^c	20–45	20–30	45–55	25–35	25–80	15–80^c; 150–300^d
8.	9000^c-9500	11,500-12,300								8000–12,000^c; 6500–8500^d
9.	3900^c			29,000^c	16,000–18,000	16,000–18,000	12,000–14,000	22,000–25,000		12,500–15,000^c(yld.)
10.	5000–12,000^c	13,000		46,500–51,000^c	15,500–17,500	15,000–16,000	14,000–16,000	12,000–13,000	15,000–20,000	17,900–1700^c; 6100^d
11.		440	1220^c–754^d	2800–3000^c	485–550	485–550	375–475	375–440	240–330	230–500^c; 230–500^d
12.					300–350	300–310	275–375	250–275		
13.	110–320^c; 130^d	400	1160^c–600^d	2500–2700^c	420–440	420–440	275–375	330–350	285–385	410–470^c; 185^d
	60–130^c									

14.	1.8-No break^c 1.8-No break^d	0.9–1.0	2.2^c–6^d	1.5–2.8^c	0.7–0.9	0.7–0.9	1.4–1.8	0.82–0.91	0.9–1.4	0.55–1.0^c; 0.85–2.1^d
15.	R81–113^c; M50	R119–120		E70^c	115–125	110–115	110–115	110–115	100–115	R120^c; M83^c; M95–M105^d
					78–83	76–78	74–78	76–78	75–81	
16.	72–120		20–25	14.0^c	50	45	35	45	40–45	80
17.	113–140^c	200	410^c	415–490^c	330–400	330–400	330–400	330–400	330–400	158–212^c
	260–367^c	230	428^c	425–505^c	400–430	400–430	400–430	400–430	400–430	425–474^c
18.										5.8
19.	1.07–1.17	1.17–1.18	1.33	1.28	1.15–1.17	1.15–1.17	1.14–1.15	1.14–1.16	1.10–1.13	1.13–1.15
20.	1.3–1.7	1.1–1.4	2.0	0.7–1.0	0.5–0.6	0.5–0.6	0.5–0.6	0.5–0.6	0.5–0.6	1.0–2.8
	8.5		6.2		5–6	5–6	2–2.5	5–6	4–5	8.5
21.	450–470^c				500–600	500–600	500–600	500–600	500–600	600^c
	Adell; AlliedSignal; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; Custom Resins; EMS; M.A. Hanna Eng.; M.A. Polymers; Network Polymers; Nyltech; Polymers Intl.; RTP; A. Schulman; Wellman	Ashley Polymers; DSM; LNP; M.A. Hanna Eng.; Nyltech; RTP; Ticona	Adell; Albis; AlliedSignal; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; ComAlloy; EMS; Ferro; LNP;M.A. Hanna Eng.; M.A. Polymers; Network Polymers; Polymers Intl.; RTP	ComAlloy; DSM; Ferro; LNP; Nyltech; RTP; Thermofil	Cast Nylons Ltd.	Cast Nylons Ltd.	Cast Nylons Ltd.	Cast Nylons Ltd.	Cast Nylons Ltd.	Adell; Albis; ALM; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; ComAlloy; DSM; DuPont; EMS; M.A. Hanna Eng.; MRC; Network Polymers; Nyltech; Polymer Resources; Polymers Intl.; A. Schulman; Solutia; Thermofil; Ticona; Wellman

Polyamide (Cont'd)

Nylon, Type 66 (Cont'd)

Materials	Properties		ASTM Test Method	13% Glass Fiber-reinforced, Heat-estabilized	15% Glass Fiber-reinforced	30–33% Glass Fiber-reinforced	50% Glass Fiber-reinforced	30% Long Glass Fiber-reinforced
Processing	1a. Melt flow (gm./10 min.)		D1238					
	1. Melting temperature, °C.	T_m(crystalline)		257	260	260–265	260	260–265
		T_g(amorphous)						
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)			I: 520–570	535–575	I: 510–580	555–590	I: 530–570
	3. Molding pressure range, 10^{3} p.s.i.			7–20		5–20		10–20
	4. Compression ratio			3.0–4.0		3.0–4.0		
	5. Mold (linear) shrinkage, in./in.		D955	0.005–0.009	4×10^{-3}	0.002–0.006	1×10^{-3}	0.003
Mechanical	6. Tensile strength at break, p.s.i.		D638^{b}	15,000–17,000	18,900^{c}; 11,600^{d}	27,600^{c}; 20,300^{d}	33,400^{c}; 26,100^{d}	24,000–28,000^{c}
	7. Elongation at break, %		D638^{b}	3.0–5	3^{c}; 6^{d}	2.0–3.4^{c}; 3–7^{d}	2^{c}; 3^{d}	2.1–2.5^{c}
	8. Tensile yield strength, p.s.i.		D638^{b}			25,000^{c}		
	9. Compressive strength (rupture or yield), p.s.i.		D695			24,000–40,000^{c}		28,000–34,200^{c}
	10. Flexural strength (rupture or yield), p.s.i.		D790	27,500^{c}; 15,000^{d}	25,800^{c}; 17,800^{d}	40,000^{c}; 29,000^{d}	46,500^{c}; 37,500^{d}	40,000–40,300^{c}
	11. Tensile modulus, 10^{3} p.s.i.		D638^{b}		870^{c}; 853^{d}	1380^{c}; 1090^{d}	2320^{c}; 1890^{d}	
	12. Compressive modulus, 10^{3} p.s.i.		D695					
	13. Flexural modulus, 10^{3} p.s.i.	73° F.	D790	700–750	720^{c}; 480^{d}	1200–1450^{c}; 800^{d}; 900	1700^{c}; 1460^{d}	1200–1300^{c}
		200° F.	D790					
		250° F.	D790					
		300° F.	D790					

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	0.95–1.1	1.1	1.6–4.5[c]; 2.6–3.0[d]	2.5	4.0–5.1[c]
	15. Hardness	Rockwell	D785	95M/R120	M97[c]; M87[d]	R101–119[c]; M101–102[c]; M96[d]	M102[c];M96[d]	E60[c]
		Shore/Barcol	D2240/ D2583					
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696		52	15–54	0.33	23.4
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	450–470	482	252–490[c]	482	485–495
		66 p.s.i.	D648	494	482	260–500[c]	482	505
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177			5.1–11.7		
Physical	19. Specific gravity		D792	1.21–1.23	1.23	1.15–1.40	1.55	1.36–1.4
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	1.1		0.7–1.1		0.9
		Saturation	D570	7.1	7	5.5–6.5	4	
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149			360–500		500
			SUPPLIERS[a]	Adell; Albis; ALM; Ashley Polymers; ComAlloy; DSM; LNP; M.A. Hanna Eng.; Network Polymers; Polymers Intl.; RTP; A. Schulman; Ticona; Wellman	Ashley Polymers; BASF; EMS; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymers Intl.; RTP; Wellman	Adell; Albis; ALM; Ashley Polymers; BASF; Bamberger Polymers; Bayer Corp.; ComAlloy; DSM; DuPont; EMS; Ferro; LNP; M.A. Hanna Eng.; MRC; Network Polymers; Nyltech; Polymer Resources; Polymers Intl.; RTP; A. Schulman; Solutia; Thermofil; Ticona; Wellman	Ashley Polymers; BASF; ComAlloy; EMS; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymers Intl.; RTP	Ashley Polymers; DSM; Ferro; LNP; RTP; Ticona

Polyamide (Cont'd)

Nylon, Type 66 (Cont'd)

	40% Long Glass Fiber-reinforced	50% Long Glass Fiber-reinforced	60% Long Glass Fiber-reinforced	Toughened		Modified High-impact, 25–30% Mineral-filled	Flame-retarded Grade	
				Unreinforced	15–33% Glass Fiber-reinforced		Unreinforced	20–25% Glass Fiber-reinforced
1a.								
1.	257–265	260	260	240–265	256–265	250–260	249–265	200–265
2.	I: 520–570	I: 550–580	I: 560–600	I: 520–580	I: 530–575	I: 510–570	I: 500–560	I: 500–560
3.	10–20	10–20	10–20	1–20				
4.	3.0–4.0	3–4				10–20		
5.	0.002–0.10	0.002–0.007	0.002–0.006	0.012–0.018	0.0025–0.0045^{c}	0.01–0.018	0.01–0.016	0.004–0.005
6.	32,800–32,900	37,200–38,000^{c}	40,500–41,800^{c}	7000^{c}–11,000; 5800^{d}	10,900–20,300^{c}; 14,500^{d}	9000–18,900^{c}	8500^{c}-10,600	20,300^{c}–14,500^{d}
7.	2.1–2.5	2.0–2.1^{c}	2.0–2.1^{c}	4–200^{c}; 150–300^{d}	4.7^{c}; 8^{d}	5–16^{c}	4–10.0^{c}	2.3–3^{c}
8.				7250–7500^{c}; 5500^{d}			10,600	
9.	37,700–42,700	42,900–44,900^{c}	47,000–47,900^{c}		15,000^{c}-20,000		25,000^{c}	
10.	49,100	54,500–57,000^{c}	65,000^{c}	8500–14,500^{c}; 4000^{d}	17,400–29,900^{c}	20,000^{c}	14,000–15,000^{c}	23,000^{c}
11.	1700–1790	2270–2300^{c}	2900–3170^{c}	290^{c}-123^{d}	1230^{c}; 943^{d}		420^{c}	1230^{c}; 870^{d}
12.								
13.	1560–1600	1900–1920^{c}	2580–2600^{c}	225–380^{c}; 125–150^{d}	479–1100^{c}	600^{c}-653	400–420^{c}	1102
	810	990	1440					

14.	6.2; 6.6^{c}; 6.9	8.0–9.2^{c}	10.0–11.0^{c}	12.0^{c}-19.0; 3-N.B.^{c}; 1.4-N.B.^{d}	> 3.2–5.0	1.0–3.0^{c}	0.5–1.5^{c}	1.1^{c}
15.				M60^{c}; R100^{c}; R107^{c}; R113; R114–115^{c}; M50^{d}	R107^{c}; R115; R116; M86^{c}; M70^{d}	R120; M86^{c}	M82^{c}; R119	M98^{c}; M90^{d}
16.				80	43	30		50
17.	490	500	505	140–175^{c}	446–470	300–470	170–200	482
	490			385–442^{c}	480–495	399–460	410–415	482
18.								
19.	1.45	1.56	1.69	1.06–1.11	1.2–1.34	1.28–1.4	1.25–1.42	1.3–1.51
20.				0.8–2.3	0.7–1.5	0.9–1.1	0.9–1.1	0.7
				7.2	5			
21.							520	430
	DSM; Ferro; LNP; RTP; Ticona	Ashley Polymers; RTP; Ticona	RTP; Ticona	Adell; ALM; Ashley Polymers; BASF; Bamberger Polymers; ComAlloy; DSM; DuPont; Ferro; LNP; M.A. Hanna Eng.; MRC; Network Polymers; Nyltech; Polymers Intl.; RTP; A. Schulman; Solutia; Ticona; Wellman	Adell; ALM; Ashley Polymers; BASF; Bamberger Polymers; ComAlloy; DSM; DuPont; EMS; Ferro; LNP; M.A. Hanna Eng.; Network Polymers; Nyltech; Polymers Intl.; RTP; Solutia; Ticona; Wellman	ALM; Ashley Polymers; ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng.; Network Polymers; RTP; Wellman	Ashley Polymers; BASF; ComAlloy; DSM; DuPont; EMS; M.A. Hanna Eng.; Nyltech; Polymers Intl.; RTP; Wellman	BASF; ComAlloy; DSM; DuPont; Ferro; LNP; M.A. Hanna Eng.; Nyltech; Polymers Intl.; RTP; Wellman

			Polyamide (Cont'd)					
			Nylon, Type 66 (Cont'd)					
					EMI Shielding (Conductive)			
Materials	Properties	ASTM Test Method	40% Glass- and Mineral-reinforced	40–45% Mineral-filled	30% Graphite or PAN Carbon Fiber	40% Aluminum Flake	5% Stainless Steel, Long Fiber	6% Stainless Steel, Long Fiber
Processing	1a. Melt flow (gm./10 min.)	D1238						
	1. Melting temperature, °C. T_m(crystalline)		250–260	250–265	258–265	265	260–265	260–265
	T_g(amorphous)							
	2. Processing temperature range, °F. (C = compression: T = transfer; I = injection; E = extrusion)		I: 510–590	I: 520–580	I: 500–590	I: 525–600	I: 530–570	I: 530–570
	3. Molding pressure range, 10^3 p.s.i.		9–20	5–20	10–20	10–20		5–18
	4. Compression ratio		3–4	3.0–4.0				
	5. Mold (linear) shrinkage, in./in.	D955	0.001–0.005	0.012–0.022	0.001–0.003	0.005	0.004	0.004–0.006
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	15,500–31,000[c]; 13,100[d]	14,000[c]; 11,000[d]	27,600–35,000[c]	6000[c]	10,000[c]	10,000–11,300[c]
	7. Elongation at break, %	D638[b]	2–7[c]	5–10[c]; 16[d]	1–4[c]	4[c]	5.0[c]	2.9; 5.0[c]
	8. Tensile yield strength, p.s.i.	D638[b]		13,900				
	9. Compressive strength (rupture or yield), p.s.i.	D695	18,000–37,000[c]	15,500–22,000[c]	24,000–29,000[c]	7500[c]		
	10. Flexural strength (rupture or yield), p.s.i.	D790	24,000–48,000[c]	22,000[c]; 9000[d]	45,000–51,000[c]	11,700[c]	16,000[c]	16,000–38,700[c]
	11. Tensile modulus, 10^3 p.s.i.	D638[b]		900[c]; 500[d]	3200–3400[c]	720[c]	450[c]	450–1500[c]
	12. Compressive modulus, 10^3 p.s.i.	D695		370[c]				
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	965–1750[c]; 600[d]	900–1050[c]; 400[d]	1500–2900[c]	690[c]	450[c]	500–1400
	200° F.	D790	600[c]					
	250° F.	D790						
	300° F.	D790						

	14. Izod impact, ft-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	0.6–3.8^{c}	0.9–1.4^{c}; 3.9^{d}	1.3–2.5^{c}	2.5^{c}	1.3^{c}	0.7; 2.2
	15. Hardness	Rockwell	D785	M95–98^{c}	R106–121^{c}	R120^{c}; M106^{c}	R114^{c}		
		Shore/Barcol	D2240/ D2583						
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	20–54	27	11–16	22		
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	432–485^{c}	300–438	470–500	380	285	175–480
		66 p.s.i.	D648	480–496^{c}	320–480^{c}	500–510	400	295	
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	11	9.6	24.1			
Physical	19. Specific gravity		D792	1.42–1.55	1.39–1.5	1.28–1.43	1.48	1.27	1.19–1.45
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.4–0.9	0.6–0.55	0.5–0.8	1.1	0.12	
		Saturation	D570	5.1	6.0–6.5				
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	300–525	450^{c}				
SUPPLIERS^{a}				Adell; ALM; Ashley Polymers; BASF; ComAlloy; DSM; DuPont; EMS; Ferro; LNP; M.A. Hanna Eng.; MRC; Network Polymers; Nyltech; RTP; Solutia; Thermofil; Ticona; Wellman	Adell; Albis; ALM; Ashley Polymers; ComAlloy; DSM; DuPont; Ferro; LNP; M.A. Hanna Eng.; MRC; Network Polymers; Nyltech; RTP; Solutia; Thermofil; Ticona; Wellman	ComAlloy; DSM; Ferro; LNP; RTP; Thermofil	Thermofil	DSM; RTP	RTP; Ticona

	Polyamide (Cont'd)									
	Nylon, Type 66 (Cont'd)									
	EMI shielding (Conductive) (Cont'd)							Lubricated		
	10% Stainless Steel, Long Fiber	50% PAN Carbon Fiber	30% Pitch Carbon Fiber	40% Pitch Carbon Fiber	15% Nickel-Coated Carbon Filter	40% nickel-Coated Carbon Fiber	Antifriction Molybdenum Disulfide-filled	5% Silicone	10% PTFE	30% PTFE
1a.										
1.	257–265	260–265	260–265	260–265	260–265	260–265	249–265	260–265	260–265	260–265
2.	I: 530–570	I: 530–570	I: 530–570	I: 530–570	I: 530–570	I: 530–570	I: 500–600	I: 530–570	I: 530–570	I: 530–570
3.	5–20						5–25			
4.	3.0–4.0									
5.	0.003–0.004	0.0005	0.003	0.002	0.005	0.001	0.007–0.018	0.015	0.01	0.007
6.	11,500	38,000^{c}	15,500^{c}–15,600	17,500^{c}; 19,250	14,000^{c}	20,000^{c}	10,500–13,700^{c}	8500^{c}	9500^{c}	5500^{c}
7.	2.6	1.2^{c}	2.0^{c}	1.5^{c}	1.6^{c}	2.5^{c}	4.4–40^{c}			
8.										
9.			20,500	24,000			12,000–12,500^{c}			
10.	18,100	54,000^{c}	24,800–26,000^{c}	28,000^{c}–29,000	21,000^{c}	27,000^{c}	15,000–20,300^{c}	15,000^{c}	13,000^{c}	8000^{c}
11.	600	5000^{c}	1400–2000^{c}	2250–2600^{c}	1100^{c}		350–550^{c}			
12.										
13.	500	4200^{c}	1200–1500^{c}	1800–2000^{c}	1000^{c}	2000^{c}	420–495^{c}	300^{c}	420^{c}	460^{c}

14.	0.7; 1.9^{c}	2.0^{c}	0.6–0.7^{c}	0.7–0.8^{c}	0.7^{c}	1.0^{c}	0.9–4.5^{c}	1.0^{c}	0.8^{c}	0.5^{c}
15.							R119^{c}			
16.			16.0–19.0	9.0–14.0			54	63.0	35.0	45.0
17.	175–480	495	465–490	475–490	460	470	190–260^{c}	170	190	180
		505	490–500	498–500			395–430			
18.										
19.	1.24	1.38	1.30–1.31	1.36–1.38	1.20	1.46	1.15–1.18	1.16	1.20	1.34
20.		0.5	0.6	0.5	1.0	0.8	0.8–1.1	1.0	0.7	0.55
							8.0			
21.							360^{c}			
	RTP; Ticona	DSM; LNP; RTP	ComAlloy; LNP; Polymers Intl.; RTP	ComAlloy; LNP; RTP	DSM; RTP	DSM; RTP	Adell; ALM; Ashley Polymers; ComAlloy; DSM; LNP; M.A. Hanna Eng.; Nyltech; RTP; Thermofil	ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng.; RTP	ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng.; RTP	ComAlloy DSM; Ferro; LNP; M.A. Hanna Eng.; RTP

Materials				**Polyamide** (Cont'd)					
				Nylon, Type 66 (Cont'd)		Nylon, Type 610			
				Lubricated (Cont'd)					Flame-retarded Grade
		Properties	ASTM Test Method	5% Molybdenum Disulfide and 30% PTFE	Copolymer	Molding and Extrusion Compound	30–40% Glass Fiber-reinforced	30–40% Long Glass Fiber-reinforced	30% Glass Fiber-reinforced
Processing	1a.	Melt flow (gm./10 min.)	D1238						
	1.	Melting temperature, °C.							
		T_m(crystalline)		260–265	200–255	220	220	220	220
		T_g (amorphous)							
	2.	Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 530–570	I: 430–500	I: 445–485 E: 480–500	I: 510–550	I: 510–550	I: 500–560
	3.	Molding pressure range, 10^3 p.s.i.			1–15	1–19			
	4.	Compression ratio				3–4			
	5.	Mold (linear) shrinkage. in./in.	D955	0.01	0.006–0.015	0.005–0.015	0.015–0.04	0.013–0.03	0.002
Mechanical	6.	Tensile strength at break, p.s.i.	D638^{b}	7500^{c}	7400–12,400^{c}	10,150^{c}; 7250^{d}	22,000–26,700^{c}	22,400–25,400^{c}	19,000^{c}
	7.	Elongation at break, %	D638^{b}		40–150^{c}; 300^{d}	70^{c}; 150^{d}	4.3–4.7^{c}	4.0–4.1^{c}	3.5^{c}
	8.	Tensile yield strength, p.s.i.	D638^{b}						
	9.	Compressive strength (rupture or yield), p.s.i.	D695				20,400–21,000^{c}	20,000^{c}	23,000^{c}
	10.	Flexural strength (rupture or yield), p.s.i.	D790	1200^{c}	12,000	350^{c}; 217^{d}	32,700–38,000^{c}	34,000–37,400^{c}	28,000^{c}
	11.	Tensile modulus, 10^3 p.s.i.	D638^{b}		150–410^{c}		800^{c}	950–1600^{c}	
	12.	Compressive modulus, 10^3 p.s.i.	D695						
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	400^{c}	150–410		1150–1500^{c}	1200–1430^{c}	1230^{c}
		200° F.	D790						
		250° F.	D790						
		300° F.	D790						

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	0.6^{c}	0.7^{c}; No break^{d}		1.6–2.4	3.2–4.2^{c}	1.5^{c}
	15. Hardness	Rockwell	D785		R114–119; R83^{d}, M75^{c}		E43–48^{c}	E42–56^{c}	M89^{c}
		Shore/Barcol	D2240/ D2583						
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696						
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	185	135–170^{c}		410–415	425	390
		66 p.s.i.	D648		430^{c}– 440		430	430	
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177						
Physical	19. Specitic gravity		D792	1.37	1.08–1.14		1.3–1.4	1.33–1.39	1.55
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.55	1.5–2.0	1.4	0.17–0.19	0.17–0.21	0.16
		Saturation	D570		9.0–10.0	3.3			
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149		400^{c}			500	
			SUPPLIERS^{a}	ComAlloy; DSM; M.A. Hanna Eng.; RTP	AlliedSignal; Ashley Polymers; BASF; DuPont; EMS; M.A. Hanna Eng.; Nyltech; Polymers Intl.; Solutia	EMS; M.A. Hanna Eng.	Ashley Polymers; DSM; Ferro; LNP; M.A. Hanna Eng.; RTP	DSM; LNP	DSM; LNP; RTP

Polyamide (Cont'd)

Nylon, Type 612									Nylon, Type 46	
			Toughened		Flame-retarded Grade	Lubricated				
Molding Compound	30–35% Glass Fiber-reinforced	35–45% Long Glass Fiber-reinforced	Unrein-forced	33% Glass Fiber-reinforced	30% Glass Fiber-reinforced	10% PTFE	15% PTFE, 30% Glass Fiber-reinforced	10% PTFE, 30% PAN Carbon Fiber	Extrusion	Un-reinforced
1a.										
1. 195–219	213–217	195–217	195–217	195–217	195–217	195–217	195–217	195–217	295	295
2. I: 450–550 E: 464–469	I: 450–550	I: 510–550	I: 510–550	I: 510–550	I: 500–560	I: 510–550	I: 510–550	I: 510–550	E: 560–590	I: 570–600
3. 1–15	4–20									5–15
4.									3–4	3–4
5. 0.011	0.002–0.005	0.001–0.002				0.012	0.002–0.003	0.0013		0.018–0.020
6. 6500–8800^c	22,000^c; 20,000^d	26,000–29,000^c	5500^c	18,000^c	18,000–19,000^c	7000^c	19,500–20,000^c	28,000^c	8,500	14,400
7. 150^c; 300^d	4^c; 5^d	2.9–3.2^c	40^c	5^c	2.0–3.5^c		2.5		60	25
8. 5800–8400^c; 3100^d										
9.	22,000^c	23,000^c			15,000–21,000^c		19,000			13,000
10. 11,000^c; 4300^d	32,000–35,000^c	39,000–44,000^c	6500^c	27,000^c	28,000^c		30,500–31,000^c	42,000^c	11,500	21,700
11. 218–290^c; 123–180^d	12,00^c; 900^d				1000^c–1400		1200		250	435
12.										319
13. 240–334^c; 74–100^d	1100–1200^c; 900^d	1200–1500^c	195^c	1050^c	1200–1250^c	100^c	1100–1200^c	2600^c	270	480

14.	1.0–1.9s; 1.4-No break[d]	1.8–2.6[c]	4.2–6.3[c]	12.5[c]	4.5[c]	1.0–1.5[c]	1.0[c]	2.5–3.0[c]	2.4[c]	17	1.8
15.	M78[c]; M34[d]; R115	M93[c]; E40–50[d];	E40[c]			M89[c]					R113
	D72–80[c]; D63[d]	R116									D85
16.			21.6–25.2					18.0			
17.	136–180[c]	390–425[c]	410–415	135	385	385–390	202[c]	385	390	194	320
	311–330[c]	400–430[c]	420–425			400					
18.	5.2	10.2									
19.	1.06–1.10	1.30–1.38	1.34–1.45	1.03	1.28	1.55–1.60	1.13	1.42–1.45	1.30	1.10	1.18
20.	0.37–1.0	0.2	0.2	0.3	0.2	0.16	0.2	0.13	0.15	1.84	2.3
	2.5–3.0	1.85									
21.	400[c]	520[c]				450					673
	ALM; Ashley Polymers; Creanova; DuPont; EMS; M.A. Hanna Eng.; A. Schulman	ALM; Ashley Polymers; ComAlloy; DSM; DuPont; Ferro; LNP; M.A. Hanna Eng.; RTP	DSM; RTP	DSM; DuPont; M.A. Hanna Eng.; RTP	DSM; DuPont; LNP; M.A. Hanna Eng.; RTP	ComAlloy; DSM; LNP; M.A. Hanna ENg.; RTP	ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng: RTP	ComAlloy; DSM; Ferro; LNP; M.A. Hanna Eng.; RTP	ComAlloy; DSM; LNP; RTP	DSM	DSM

Materials				**Polyamide** (Cont'd)						
				Nylon, Type 46 (Cont'd)						
		Properties	ASTM Test Method	Super-tough	15% Glass-reinforced	15% Glass-reinforced, V-0	30% Glass-reinforced	30% Glass-reinforced V-0	50% Glass-reinforced	50% Glass and Mineral-filled
Processing	1a.	Melt flow (gm./10 min.)	D1238							
	1.	Melting temperature, °C.								
		T_m(crystalline)		295	295	295	295	295	295	295
		T_g (amorphous)								
	2.	Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 570–600	I: 570–600	I: 570–600	I: 570–600	I: 570–600	I: 570–600	I: 570–600
	3.	Molding pressure range, 10^3 p.s.i.		5–15	5–15	5–15	5–15	5–15	5–15	5–15
	4.	Compression ratio		3–4	3–4	3–4	3–4	3–4	3–4	3–4
	5.	Mold (linear) shrinkage, in./in.	D955	0.018–0.020	0.005–0.009	0.006–0.009	0.004–0.006	0.004–0.006	0.002–0.004	0.003–0.006
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	8,500	21,500	16,500	30,000	23,000	34,000	20,000
	7.	Elongation at break, %	D638[b]	60	3	8	4	3	3	2
	8.	Tensile yield strength, p.s.i.	D638[b]							
	9.	Compressive strength (rupture. or yield), p.s.i	D695				33,000	34,000		
	10.	Flexural strength (rupture or yield), p.s.i	D790	11,500	31,900	27,000	43,000	34,000	50,750	34,000
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	250	841	1,000	1,300	1,500	2,320	2,100
	12.	Compressive modulus, 10^3 p.s.i.	D695				507	688		
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	270	798	1125	1,200	1,300	2,030	1700
		200° F.	D790							
		250° F.	D790							
		300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	17	1.6	.5	2.0	1.3	2.2	1.1
	15. Hardness	Rockwell	D785				R120	R120		
		Shore/Barcol	D2240/ D2583				D89	D88		
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696							
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	194	480	480	545	545	545	545
		66 p.s.i.	D648							
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2}-°C.		C177							
Physical	19. Specific gravity		D792	1.10	1.3	1.47	1.41	1.68	1.62	1.6
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	1.84			1.5	0.9	1.15	
		Saturation	D570							
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149				863	838		
SUPPLIERS[a]				DSM	DSM	DSM	DSM	DSM	DSM	DSM

	Polyamide (cont'd)								Polyamide-imide	
	Nylon, Type 11	Nylon, Type 12	Aromatic Polyamide		Partially Aromatic					
	Molding and Extrusion Compound	Molding and Extrusion Compound	Amorphous Transparent Copolymer	Aramid Molded Parts, Unfilled	35% Glass fiber-reinforced Impact Modified	40% Glass fiber-reinforced	50% Glass Fiber-reinforced	60% Glass Fiber-reinforced	Unfilled Compression and Injection Molding Compound	30% Glass Fiber-reinforced
1a.										
1.	180–190	160–209		275	260	260	260	260		
		125–155							275	275
2.	I: 390–520 E: 390–475	I: 356–525 E: 350–500	I: 480–610 E: 520–595		270–310	270–310	270–310	270–310	C: 600–650 I: 610–700	C: 630–650 I: 610–700
3.	1–15	1–15	5–20						2–40	15–40
4.	2.7–3.3	2.5–4							1.0–1.5	1.0–1.5
5.	0.012	0.003–0.015	0.004–0.007		0.15/0.95	0.15/0.95	0.15/0.90	0.10/0.80	0.006–0.0085	0.001–0.0025
6.	8000[c]–9,500	5100–10,000[c]; 8000[d]	7600–14,000[c]; 13,000[d]	17,500[c]	26,000	31,500	34,700	36,200	22,000	
7.	300[c]–400	250–390[c]	40–150[c]; 260[d]	5[c]	5	3	3	3	15	7
8.		3000–6100[c]	11,000–14,861[c]; 11,000[d]						27,800	29,700
9.	7300–7800		17,500[c]; 14,000[d]	30,000[c]			28,800		32,100	38,300
10.		1400–8100[c]	10,000–16,400[c]; 14,000[d]	25,800[c]	39,400	48,900	54,400	57,100	34,900	48,300
11.	185[c]	36–180[c]	275–410[c]; 270[d]						700	1560
12.	180[c]		340[c]	290[c]						1150
13.	44–180[c]	27–190[c]	306–400[c]; 350[d]	640[c]	1,270	1,634	2,106	2,680	730	1700
	20									

14.	1.8[c]-N.B.	1.0-N.B.	0.8–3.5[c]; 1.8–2.7[d]	1.4[c]	2.9	2.3	2.3	2.3	2.7	1.5
15.	R108[c]; R80	R70–109[c]; 105[d]	M77–93[c]	E90[c]	86	89	89	91	E86	E94
		D58–75[d]	D83[c]; D85[d]							
16.	100	61–100	28–70	40	18	14	14	11	30.6	16.2
17.	104–126	95–135[c]	170–268	500[c]	440	455	460	460	532	539
	300[c]	158–302[c]	261–330[c]							
18.	8	5.2–7.3	5	5.2					6.2	8.8
19.	1.03–1.05	1.01–1.02	1.0–1.19	1.30	1.39	1.47	1.58	1.72	1.42	1.61
20.	0.4	0.25–0.30	0.4–1.36	0.6	0.59	0.56	0.45	0.36		
	1.9	0.75–1.6	1.3–4.2		5.0	4.6	4.0	3.80	0.33	0.24
21.	650–750	450[c]	350[c]	800[c]					580	840
	Elf Atochem N.A.	ALM; Ashley Polymers; Creanova; Elf Atochem N.A.; EMS	AlliedSignal; Ashley Polymers; Bayer Corp.; Creanova; DuPont; EMS; M.A. Hanna Eng.; Nyltech	DuPont	EMS	EMS	EMS	EMS	Amoco Polymers	Amoco Polymers

Materials			Polyamide-imide (Cont'd)						Polybutadiene
	Properties	ASTM Test Method	Graphite Fiber-reinforced	Bearing Grade	High Compressive Strength	Wear Resistant for Speeds	Stiffness and Lubricity	Cost/ Performance Ratio	Casting Resin
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C.								
	T_m(crystalline)								Thermoset
	T_g(amorphous)		275	275					
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		C: 630–650 I: 610–700	I: 580–700					
	3. Molding pressure range, 10^3 p.s.i.		15–40	15–40					
	4. Compression ratio		1.0–1.5	1.0–1.5					
	5. Mold (linear) shrinkage, in./in.	D955	0.000–0.0015	0.0025–0.0045	3.5–6.0	3.5–6.0	0.0–1.5		
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]							
	7. Elongation at break, %	D638[b]	6	7	7	9	6	7	
	8. Tensile yield strength, p.s.i.	D638[b]	26,000	22,000	23,700	17,800	26,000	31,800	
	9. Compressive strength (rupture or yield), p.s.i.	D695	36,900		24,100	18,300	30,300	46,700	
	10. Flexural strength (rupture or yield), p.s.i.	D790	50,700	27,100–31,200	31,200	27,000	40,100	52,000	8000–14,000
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	3220	870–1130	950	870		2020	560
	12. Compressive modulus, 10^3 p.s.i.	D695	1430						
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	2880	910–1060	1000	910	2440	2100	
	200° F.	D790							
	250° F.	D790							
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	0.9	1.2–1.6	1.2	1.3	1.0	1.5	
	15. Hardness	Rockwell	D785	E94	E66-E72	72	66		107	R40
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	9.0	25.2–27.0	14	15	7	7	
	17. Deflection temperature under flexural load, °F.		264 p.s.i.	D648	540	532–536	534	532	534	536
			66 p.s.i.	D648						
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2}-°C.		C177	12.7		3.7				
Physical	19. Specific gravity		D792	1.48	1.46–1.51	1.46	1.50	1.50		0.97
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570		0.17–0.33					0.03
		Saturation	D570	0.26	0.33	0.28	0.17		0.21	
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149					Conductive	490	630
SUPPLIERS[a]				Amoco Polymers	Amoco Polymers	Amoco Polymers	Amoco Polymers	Amoco Polymers	Amoco Polymers	OxyChem

	Polybutylene			Polycarbonate							
				Unfilled Molding and Extrusion Resins		Glass Fiber-reinforced					
	Extrusion Compound	Film Grades	Adhesive Resin	High Viscosity	Low Viscosity	10% Glass	30% Glass	20–30% Long Glass Fiber-reinforced	40% Long Glass Fiber-reinforced	50% Long Glass Fiber-reinforced	35% Random Glass Mat
1a.				3–10	10–30	7.0					
1.	126	118	90								
				150	150	150	150	150	150	150	
2.	C: 300–350 I: 290–380 E: 290–380	E: 380–420	300–350	I: 560	I: 520	I: 520–650	I: 550–650	I: 590–650	I: 575–620	570–620	C: 560–600
3.	10–30			10–20	8–15	10–20	10–30	10–30	10–20	10–20	2–3.5
4.	2.5	2.5		1.74–5.5	1.74–5.5					3	
5.	0.003 (unaged) 0.026 (aged)			0.005–0.007	0.005–0.007	0.002–0.005	0.001–0.002	0.001–0.003	0.001–0.003	0.001–0.003	0.002–0.003
6.	3800–4400	4000	3500	9100–10,500	9100–10,500	7000–10,000	19,000–20,000	18,000–23,000	23,100	25,100–26,000	18,000
7.	300–380	350	500	110–120	110–150	4–10	2–5	1.9–3.0	1.4–1.7	1.3–1.5	2.5
8.	1700–2500	1700	600	9000	9000	8500–11,600					18,000
9.				10,000–12,500	10,000–12,500	12,000–14,000	18,000–20,000	18,000–29,800	31,600	32,700	14,800
10.	2000–2300			12,500–13,500	12,000–14,000	13,700–16,000	23,000–25,000	22,000–36,900	36,400	40,800	30,000
11.	30–40	30	10–15	345	345	450–800	1250–1400	1200–1500	1700	2200	1100
12.	31			350	350	520	1300				
13.	45–50		13	330–340	330–340	460–580	1100	800–1500	1500–1700	2100	1000
				275	275	440	960				
				245	245	420	900				

14.	No break	No break	No break	12–18 @$^{1}/_{8}$ in. 2.3 @$^{1}/_{4}$ in.	12–16 @$^{1}/_{8}$ in. 2.0 @$^{1}/_{4}$ in.	2–4	1.7–3.0	3.5–4.7	5.0	6.6	11.8
15.		D45	A90	M70-M75	M70-M75	M62–75; R118–122	M92, R119	M85–95			
	Shore D55–65		D25								
16.	128–150			68	68	32–38	22–23				
17.	130–140			250–270	250–270	280–288	295–300	290–300	305	310	290
	215–235			280–287	273–280	295	300–305	305			
18.	5.2			4.7	4.7	4.6–5.2	5.2–7.6				
19.	0.91–0.925	0.909	0.895	1.2	1.2	1.27–1.28	1.4–1.43	1.34–1.43	1.52	1.63	1.39
20.	0.01–0.02			0.15	0.15	0.12–0.15	0.06–0.14	0.09–0.11			
				0.32–0.35	0.32–0.35	0.25–0.32					
21.	>450			380- >400	380- >400	470–530	470–475				528
	Shell	Shell	Shell	Albis; American Polymers; Ashley Polymers; Bamberger Polymers; Bayer Corp.; Dow Plastics; Federal Plastics; GE Plastics; MRC; Network Polymers; Polymers Intl.; Polymer Resources; RTP; Shuman	Albis; American Polymers; Ashley Polymers; Bayer Corp.; Dow Plastics; Federal Plastics; GE Plastics; MRC; Network Polymers; Polymers Intl.; Polymer Resources; RTP; Shuman	Albis; American Polymers; Ashley Polymers; Bayer Corp.; ComAlloy DSM; Dow Plastics; Federal Plastics; Ferro; GE Plastics; LNP; M.A. Polymers; MRC; Network Polymers; Polymers Intl.; Polymer Resources; RTP	Albis; American Polymers; Ashley Polymers; ComAlloy; DSM; Ferro; GE Plastics; LNP; M.A. Polymers; MRC; Network Polymers; Polifill; Polymers Intl.; Polymer Resources; RTP	DSM; RTP; Ticona	RTP; Ticona	RTP; Ticona	Azdel

			Polycarbonate (Cont'd)						
			Flame-retarded Grade	High-heat			Conductive Poly-carbonate	EMI shielding (Conductive)	
Materials	Properties	ASTM Test Method	20–30% Glass Fiber-reinforced	Polyester Copolymer	Poly-carbonate Copolymer	Impact-modified Poly-carbonate/ Polyester Blends	6% Stainless Steel Fiber	10% Stainless Steel Fiber	20% PAN Carbon Fiber
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C. T_m(crystalline)								
	T_g(amorphous)		149	160–195	160–205		150	150	150
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 530–590	I: 575–710	I: 580–660	I: 475–560		I: 590–650	I: 590–650
	3. Molding pressure range, 10^3 p.s.i.			8–20	8–20	15–20	10–20		
	4. Compression ratio			1.5–3	2–3	2–2.5	3		
	5. Mold (linear) shrinkage, in./in.	D955	0.002–0.004	0.007–0.010	0.007–0.009	0.006–0.009	0.004–0.006	0.003–0.006	0.001
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	14,000–20,000	9500,11,300	8300–10,000	7600–8500	9800	10,110–11,000	18,000–20,000
	7. Elongation at break, %	D638[b]	2.0–3.0	50–122	70–90	120–165	4.7	4.0	2.0
	8. Tensile yield strength, p.s.i.	D638[b]		8500–9800	9300–10,500	7400–8300			
	9. Compressive strength (rupture or yield), p.s.i.	D695	18,000–21,000	11,500		7000			18,500
	10. Flexural strength (rupture or yield), p.s.i.	D790	21,000–30,000	10,000–13,800	12,000–14,000	10,900–12,500	14,000	16,300–17,000	27,000–28,000
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	1000–1100	320–340	320–340		410	500	2000
	12. Compressive modulus, 10^3 p.s.i.	D695							
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	900–1200	294–340	320–340	280–325	400	500	1500–1800
	200° F.	D790							
	250° F.	D790							
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.8–2.0	1.5–10	1.5–12	2–18	0.8–1.7	1.1–1.7	1.4–2.0
	15. Hardness	Rockwell	D785	M77–85	M74–92	M75–91	R114–122			
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696		70–92	70–76	80–95		1410	180
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	288–305	285–335	284–354	190–250	270	270–295	290–295
		66 p.s.i.	D648	295	305–365	306–383	223–265			300
	18. Thermal conductivity, 10^{-4} cal./-cm./ sec.-cm.^{2}-°C.		C177		4.7–5.0	4.7–4.8	4.3			
Physical	19. Specific gravity		D792	1.36–1.45	1.15–1.2	1.14–1.18	1.20–1.22	1.28	1.26–1.35	1.28
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.15–0.17	0.15–0.2	0.15–0.2	0.12–0.16		0.12	0.2
		Saturation	D570				0.35–0.60			
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149		509–520	>400	440–500			
			SUPPLIERS[a]	ComAlloy; DSM; Ferro; GE Plastics; LNP; Polymer Resources; RTP	Ferro; GE Plastics	Bayer Corp.	Bayer Corp.; Eastman; GE Plastics; MRC; Polymer Resources	RTP; Ticona	DSM; LNP; RTP; Ticona	ComAlloy; DSM; Ferro; LNP; RTP

	Polycarbonate (Cont'd)						**Polydicyclopentadiene**	**Polyester, Thermoplastic**		
	EMI Shielding (conductive) (Cont'd)		Lubricated					Polybutylene Terephthalate		
	30% Graphite Fiber	40% PAN Carbon Fiber	10–15% PTFE	30% PTFE	10–15% PTFE, 20% Glass Fiber-reinforced	2% Silicone, 30% Glass Fiber-reinforced	RIM Solid; Unfilled	Unfilled	30% Glass Fiber-reinforced	30% Long Glass Fiber-reinforced
1a.										
1.						Thermoset	Thermoset	220–267	220–267	235
	149–150		150	150	150	150	90–165			
2.	I: 540–650	I: 580–620	I: 590–650	I: 590–650	I: 590–650	I: 590–650	T: < 95–< 100	I: 435–525	I: 440–530	I: 480–540
3.	15–20	15–20					< 0.050	4–10	5–15	10–20
4.										3–4
5.	0.001–0.002	0.0005–0.001	0.007	0.009	0.002	0.002	0.008–0.012	0.009–0.022	0.002–0.008	0.001–0.003
6.	20,000–24,000	23,000–24,000	7500–10,000	6000	12,000–15,000	16,000	5300–6000	8200–8700	14,000–19,500	20,000
7.	1–5	1–2	8–10		2		5–70	50–300	2–4	2.2
8.							5000–6700	8200–8700		
9.	19,000–26,000	22,000	110,000		11,000		8500–9000	8800–14,500	18,000–23,500	26,000
10.	30,000–36,000	34,000–35,000	11,000–11,500	7600	18,000–23,000	22,000	10,000–11,000	12,000–16,700	22,000–29,000	35,000
11.	250–2150	3000–3100	340		1200		240–280	280–435	1300–1450	1400
12.								375	700	
13.	240–1900	2800–2900	250–300	460	850–900	900	260–280	330–400	850–1200	1300

14.	1.8	1.5–2.0	2.5–3.0	1.3	1.8–3.5	3.5	5.0–9.0	0.7–1.0	0.9–2.0	5.7
15.	R118, R119	R119						M68–78	M90	
							D72–D84			
16.	9	11.0–14.4	58.0		21.6–23.4	12.0	46–49 in./in./°F.	60–95	15–25	
17.	280–300	295–300	270–275	260	280–290	290	217–240	122–185	385–437	405
	295	300			290		239	240–375	421–500	
18.	16.9	17.3						4.2–6.9	7.0	
19.	1.32–1.33	1.36–1.38	1.26–1.29	1.39	1.43–1.5	1.46	1.03–1.04	1.30–1.38	1.48–1.54	1.56
20.	0.04–0.08	0.06–0.13	0.13	0.06	0.11	0.12	0.09	0.08–0.09	0.06–0.08	
								0.4–0.5	0.35	
21.								420–550	460–560	
	ComAlloy; DSM; LNP; RTP; Thermofil	ComAlloy; DSM; Ferro; LNP; RTP	ComAlloy; DSM; GE Plastics; LNP; Polymer Resources; RTP	DSM; Polymer Resources; RTP	ComAlloy; DSM; Ferro; GE Plastics; LNP; Polymer Resources; RTP	ComAlloy; DSM; Ferro; LNP; RTP	BF Goodrich; Hercules	Albis; Ashley Polymers; BASF; ComAlloy; Creanova; DuPont; GE Plastics; M.A. Hanna Eng.; RTP; Ticona	Albis; Adell; Ashley Polymers; BASF; ComAlloy; Creanova; DSM; DuPont; Ferro; GE Plastics; LNP; M.A. Hanna Eng.; Polymer Resources; RTP; Ticona	Ticons

Materials			**Polyester, Thermoplastic** (Cont'd)						
			Polybutylene Terephthalate (Cont'd)						
	Properties	ASTM Test Method	40% Long Glass Fiber-reinforced	50% Long Glass Fiber-reinforced	60% Long Glass Fiber-reinforced	25% Random Glass Mat	35% Random Glass Mat	40-45% Glass Fiber- and Mineral-Reinforced	35% Glass Fiber-and Mica-reinforced
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C. T_m(crystalline)		235	235	235			220–228	220–224
	T_g (amorphous)								
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 470–540	I: 480–540	I: 490–530	C: 520–560	C: 520–560	I: 450–520	I: 480–510
	3. Molding pressure range, 10^3 p.s.i.		10–15	10–20	10–20	1.5–3	2–3	10–15	9–15
	4. Compression ratio		3.5–4.0	3–4	3–4			3–4	
	5. Mold (linear) shrinkage, in./in.	D955	0.001–0.008	0.001–0.007	0.001–0.006	0.0035–0.0045	0.003–0.004	0.003–0.010	0.003–0.012
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	22,900	24,000	20,000	12,000	15,000	12,000–14,800	11,400–13,800
	7. Elongation at break, %	D638[b]	1.4	1.3	1.0	2.8	2.1	2–5	2–3
	8. Tensile yield strength, p.s.i.	D638[b]				12,000	15,000		
	9. Compressive strength (rupture or yield), p.s.i.	D695	24,500	24,600	24,600		14,700	15,000	
	10. Flexural strength (rupture or yield), p.s.i.	D790	35,200	35,500	41,000	28,000	32,000	18,500–23,500	18,000–22,000
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	1900	1900	2100	980	1300	1350–1800	
	12. Compressive modulus, 10^3 p.s.i.	D695						1000	
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	1600	2200	2500	900	1200	1250–1600	1200–1600
	200° F.	D790							
	250° F.	D790							
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	6.6	8.5	8.0		13.0	0.7–2.0	0.7–1.8
	15. Hardness	Rockwell	D785						M75–86	M50–76
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696				29	20	1.7	
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	415	420	450	403	425	388–395	330–390
		66 p.s.i.	D648						408–426	410–416
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	1.72						
Physical	19. Specific gravity		D792	1.65	1.75	1.87	1.45	1.59	1.58–1.74	1.59–1.74
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570						0.04–0.07	0.04–0.11
		Saturation	D570							
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149					440	540–590	450–600
SUPPLIERS[a]				Ticona	Ticona	Ticona	Azdel	Azdel	Ashley Polymers; ComAlloy; DSM; GE Plastics; LNP; M.A. Hanna Eng.; Polymer Resources; RTP; Ticona	ComAlloy; GE Plastics; LNP; RTP; Ticona

Polyester, Thermoplastic (Cont'd)

	Polybutylene Terephthalate (Cont'd)					Polyester Alloy			PCT	
			Flame-retarded Grade							
	Impact-Modified	50% Glass Fiber-reinforced	7–15% Glass Fiber-reinforced	30% Glass Fiber-reinforced	EMI Shielding (conductive); 30% Carbon Fiber	Unfilled	7.0–30% Glass Fiber-reinforced	Unreinforced Flame Retardant	15% Glass Fiber-reinforced	30% Glass Fiber-reinforced
1a.										
1.	225	225	220–260	220–260	222					
2.	I: 482–527	I: 482–527	I: 490–560	I: 490–560	I: 430–550	I: 475–540	I: 475–540	I: 470–510	I: 565–590	I: 555–595
3.					5–20	5–17	5–17	5–17		
4.						3.0–4.0	3.0–4.0	3.0–4.0		
5.	20×10^{-3}	4×10^{-3}	0.005–0.01	0.002–0.006	0.001–0.004	0.016–0.018	0.003–0.014		0.001–0.004	0.001–0.004
6.		21,800	11,500–15,000	17,400–20,000	22,000–23,000	4900–6300	7200–12,000	5000	13,700	18,000–19,500
7.		2.5	4.0	2.0–3.0	1–3	150–300	4.5–45	50	2.0	1.9–2.3
8.	6530									
9.			17,000	18,000						
10.			18,000–23,500	30,000	29,000–34,000	7100–8700	14,400–19,000	8500	23,900	24,000–29,800
11.	276	2470	800	1490; 1700	3500					
12.										
13.			580–830	1300–1500	2300–2700	210–280	395–925	260	812	1200–1450

14.	3.3	1.4	0.6–1.1	1.3–1.6	1.2–1.5	NB	2.8–4.1	NB	0.76	1.3–1.8
15.			M79–88	M88; M90	R120	R101–R109; > R115	R104–R111; > R115	R105	M88	> R115
16.	135	25	5	1.5		20	18			20
17.	122	419	300–450	400–450	420–430	105–125	170–374	130	475	500
	248	428	400–490	425–490		180–260	379–417	240	518	> 500
18.					15.8	6.9	8.3			6.9
19.	1.20	1.73	1.48–1.53	1.63	1.41–1.42	1.23–1.25	1.30–1.47	1.31	1.33	1.45
20.			0.06	0.06–0.07	0.04–0.45	0.1	0.11	0.10		0.04–0.05
	0.3	0.3								
21.			460	490		460	435		462	440–460
	Ashley Polymers; BASF; M.A. Hanna Eng.	Ashley Polymers; BASF	Albis; Ashley Polymers; ComAlloy; DSM; DuPont; GE Plastics; LNP; M.A. Hanna Eng.; M.A. Polymers; Polymer Resources; RTP; Ticona	Albis; Ashley Polymers; BASF; ComAlloy; DSM; DuPont; Ferro; LNP; M.A. Hanna Eng.; M.A. Polymers; Polymer Resources; RTP; Ticona	ComAlloy; DSM; LNP; RTP	Eastman; GE Plastics; Ticona	Albis; GE Plastics; Ticona	Ticona	Eastman	Eastman; GE Plastics

			Polyester, Thermoplastic (Cont'd)						
			PCT (Cont'd)						PCTA
Materials	Properties	ASTM Test Method	40% Glass Fiber-reinforced	27–30% Glass Fiber- and Mineral-reinforced	40% Glass Fiber- and Mineral-reinforced	20% Glass, Flame Retarded	30% Glass, Flame Retarded	40% Glass, Flame Retarded	15% Glass Fiber-reinforced
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C.								
	T_m(crystalline)								285
	T_g (amorphous)								92
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 565–590	I: 565–590	I: 565–590	I: 565–590	I: 565–590	I: 565–590	I: 580–590
	3. Molding pressure range, 10^3 p.s.i.								8–16
	4. Compression ratio								2.5–3.5
Mechanical	5. Mold (linear) shrinkage, in./in.	D955	0.0005–0.003	0.002–0.005	0.002–0.005	0.001–0.004	0.002–0.004	0.001–0.003	0.004–0.006
	6. Tensile strength at break, p.s.i.	D638[b]	22,000	17,500	17,000	15,400	19,000	20,600	11,600
	7. Elongation at break, %	D638[b]	2.1	2.4	1.18	1.4–2.0	1.7	1.4	3.4
	8. Tensile yield strength, p.s.i.	D638[b]							
	9. Compressive strength (rupture or yield), p.s.i.	D695							
	10. Flexural strength (rupture or yield), p.s.i.	D790	33,000	26,700	27,400	24,000	29,000	32,000	18,900
	11. Tensile modulus, 10^3 p.s.i.	D638[b]							
	12. Compressive modulus, 10^3 p.s.i.	D695							
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	1690	1180	1550	1080	1450	1910	560
	200° F.	D790							
	250° F.	D790							
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch (1/8-in. thick specimen)		D256A	1.5	1.0	1.0	0.9	1.0	1.4	1.8
	15. Hardness	Rockwell	D785	M88	M96	R119	M96	R122	M94	R119
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696							
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	491	482	500	442	477	489	284
		66 p.s.i.	D648	518	523	527	514	527	518	495
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2}-°C.		C177							
Physical	19. Specific gravity		D792	1.53	1.43	1.55	1.54	1.62	1.70	1.31
	20. Water absorption (1/8-in. thick specimen), %	24 hr.	D570							
		Saturation	D570							
	21. Dielectric strength (1/8-in. thick specimen), short time, v./mil		D149	420	452	462	444	430	440	
SUPPLIERS[a]				Eastman	Eastman	Eastman	Eastman	Eastman	Eastman	Eastman

	Polyester, Thermoplastic (Cont'd)										
	PCTA (Cont'd)			Polyethylene Terephthalate							
	20% Glass Fiber-reinforced	30% Glass Fiber-reinforced	Unfilled	Unfilled	15% Glass Fiber-reinforced	30% Glass Fiber-reinforced	40–45% Glass Fiber-reinforced	35% Glass, Super Toughened	15% Glass, Easy Processing	30% Glass, Flame Retarded, V-0 1/32	15% Glass Flame Retarded, V-0 1/32
1a.											
1.	285	285	285	212–265		245–265	252–255	245–255	245–255	245–255	245–255
	92	92	92	68–80							
2.	I: 560–590	I: 560–590	I: 299–316 E: 299–302	I: 440–660 E: 520–580	I: 540–570	510–590	I: 500–590	I: 525–555	I: 525–555	I: 525–555	I: 525–555
3.	8–16	8–16		2–7		4–20	8–12	8–18	8–18	8–18	8–18
4.	2.5–3.5	2.5–3.5		3.1	2–3	2–3	4	3: 1	3: 1	3: 1	3: 1
5.	0.004–0.006	0.003–0.005	0.004	0.002–0.030	0.001–0.004	0.002–0.009	0.002–0.009	0.002–0.009	0.003–0.010	0.002–0.009	0.003–0.010
6.	12,600	14,100		7000–10,500	14,600	20,000–24,000	14,000–27,500	15,000	11,500	22,000	15,500
7.	3.3	3.1	25–250	30–300	2.0	2–7	1.5–3	6.0	6.0	2.3	2.6
8.			5900–9000	8600		23,000					
9.				11,000–15,000		25,000	20,500–24,000	11,700	13,500	25,000	25,000
10.	20,600	22,700		12,000–18,000	20,000	30,000–36,000	21,000–42,400	21,000	13,500	32,000	23,000
11.				400–600		1300–1440	1800–1950				
12.											
13.	690	980	240–285	350–450	830	1200–1590	1400–2190	1000	525	1500	850
						520	489	360	185	620	350
						390	320	275	155	420	220

14.	2.2	2.8	1.5–NB	0.25–0.7	1.9	1.5–2.2	0.9–2.4	4.4	2.2	1.6	1.2
15.	R118	R113	105–122	M94–101; R111	R121	M90; M100	R118; R119	M62; R107	M58, R111	M100, R120	M88, R120
16.			5.8×10^{-5}	65×10^{-6}		18–30	18–21	1.5	1.0	1.1	1.0
17.	381	430	69–95	70–150	400	410–440	412–448	428	405	435	410
	507	514	83–142	167	464	470–480	420–480	475	454	475	471
18.			5×10^{-4} or 5	3.3–3.6		6.0–7.6	10.0				
19.	1.33	1.41	1.195–1.215	1.29–1.40	1.33	1.55–1.70	1.58–1.74	1.51	1.39	1.67	1.53
20.				0.1–0.2		0.05	0.04–0.05	0.25	0.24	0.05	0.07
				0.2–0.3							
21.			422–441	420–550	475	405–650	415–600	530	450	430	490
	Eastman	Eastman	Eastman	DuPont; Eastman; M.A. Polymers; A. Schulman; Ticona; Wellman	Eastman	Albis; AlliedSignal; ComAlloy; DSM; DuPont; EMS; Eastman; Ferro; GE Plastics; M.A. Polymers; MRC; RTP; Ticona; Wellman	Albis; AlliedSignal; ComAlloy; DSM; DuPont; EMS; Eastman; Ferro; GE Plastics; RTP; Ticona	DuPont	DuPont	Albis; DuPont	DuPont

Polyester, Thermoplastic (Cont'd)

Polyethylene Terephthalate (Cont'd)

Materials	Properties		ASTM Test Method	15–20% Glass, Flame Retarded	30% Glass, Flame Retarded	40% Glass, Flame Retarded	35–45% Glass Fiber- and Mica-reinforced	30% Long Glass Fiber-reinforced	40% Long Glass Fiber-reinforced	50% Long Glass Fiber-reinforced
Processing	1a. Melt flow (gm./10 min.)		D1238							
	1. Melting temperature, °C.	T_m(crystalline)					252–255	275	275	275
		T_g (amorphous)								
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)			I: 540–560	I: 540–560	I: 540–560	I: 500–590	I: 470–530	480–540	I: 470–530
	3. Molding pressure range, 10^3 p.s.i.						5–20	10–20	10–20	10–20
	4. Compression ratio			2–3	2–3	2–3	4	3–4		3–4
	5. Mold (linear) shrinkage, in./in.		D955	0.0015–0.004	0.001–0.004	0.001–0.004	0.002–0.007	0.001–0.008	0.001–0.005	0.001–0.008
Mechanical	6. Tensile strength at break, p.s.i.		D638[b]	13,700–15,700	18,600	19,000	14,000–26,000	20,200	23,200	23,500
	7. Elongation at break, %		D638[b]	2.2	1.8	1.5	1.5–3	1.4	1.4	1.0
	8. Tensile yield strength, p.s.i.		D638[b]							
	9. Compressive strength (rupture or yield), p.s.i.		D695				20,500–24,000	31,000	34,200	35,100
	10. Flexural strength (rupture or yield), p.s.i.		D790	20,000–23,200	27,500	29,300	21,000–40,000	29,300	35,400	36,500
	11. Tensile modulus, 10^3 p.s.i.		D638[b]				1800–1950	1700	2100	2400
	12. Compressive modulus, 10^3 p.s.i.		D695							
	13. Flexural modulus, 10^3 p.s.i.	73° F.	D790	850–1090	1540	2020	1400–2000	1500	1900	2100
		200° F.	D790				489			
		250° F.	D790							
		300° F.	D790				320			

	14. Izod impact, ft.-lb./in. of notch (1/8-in. thick specimen)		D256A	1–1.2	1.4	1.6	0.9–2.4	4.0	5.0	6.2
	15. Hardness	Rockwell	D785	M83	M84	M79	R118; R119			
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696				18–21			
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	383–409	425	429	396–440	470	475	480
		66 p.s.i.	D648	455–462	459	466	420–480			
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177				10.0			
Physical	19. Specific gravity		D792	1.60–1.63	1.71	1.78	1.58–1.74	1.61	1.70	1.85
	20. Water absorption (1/8-in. thick specimen), %	24 hr.	D570				0.04–0.05			
		Saturation	D570							
	21. Dielectric strength (1/8-in. thick specimen), short time, v./mil		D149	437–460	427	399	550–687			
			SUPPLIERS[a]	Eastman	Eastman	Eastman	Albis; AlliedSignal; Bayer Corp.; ComAlloy; DSM; DuPont; M.A. Polymers; MRC; RTP; Ticona; Wellman	Ticona	Ticona	Ticona

Polyester, Thermoplastic (Cont'd)												
	Polyethylene Terephthalate (Cont'd)					PETG	PCTG	Polyester/Polycarbonate Blends			Wholly Aromatic (Liquid Crystal)	
	60% Long Glass Fiber-reinforced	EMI Shielding (Conductive); 30% PAN Carbon Fiber	Recycled Content, 30% Glass Fiber	Recycled Content, 45% Glass Fiber	Recycled Content, 35% Glass/ Mineral-reinforced	Unfilled	Unfilled	High-impact	30% Glass Fiber-reinforced	Flame Retarded	Unfilled Medium Melting Point	Unfilled High Melting Point
1a.												
1.	270–280										280–421	400
						81–91						
2.	I: 500–530	I: 550–590	I: 530–550	I: 530–550	I: 530–550	I: 480–520 E: 490–550	I: 530–560	I: 460–630	470–560	I: 480–550	I: 540–770	I: 700–850
3.	10–20					1–20	1–20	8–18	10–18	10–20	1–16	5–18
4.	3–4		2–3	2–3	2–3	2.4–3	2.4–3				2.5–4	2.5–3
5.	0.001–0.007	0.001–0.002				0.002–0.005	0.002–0.005	0.005–0.019	0.003–0.009	0.005–0.007	0.001–0.008	0–0.002
6.	23,500	25,000	24,000	28,500	14,000–15,000	4100	7600	4500–9000	12,000–13,300	8900	15,900–27,000	12,500
7.	0.9	1.4	2.0	2.0	2.1–2.2	110	330	100–175		130	1.3–4.5	2
8.						7300	6500	5000–8100		7400		
9.	35,100							8600–10,000	10,860–11,600		6200–19,000	10,000
10.	40,100	38,000	35,500	45,000	21,500–22,000	10,200	9600	8500–12,500	20,000	14,100	19,000–35,500	19,000
11.	3000	3600						240–325			1400–2800	1750
12.											400–900	309
13.	2600	2700	1400	2100	1400	300	260	310	780–850	380,000	1770–2700^{a}	1860
											1500–1700^{a}	
											1300–1500^{a}	450F; 870
											1200–1450^{a}	575F; 450

14.	8.0	1.5	1.5	2.0	1.1	1.9	NB	12–19–No break	3.1–3.2	1.3	1.7–10	1.2
15.						R106	R105	R112–116	R109–110	R122	M76; R60–66	R97
16.								58–150	25	0.64	5–7	8.9
17.	480	430	435	445	395–420	147	149	140–250	300–330	212	356–671	606
		470				158	165	210–265	400–415	239		
18.								5.2			2	
19.	1.91	1.42	1.58	1.70	1.60	1.27	1.23	1.20–1.26	1.44–1.51	1.3	1.35–1.84	1.79
20.		0.05				0.13	0.13	0.13–0.80	0.09–0.10	0.07	0 < 0.1	0
								0.30–0.62		0.22	< 0.1	0.02
21.			565	540	450–550			396–500		660	600–980	470
	Ticona	ComAlloy; DSM; Ferro; RTP	Ticona; Wellman	Ticona	Ticona; Wellman	Eastman	Eastman	Bayer Corp.; ComAlloy; Eastman; GE Plastics; M.A. Polymers; MRC	ComAlloy; Ferro; GE Plastics; M.A. Polymers; MRC; RTP	Bayer Corp.	Amoco Polymers; Ticona	Amoco Polymers

	Properties	ASTM Test Method	Polyester, Thermoplastic (Cont'd)						
			Wholly Aromatic (Liquid Crystal) (Cont'd)						
Materials			30% Carbon Fiber-reinforced	40% Glass Fiber-filled	40% Glass Plus 10% Mineral-filled	30-50% Mineral-filled	30% Glass Fiber-reinforced	30% Glass-reinforced, High HDT	Unfilled Platable Grade
Processing	1a. Melt flow (gm./10 min.)	D1238							
	1. Melting temperature, °C.		280			327	280	355	
	T_m(crystalline)								
	T_g (amorphous)								
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		555–600	I: 660–770	I: 660–770	I: 605–770	I: 555–770	I: 625–730	I: 600–620
	3. Molding pressure range, 10^3 p.s.i.		1–14	5–14	5–14	1–14	1–14	4–8	
	4. Compression ratio		2.5–4	2.5–3	2.5–3	2.5–4	2.5–4	2.5–4	3–4
	5. Mold (linear) shrinkage, in./in.	D955	0–0.002			0.003	0.001–0.09		
Mechanical	6. Tensile strength at break, p.s.i.	D638^b	35,000	13,600	14,200	10,400–16,500	16,900–30,000	18,000–21,000	13,500
	7. Elongation at break, %	D638^b	1.0	1.8	2.3	1.1–4.0	1.7–2.7	1.7–2.2	2.9
	8. Tensile yield strength, p.s.i.	D638^b							
	9. Compressive strength (rupture or yield), p.s.i.	D695	34,500	10,400	9700	6900–7500	9900–21,000	9800–12,500	
	10. Flexural strength (rupture or yield), p.s.i.	D790	46,000	20,500	19,700	14,200–23,500	21,700–24,600	24,000–26,000	
	11. Tensile modulus, 10^3 p.s.i.	D638^b	5400	1870	1870	1500–2700	700–3000	2330–2600	1500
	12. Compressive modulus, 10^3 p.s.i.	D695	4800	420	473	490–2016	470–1000	447–700	
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	4600	1320	1730	1250–2500	1680–2100	1800–2050	1500
	200° F.	D790							
	250° F.	D790					900	1100	
	300° F.	D790					800	1100	

	14. Izod impact, ft.-lb./in. of notch (1/8-in. thick specimen)		D256A	1.4	1.6	1.9	0.8–3.0	2.0–3.0	2.0–2.5	0.6
	15. Hardness	Rockwell	D785	M99	79		82	61–87	63	
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	-2.65	14.9	12.9–52.8	9–65	4.9–77.7	14–36	
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	440	606	493	429–554	485–655	518–568	410
		66 p.s.i.	D648					489–530		
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177			2.5	2.57	1.73	1.52	
Physical	19. Specific gravity		D792	1.49	1.70	1.78	1.63–1.89	1.60–1.67	1.6–1.66	
	20. Water absorption (1/8-in. thick specimen), %	24 hr.	D570	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.03
		Saturation	D570							
	21. Dielectric strength (1/8-in. thick specimen), short time, v./mil		D149		510	1145	900–955	640–900	900–1050	600
	SUPPLIERS^a			RTP; Ticona	Amoco Polymers; RTP	Amoco Polymers; RTP	Amoco Polymers; DuPont; RTP; Ticona	Amoco Polymers; DuPont; Eastman; RTP; Ticona	Amoco Polymers; DuPont; RTP; Ticona	Ticona

			Polyester, Thermoset and Alkyd							
	Cast		Glass Fiber-reinforced							
	Rigid	Flexible	High	Unidirectional Glass	Preformed, Chopped Roving	Premix, Chopped Glass	Woven Cloth	SMC	SMC, BMC Low-density	SMC Low-pressure
1a.										
1.										
	Thermoset	Thermoset			Thermoset	Thermoset	Thermoset		Thermoset	Thermoset
2.			C: 260–320	C: 260–320	C: 170–320	C: 280–350	C: 73–250	C: 270–380 I: 280–310 T: 280–310	C: 270–330 I: 270–350 T: 270–350	C: 270–330
3.			0.2–2.0	0.4–2.0	0.25–2	0.5–2	0.3	0.3–2	0.5–2	0.25–0.8
4.			1.0	1.0	1.0	1.0		1.0	1.0	1.0
5.			0.001	0.000	0.0002–0.002	0.001–0.012	0.0002–0.002	0.0005–0.004	0.0002–0.001	0.0002–0.001
6.	600–13,000	500–3000	50,000	90,000	15,000–30,000	3000–10,000	30,000–50,000	7000–25,000	4000–20,000	7000–25,000
7.	< 2.6	40–310	1–2	1–2	1–5	< 1	1–2	3	2–5	3
8.										
9.	13,000–30,000		42,000		15,000–30,000	20,000–30,000	25,000–50,000	15,000–30,000	15,000–30,000	15,000–30,000
10.	8500–23,000		90,000	160,000	10,000–40,000	7000–20,000	40,000–80,000	10,000–36,000	10,000–35,000	10,000–36,000
11.	300–640		3500		800–2000	1000–2500	1500–4500	1400–2500	1400–2500	1400–2500
12.			2700							
13.	490–610		3000	6000	1000–3000	1000–2000	1000–3000	1000–2200	1000–2500	1000–22,000
							660			
							430			
							270			

14.	0.2–0.4	> 7	35	70	2–20	1.5–16	5–30	7–22	2.5–18	7–24
15.										
	Barcol 35–75	Shore D64–94	60		Barcol 50–80	Barcol 50–80	Barcol 60–80	Barcol 50–70		Barcol 40–70
16.	55–100		15.5	6	20–50	20–33	15–30	13.5–20	6–30	6–30
17.	140–400		> 500	> 500	> 400	> 400	> 400	375–500	> 375	375–500
18.										
19.	1.04–1.46	1.01–1.20	1.9	1.95	1.35–2.30	1.65–2.30	1.50–2.10	1.65–2.6	1.0–1.5	1.65–2.30
20.	0.15–0.6	0.5–2.5	0.08	0.10	0.01–1.0	0.06–0.28	0.05–05	0.1–0.25	0.4–0.25	0.1–0.25
21.	380–500	250–400	310		350–500	345–420	350–500	380–500	300–400	380–500
	AOC; Aristech Chem; ICI Americas; Interplastic; Reichhold	AOC; Aristech Chem.; ICI Americas; Interplastic; Reichhold	Quantum Composites	Quantum Composites	Glastic; Haysite; Jet Moulding; Premix; Reichhold; Rostone	Bulk Molding Compounds; Cytec Fiberite; Glastic; Haysite; Jet Moulding; Premix; Reichhold; Rostone	Glastic; Haysite; Jet Moulding; Premix; Reichhold; Rostone	Budd; Haysite; Interplastic; Jet Moulding; Plastics Mfg.; Polyply; Premix; Rostone	Cytec Fiberite; Interplastic; Jet Moulding; Rostone	Interplastic; Jet Moulding; Rostone

Polyester, Thermoset and Alkyd (Cont'd)

Materials		Properties	ASTM Test Method	Glass Fiber-reinforced (Cont'd)		EMI Shielding (Conductive)		High-strength SMC	Alkyd Molding Compounds	
				SMC Low-shrink	BMC, TMC	SMC, TMC	BMC	Granular 50% Glass Fiber-reinforced	and Putty, Mineral-filled	Glass Fiber-reinforced
Processing	1a.	Melt flow (gm./10 min.)	D1238							
	1.	Melting temperature. °C.								
		T_m(crystalline)		Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset
		T_g(amorphous)								
	2.	Processing temperature range, °F. (C 5 compression; T 5 transfer; I 5 injection; E 5 extrusion)		C: 270–330 I: 270–380	C: 280–380 I: 280–370 T: 280–320	C: 270–380 I: 270–370 T: 280–320	C: 310–380 I: 300–370 T: 280–320	C: 270–330	C: 270–350 I: 280–390 T: 320–360	C: 290–350 I: 280–380
	3.	Molding pressure range, 10^3p.s.i.		0.5–2	0.4–1.1	0.5–2		0.5–2	2–20	2–25
	4.	Compression ratio		1.0	1.0	1.0		1.0	1.8–2.5	1–11
	5.	Mold (linear) shrinkage, in./in.	D955	0.0002–0.001	0.0003–0.007	0.0002–0.001	0.0005–0.004	0.002–0.003	0.003–0.010	0.001–0.010
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	4500–20,000	3000–13,000	7000–8000	4000–4500		3000–9000	4000–9500
	7.	Elongation at break, %	D638[b]	3–5	1–2			3–5		
	8.	Tensile yield strength, p.s.i.	D638[b]					27,000–30,000		
	9.	Compressive strength (rupture or yield), p.s.i.	D695	15,000–30,000	14,000–30,000	20,000–24,000	18,000		12,000–38,000	15,000–36,000
	10.	Flexural strength (rupture or yield), p.s.i.	D790	9000–35,000	11,000–33,000	18,000–20,000	12,000	45,000–50,000	6000–17,000	8500–26,000
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	1000–2500	1500–2500			1200–1600	500–3000	2000–2800
	12.	Compressive modulus, 10^3 p.s.i.	D695						2000–3000	
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	1000–2500	1500–1800	1400–1500	1400–1500	900–1400	2000	2000
		200° F.	D790							
		250° F.	D790							
		300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	2.5–15	2–18.5	10–12	5–7	22–28	0.3–0.5	0.5–16
	15. Hardness	Rockwell	D785						E98	E95
		Shore/Barcol	D2240/ D2583	Barcol 40–70	Barcol 50–65	Barcol 45–50	Barcol 50	50–60		
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	6–30	20			6–30	20–50	15–33
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	375–500	320–536	395–400+	400+	> 425	350–500	400–500
		66 p.s.i.	D648							
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2} °C.		C177		18–22				12–25	15–25
Physical	19. Specific gravity		D792	1.6–2.4	1.72–2.10	1.75–1.80	1.80–1.85	1.77–1.83	1.6–2.3	2.0–2.3
	20. Water absorption (1/8-in. thick specimen), %	24 hr.	D570	0.01–0.25	0.1–0.45			0.19–0.25	0.05–0.5	0.03–0.5
		Saturation	D570			0.5	0.5			
	21. Dielectric strength ($^1/_8$-in thick specimen), short time, v./mil		D149	380–450	300–390				350–450	259–530
			SUPPLIERS[a]	Budd; Haysite; Interplastic; Jet Moulding; Polyply; Premix; Rostone	BP Chemicals; Budd; Bulk Molding Compounds; Cytec Fiberite; Epic Resins; Glastic; Haysite; Jet Moulding; Plaslok; Polyply; Premix; Rostone	Jet Moulding; Premix; Rostone	Jet Moulding; Premix; Rostone	Jet Moulding	Cytec Fiberite; Plastics Eng.; Premix	Cosmic Plastics; Cytec Fiberite; Plastics Eng.; Premix; Rogers

	Polyester, Thermoset and Alkyd (Cont'd)	**Polyetherimide**			**Polyethersulfone**					**Polyethylene and Ethylene Copolymers**	
	Vinyl Ester BMC									Low and Medium Density	
	Glass Fiber-reinforced	Unfilled	30% Glass Fiber-reinforced	EMI Shielding (conductive); 30% Carbon Fiber	10% Glass fiber-reinforced	20–30% Glass Fiber-Reinforced	20% Mineral-filled	30% Carbon-filled	Polyether-sulfone Unreinforced	Branched Homopolymer	Linear Copolymer
1a.									12.5–30	0.25–27.0	
1.	Thermoset									98–115	122–124
		215–217	215	215						−25	
2.	C: 290–350 I: 290–350	I: 640–800	I: 620–800	I: 600–780	I: 680–715	I: 660–765	I: 662–716	I: 680–734		I: 300–450 E: 250–450	I: 350–500 E: 450–600
3.	0.5–2	10–20	10–20	10–30						5–15	5–15
4.	1.0	1.5–3	1.5–3	1.5–3						1.8–3.6	3
5.	0–2	0.005–0.007	0.001–0.004	0.0005–0.002	0.005–0.006	0.004–0.006	0.007–0.008		0.007	0.015–0.050	0.020–0.022
6.	9–12	14,000	23,200–28,500	29,000–34,000	16,500	20,000–22,000	7975	15,800	12,000	1200–4550	1900–4000
7.	1–2	60	2–5	1–3	4.3	2.1–2.8	5	1.4		100–650	100–965
8.		15,200	24,500							1300–2100	1400–2800
9.	23,000–28,000	21,900	23,500–30,700	32,000							
10.	20,000–31,000	22,000	33,000	37,000–45,000	24,500	26,500–28,500			16,100		
11.		430	1300–1600	2600–3300	740	1150–1550	522	1740	385	25–41	38–75
12.		480	550–938								
13.		480	1200–1300	2500–2600	650	980–1300			420	35–48	40–105
		370	1100								
		360	1060								
		350	1040								

14.	5–15	1.0–1.2	1.7–2.0	1.2–1.6	1.3	1.4–1.7	1.5		1.6	No break	1.0-No break
15.		M109–110	M114, M125, R123	M127	M94	M96–M97					
	45–65									Shore D44–50	Shore D55–56
16.	20	47–56	20–21		19	12–14	47	12	49	100–220	
17.	500+	387–392	408–420	405–420	414	419	399	433	400		
		405–410	412–415	410–425	419	430	414	440		104–112	
18.	15–25	1.6	6.0–9.3	17.6						8	
19.	1.7–1.9	1.27	1.49–1.51	1.39–1.42	1.45	1.53–1.60	1.52	1.53	1.37	0.917–0.932	0.918–0.940
20.	0.1–0.2	0.25	0.16–0.20	0.18–0.2					1.85	< 0.01	
		1.25	0.9		1.9	1.5–1.7	1.7				
21.	300–400	500	495–630						380	450–1000	
	Cytec Fiberite	GE Plastics	ComAlloy; DSM; Ferro; GE Plastics; LNP; Polymer Resources; RTP	ComAlloy; DSM; Ferro; LNP; RTP	Amoco Polymers; BASF; RTP	BASF; RTP	BASF; RTP	BASF; RTP	Amoco Polymers	American Polymers; Bamberger Polymers; Chevron; Dow Plastics; DuPont; Eastman; Equistar; Exxon; Huntsman; Mobil; Network Polymers; NOVA Chemicals; RSG Polymers; A. Schulman; Union Carbide; Wash. Penn; Westlake	Bamberger Polymers; Chevron; Dow Plastics; DuPont; Eastman; Equistar; Exxon Exxon Chemical Canada; Mobil; Montell NA; Network Polymers; NOVA Chemicals; RSG Polymers; A. Schulman; Solvay Polymers; Union Carbide

Polyethylene and Ehtylene Copolymers (Cont'd)

				Low and Medium Density (Cont'd)			High Density			
				LDPE Copolymers					Copolymers	
Materials		Properties	ASTM Test Method	Ethylene-vinyl Acetate	Ethylene-Ethyl Acrylate	Ethylene-methyl Acrylate	Polyethylene Homopolymer	Rubber-Modified	Low and Medium Molecular Weight	High Molecular Weight
Processing	1a.	Melt flow (gm./10 min.)	D1238	1.4–2.0			5–18			5.4–6.8
	1.	Melting temperature, °C.								
		T_m(crystalline)		103–110		83	130–137	122–127	125–132	125–135
		T_g(amorphous)								
	2.	Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion		C: 200–300 I: 350–430 E: 300–380	C: 200–300 I: 250–500	E: 200–620	I: 350–500 E: 350–525	E: 360–450	I: 375–500 E: 300–500	I: 375–500 E: 375–475
	3.	Molding pressure range, 10^3 p.s.i.		1–20	1–20		12–15		5–20	
	4.	Compression ratio					2		2	
	5.	Mold (linear) shrinkage, in./in.	D955	0.007–0.035	0.015–0.035		0.015–0.040		0.012–0.040	0.015–0.040
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	2200–4000	1600–2100	1650	3200–4500	2300–2900	3000–6500	2500–4300
	7.	Elongation at break, %	D638[b]	200–750	700–750	740	10–1200	600–700	10–1300	170–800
	8.	Tensile yield strength, p.s.i.	D638[b]	1200–6000		1650	3800–4800	1400–2600	2600–4200	2800–3900
	9.	Compressive strength (rupture or yield), p.s.i.	D695		3000–3600		2700–3600		2700–3600	
	10.	Flexural strength (rupture or yield), p.s.i.	D790							
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	7–29	4–7.5	12	155–158		90–130	136
	12.	Compressive modulus, 10^3 p.s.i.	D695							
	13.	Flexural modulus, 10^3 p.s.i 73° F.	D790	7.7			145–225		120–180	125–175
		200° F.	D790							
		250° F.	D790							
		300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	No break	No break		0.4–4.0		0.35–6.0	3.2–4.5
	15. Hardness	Rockwell	D785							
		Shore/Barcol	D2240/ D2583	Shore D17–45	Shore D27–38		Shore D66–73	Shore D55–60	Shore D58–70	Shore D63–65
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	160–200	160–250		59–110		70–110	70–110
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648							
		66 p.s.i.	D648				175–196		149–176	154–158
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2}-°C.		C177				11–12		10	
Physical	19. Specific gravity		D792	0.922–0.943	0.93	0.942–0.945	0.952–0.965	0.932–0.939	0.939–0.960	0.947–0.955
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.005–0.13	0.04	0.0	<0.01	<0.01		
		Saturation	D570							
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	620–760	450–550		450–500		450–500	
			SUPPLIERS[a]	AT Plastics; Chevron; DuPont; Equistar; Exxon; Federal Plastics; Huntsman; Mobil; Network Polymers; A. Schulman; Union Carbide; Westlake	Network Polymers; Union Carbide	Chevron Exxon; Network Polymers; A. Schulman	American Polymers; Bamberger Polymers; Chevron; Dow Plastics; Eastman; Equistar; Exxon; Exxon Chemical Canada; Federal Plastics; Fina; M.A. Polymers; Mobil; Network Polymers; NOVA Chemicals; Phillips; RSG Polymers; A. Schulman; Shuman; Solvay Polymers; Ticona; Union Carbide	Exxon; M.A. Polymers; Network Polymers	AlphaGary; American Polymers; Bamberger Polymers; Chevron; Dow Plastics; Eastman; Equistar; Exxon; Exxon Chemical Canada; Fina; Mobil; Network Polymers; NOVA Chemicals; Phillips; RSG Polymers; A. Schulman; Shuman; Ticona; Union Carbide	AlphaGary; Amoco Chemical; Bamberger Polymers; BASF; Chevron; Dow Plastics; Equistar; Exxon; Fina; Mobil; Network Polymers; NOVA Chemicals; Phillips; Solva Polymers; Ticona; Union Carbide

	Polyethylene and Ethylene Copolymers (Cont'd)				**Polyimide**					
	High Density (Cont'd)		Crosslinked		Thermolplastic					
	Ultra High Molecular Weight	30% Glass Fiber-reinforced	Moding Grade	Wire and Cable Grade	Unfilled	30% Glass Fiber-reinforced	30% Carbon Fiber-reinforced	30% carbon Fiber Reinforced, Crystallized	15% Graphite-filled	40% Graphite-filled
1a.					4.5–7.5					
1.	125–138	120–140			388	388	388		388	
					250–365	250	250		250	365
2.	C: 400–500	I: 350–600	C: 240–450 I: 250–300	E: 250–400	C: 625–690 I: 734–740 E: 734–740	I: 734–788	I: 734–788	I: 734–788	I: 734–788	C: 690
3.	1–2	10–20			3–20	10–30	10–30	10–30	10–30	3–5
4.					1.7–4	1.7–2.3	1.7–2.3	1.7–2.3	1.7–2.3	
5.	0.040	0.002–0.006	0.007–0.090	0.020–0.050	0.0083	0.0044	0.0021		0.006	
6.	5600–7000	7500–9000	1600–4600	1500–3100	10,500–17,100	24,000	33,400	31,700	8000–8400	7600
7.	350–525	1.5–2.5	10–440	180–600	7.5–90	3	2	1	3.5	3
8.	3100–4000			1200–2000	12,500–13,000					
9.		6000–7000	2000–5500		17,500–40,000	27,500	30,200		25,000	
10.		11,000–12,000	2000–6500		10,000–28,800	35,200	46,700	43,600	11,000–14,100	18,000
11.		700–900	50–500		300–400	1720	3000			14,000
12.			50–150		315–350	458	573		330	
13.	130–140	700–800	70–350	8–14	360–500	1390	2780	3210	460–500	
										700
					210	1175	2450		260	

14.	No break	1.1–1.5	1–20		1.5–1.7	2.2	2.0	2.4	1.1	0.7
15.	R50	R75–90			E52–99, R129, M95	R128, M104	R128, M105			E27
	Shore D61–63		Shore D55–80	Shore D30–65						
16.	130–200	48	100	100	45–56	17–53	6–47		41	38
17.	110–120	250	105–145	100–173	460–680	469	478	> 572	680	680
	155–180	260–265	130–225							
18.		8.6–11			2.3–4.2	8.9	11.7			41.4
19.	0.94	1.18–1.28	0.95–1.45	0.91–1.40	1.33–1.43	1.56	1.43	1.47	1.41	1.65
20.	< 0.01	0.02–0.06	0.01–0.06	0.01–0.06	0.24–0.34	0.23	0.23		0.19	0.14
					1.2					0.6
21.	710	500–550	230–550	620–760	415–560	528			250	
	Montell NA; Network Polymers; Ticona	ComAlloy; DSM; Ferro; LNP; M.A. Polymers; RTP; A. Schulman; Thermofil	Equistar; Mobil; Phillips; A. Schulman	AlphaGary; At Plastics; Equistar; A. Schulman; Union Carbide	Ciba Specialty Chemicals; DuPont; Mitsui Chemicals America; Solutia	Mitsui Chemicals America; RTP	Mitsui Chemicals America; RTP	Mitsui Chemicals America; RTP	DuPont; Mitsui Chemicals America	DuPont

Materials				Polyimide (Cont'd)	Polyketone			Polymethylpentene		Polyphenylene Oxide,
				Thermoset						Alloy with Polystyrene
		Properties	ASTM Test Method	Unfilled	Unfilled	30% Carbon	Polyketone	Unfilled	Filled	Low Glass Transition
Processing	1a.	Melt flow (gm./10 min.)	D 1238				6.0	26	30	
	1.	Melting temperature, °C.								
		T_m(crystalline)		Thermoset			428°F	230–240	240	
		T_g(amorphous)								100–112
	2.	Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		460–485	715–806	715–805	I: 480–510	I: 510–610 E: 510–650	I: 510–610	I: 400–600 E: 420–500
	3.	Molding pressure range, 10^3 p.s.i.		7–29				1–10	1–10	12–20
	4.	Compression ratio		1–1.2	gp screw	gp screw	2.5–3.0:1	2.0–3.5	2.0–3.5	1.3–3
	5.	Mold (linear) shrinkage, in./in.	D955	0.001–0.01	0.008–0.012	0.002–0.008	0.028	0.016–0.021	0.014–0.017	0.005–0.008
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	4300–22,900	13,500	30,000	8000	2300–2500	2400	6800–7800
	7.	Elongation at break, %	D638[b]	1	50	1.5	7300	20–120	25	48–35
	8.	Tensile yield strength, p.s.i.	D638[b]	4300–22,900			8700	2200–3400	3400	6500–7800
	9.	Compressive strength (rupture or yield), p.s.i.	D695	19,300–32,900	17,200	33,800				12,000–16,400
	10.	Flexural strength (rupture or yield), p.s.i.	D790	6500–50,000	24,500	40,000	8000	6300–8300		8300–12,800
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	460–4650	520	2700	230	160–280		310–380
	12.	Compressive modulus, 10^3p.s.i.	D695	421				114–171		
	13.	Flexural modulus, 10^3 p.s.i. 73°F.	D790	422–3000	2000	10,000	230	70–190	270	325–400
		200°F	D790					36		260
		250°F.	D790					26		
		300°F.	D790	1030–2690				17		

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	0.65–15	1.6	1.5		2–3		3–6
	15. Hardness	Rockwell	D785	110M–120M			105	R35–85	90	R115–116
		Shore/Barcol	D2240/ D2583				75D			
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./ °C.		D696	15–50			1×10^{-4}	65		38–70
	17. Deflection temperature under flexural load. °F.	264 p.s.i.	D648	572– >575	323	634	221	120–130		176–215
		66 p.s.i.	D648		582	652	410	180–190	230	230
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2}-°C.		C177	5.5–12				4.0		3.8
Physical	19. Specific gravity		D792	1.41–1.9	1.30	1.45	1.25	0.833–0.835	1.08	1.04–1.10
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.45–1.25	0.10	0.20	0.40	0.01	0.11	0.06–0.1
		Saturation	D570				2.1			
	21. Dielectric Strength ($^1/_8$-in. thick speciman). short time, v./mil.		D149	480–508	355	Conductive	320	1096–1098		400–665
SUPPLIERS[a]				Ciba Specialty Chemicals	Amoco Polymers	Amoco Polymers	Shell	Mitsui Petrochemical	Mitsui Petrochemical	Ashley Polymers; GE Plastics; Polymer Resources; Shuman

	Polyphenylene Oxide, Modified (Cont'd)									**Polyphenylene Sulfide**	
	Alloy with Polystyrene (Cont'd)								Alloy with Nylon		
							EMI Shielding (Conductive)				
	High Glass Transition	Impact-modified	15% Glass Fiber-reinforced	20% Glass Fiber-reinforced	30% Glass Fiber-reinforced	Mineral-filled	30% Graphite Fiber	40% Aluminum Flake	Un-reinforced	Unfilled	10–20% Glass Fiber-reinforced
1a.											
1.										285–290	275–285
	117–190	135	100–125	100–125	100–125	110–135				88	
2.	I: 425–670 E: 460–525	I: 425–550	I: 400–630 E: 460–525	I: 400–630 E: 460–525	I: 400–630 E: 460–525	I: 540–590 E: 470–530	I: 500–600			I: 590–640	I: 600–675
3.	12–20	10–15	10–40	10–40	10–40	12–20	10–20	10–20		5–15	
4.	1.3–3					2–3				2–3	
5.	0.006–0.008	0.006	0.002–0.004	0.002–0.004	0.001–0.004	0.005–0.007	0.001	0.001	0.013–0.016	0.006–0.014	0.002–0.005
6.	9600	7000–8000	10,000–12,000	13,000–15,000	15,000–18,500		18,700	6500	8500	7000–12,500	7500–14,000
7.	60	35	5–8	8.0	2–5	25	2.5	3.0	60	1–6	1.0–1.5
8.	7000–9000				14,500	9500–11,000					
9.	16,400	10,000			17,900		20,000	6000		16,000	17,000–20,000
10.	9500–14,000	8200–11,000			20,000–23,000		24,000	9500	315	14,000–21,000	9500–20,000
11.	355–380	345–360			1000–1300		1150	750		480	850–1200
12.											
13.	330–400	325–345	450–500	760	1100–1150	425–500	1100	850	290–315	550–600	900–1200
	305				1000						
							35				

14.	5	6.8	1.1–1.3	1.5	1.7–2.3	3–4	1.3	0.6	3.8	< 0.5	0.7–1.2
15.	R118–120	L108, M93	R106–110	R115	R115–116	R121	R111	R110		R123–125	R121
16.	33–77				14–25		11	11		27–49	16–20 Trans. dir.: 15.36–45
17.	225–300	190–275	252–260	262–275	275–317	190–230	240	230	250	212–275	440–480
	279	205–245	273–280	280–290	285–320		265	250	350	390	500–520
18.	5.2				3.8–4.1					2.0–6.9	
19.	1.04–1.09	1.27–1.36			1.27–1.36	1.24–1.25	1.25	1.45	1.10	1.35	1.39–1.47
20.	0.06–0.12	0.1–0.07			0.06	0.07	0.04	0.03	0.3	0.01–0.07	0.05
								1.0			
21.	500–700	530			550–630	490				380–450	
	Creanova; GE Plastics; Polymer Resources	GE Plastics; Polymer Resources	Ashley Polymers; Polymer Resources	Ashley Polymers; Polymer Resources	Ashley Polymers; ComAlloy; Ferro; GE Plastics; LNP; Polymer Resources; RTP	ComAlloy; GE Plastics; Polymer Resources; RTP	ComAlloy; LNP; RTP	ComAlloy;	Ashley Polymers; GE Plastics	Phillips; Ticona	Akzo; LNP; RTP

Polyphenylene Sulfide (Cont'd)

Materials	Properties		ASTM Test Method	30% Glass Fiber-reinforced	40% Glass Fiber-reinforced	53% Glass/Mineral-reinforced, High Elong, and Impact	30% Glass Fiber, 15% PTFE	30% Long Glass Fiber-reinforced	40% Long Glass Fiber-reinforced	50% Long Glass Fiber, Reinforced
Processing	1a. Melt flow (gm./10 min.)		D1238		30–41	50	30			
	1. Melting temperature, °C.									
		T_m (crystalline)		275–285	275–290	354	275–290	310	299	315
		T_g (amorphous)		90	88–90					
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)			I: 590–640	I: 600–675	I: 590–620	640–660	580–620	590–620	I: 580–620
	3. Molding pressure range, 10^3p.s.i.			8–12	5–20	7–15		8–10	7–20	8–10
	4. Compression ratio			3	3	3–4		3	3–4	3
	5. Mold (linear) shrinkage, in./in.		D955	0.003–0.005	0.002–0.005	0.001–0.003	0.002–0.004	0.001–0.007	0.001–0.003	0.001–0.005
Mechanical	6. Tensile strength at break, p.s.i.		D638[b]	22,000	17.500–29,100	24,000	21,000	21,000	23,000	23,200
	7. Elongation at break, %		D638[b]	1.5	0.9–4	1.5	1.8	1.2	1.1	1.0
	8. Tensile yield strength, p.s.i.		D638[b]							
	9. Compressive strength (rupture or yield), p.s.i.		D695		21,000–31,200	30,000		32,400	32,000–34,000	34,200–35,000
	10. Flexural strength (rupture or yield), p.s.i.		D790	28,000	22,700–43,600	35,000	29,000	32,900	35,000–36,400	37,300–38,000
	11. Tensile modulus, 10^3 p.s.i.		D638[b]		1100–2100		1340	1800	2200	2600
	12. Compressive modulus, 10^3 p.s.i.		D695							
	13. Flexural modulus, 10^3 p.s.i.	73° F.	D790	1700	1700–2160	2300	1360	1700	2300	2400
		200° F.	D790							
		250° F.	D790		1000					
		300° F.	D790		730					

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.3	1.1–2.0	1.5	1.6	4.6	4.8–5.3	5.0–5.5
	15. Hardness	Rockwell	D785	M102.7-M103	R123, M100–104	100M	R116			
		Shore/Barcol	D2240/ D2583							
Thermal	16 Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696		Flow dir.: 12.1–22 Trans. dir.: 14.4–45	Flow: 19–32 Trans.: 32–80				
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	507	485–515	510	480	490	500	505
		66 p.s.i.	D648	534	536					
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177		6.9–10.7					
Physical	19. Specific gravity		D792	1.38–1.58	1.60–1.67	1.80	1.60	1.52–1.62	1.62	1.72
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	< 0.03	0.004–0.05	0.02	0.005			
		Saturation	D570							
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	10^8; 380	347–450	300				
			SUPPLIERS[a]	Ferro; GE Plastics; LNP; Phillips; RTP; Ticona	Albis; DSM; Ferro; GE Plastics; LNP; Phillips; RTP; Ticona	Ticona	Ferro; GE Plastics; LNP; RTP	RTP; Ticona	RTP; Ticona	RTP; Ticona

	Polyphenylene Sulfide (Cont'd)										**Poly-phthal-amide**
							EMI Shielding (Conductive)				
	60% Long Glass Fiber-reinforced	65% Mineral- and Glass-filled	50% Glass and Mineral-reinforced	55% Glass and Mineral-reinforced	60% Glass and Mineral-reinforced	Encapsu-lation Grades	60% Stainless Steel	30% Carbon Fiber	40% PAN Carbon Fiber	30% PAN Carbon Fiber, 15% PTFE	Extra-tough
1a.		20–35	97	85	63	287					
1.	315	285–290	275–285	275–285	275–285	275–285	299	275–285	275–285	275–285	310
		88	90								
2.	I: 580–620	I: 600–675	I: 600–675	I: 600–675	I: 600–675	I: 600–675	I: 590–620	I: 500–675	I: 600–675	I: 600–675	I: 610–660
3.	8–10	5–20	4–12				7–20	5–20			5–15
4.	3	3	3				3.0–4.0				2.5–3
5.	0.001–0.005	0.001–0.004	0.002–0.004	0.003–0.005	0.007	0.006–0.007	0.005–0.007	0.005–0.003	0.0005	0.0008	0.015–0.020
6.	22,500	13,000–23,1000	18,000–22,000	12,700	8100	9800	8400	20,000–27,000	26,000–29,000	25,500	11,000
7.	1.0	1.3; < 1.4	1.0–3.5	1.6	2.0	1.0		0.5–3	1.0–1.5	2.6	30
8.		11,000									10,500
9.	30,800	11,000–32,300						26,000	27,000		
10.	38,300	17,500–33,900	28,000–33,700	20,300	11,200	15,100	17,800	26,000–36,000	40,000	34,000	17,000
11.	3000							2500–3700	4400–4800	3600	350
12.											
13.	3000	1800–2400	2240–2400	1750	1441	1574	590	2450–3300	3900–4100	3000	368
		2000									
		1200									

14.	5.5	0.5–1.37	0.8–1.3	0.7	0.5	0.4	0.2	0.8–1.2	1.2–1.5	1.2	18
15.		R121, M102	R120	M66	M85	M98		R123	R123		120
16.		12.9–20 14.3	12.2–14.6		14.3–14.8	18.0–18.2		6–16	8		
17.	510	500–510	500–510	491	340	328	450	500–505	505	500	243
		534					> 505	505			
18.							8.6–17.9				
19.	1.84	1.78–2.03	1.78–1.8	1.82	1.90	1.86	1.37	1.42–1.47	1.46–1.49	1.47	1.15
20.		0.02–0.07	0.02–0.07	0.07	0.08	0.03		0.01–0.02	0.02	0.06	0.68
21.		280–450	280–343			338					
	Ticona	Ferro; LNP; Phillips; RTP; Ticona	Albis; LNP; RTP; Ticona	LNP; Phillips; RTP	Albis; LNP; Phillips; RTP	Phillips	Ticona	DSM; Ferro; LNP; RTP	DSM; Ferro; LNP; RTP	DSM; Ferro; LNP; RTP	Amoco Polymers

Materials		Properties	ASTM Test Method	**Polyphtalamide** (Cont'd)						
				45% Glass-reinforced	33% Glass-reinforced, V-0	40% Mineral-reinforced	40% Glass/ Mineral-reinforced, Heat-stabilized	50% Glass/ Mineral Reinforced, V0	51% Glass/ Mineral Reinforced	15% Glass-reinforced
Processing	1a.	Melt flow (gm./10 min.)	D1238							
	1.	Melting temperature, °C.								
		T_m (crystalline)		310	310	310	310	310	310	
		T_g (amorphous)								
	2.	Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 610–660	I: 610–660	I: 610–660	I: 620–650	I: 610–640	I: 610–640	I: 610–640
	3.	Molding pressure range, 10^3 p.s.i.		5–15	5–15	5–15				
	4.	Compression ratio		2.5–3	2.5–3	2.5–3				
	5.	Mold (linear) shrinkage, in./in.	D955	0.002–0.006	0.002–0.004	0.008–0.010	0.004	0.003–0.3		0.006–0.007
Mechanical	6.	Tensile strength at break, p.s.i.	D638^b	38,000–39,400	26,000–27,000	15,800–17,000	23,700	22,200	17,200	
	7.	Elongation at break, %	D638^b	2.0–2.6	1.3	1.6	2.2–2.5	1.3	1.9–2	2.0
	8.	Tensile yield strength, p.s.i.	D638^b				23,500	21,000	16,200	19,000
	9.	Compressive strength (rupture or yield), p.s.i.	D695	45,500		26,000	33,000			30,000
	10.	Flexural strength (rupture or yield), p.s.i.	D790	54,000–55,100	35,900–37,300	28,600–30,000	31,500–34,300	31,000	24,000–28,400	23,700
	11.	Tensile modulus, 10^3 p.s.i.	D638^b	2500	2000	1300	1600	2400	1530	
	12.	Compressive modulus, 10^3 p.s.i.	D695							
	13.	Flexural modulus, 10^3p.s.i. 73° F.	D790	2100–2160	1900–1930	1080–1300	1200–1410	2040	1300	1090
		200° F.	D790							
		250° F.	D790							
		300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in thcik specimen)		D256A	2.1–2.5	1.1–1.5	0.8	0.8–0.9	1.2	1.3	1.1
	15. Hardness	Rockwell	D785	125	125	125	125			127
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	8		19	2.9–4.6			3.5
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	527–549	511–523	316–361	478–527	490–505	482	531
		66 p.s.i.	D648							
	18. Thermal conductivity, 10^{-4} cal.-cm./ sec.-cm.^{2} -°C.		C177	2.6		2.6				
Physical	19. Specific gravity		D792	1.56–1.60	1.71	1.53–1.54	1.54	1.82	1.66–1.68	1.26
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.12	0.18	0.14	0.16	0.12		0.30
		Saturation	D570							
	21. Dielectric strength ($^1/_8$-in. thick speciman), short time, v./mil		D149	560	458	> 560	505	635		480
			SUPPLIERS^a	Amoco Polymers; LNP; RTP;	Amoco Polymers; RTP	Amoco Polymers; RTP	Amoco Polymers; RTP	Amoco Polymers	Amoco Polymers; RTP	RTP

	Polyphthalamide (Cont'd)				Polypropylene					
					Homopolymer					
	15% Glass-reinforced, V0	45% Glass-reinforced, V0	40% Glass/ Mineral Reinforced	40% Mineral-reinforced, Heat-stabilized	Unfilled	10–40% Talc-filled	10–40% Calcium Carbonate-filled	10–30% Glass Fiber-reinforced	10–50% Mica-filled	40% Glass Fiber-reinforced
1a.					0.4–100	0.1–30.0	0.1–30.0	1–20	4–10	1–20
1.	310	310		310	160–175	158–168	168	168	168	168
					−20					
2.	I: 610–640	I: 610–640	I: 610–650	I: 610–650	I: 375–550 E: 400–500	I: 350–550	I: 375–525	I: 425–475		I: 450–550
3.			5–15		10–20	10–20	8–20			10–25
4.			2.5–3		2.0–2.4					
5.	0.005	0.002	0.004–0.007		0.010–0.025	0.008–0.022	0.007–0.018	0.002–0.008	0.002–0.015	0.003–0.005
6.	18,600	28,100		16,500	4500–6000	3545–5000	3400–4500	6500–13,000		8400–15,000
7.	2.0		2.5	1.6	100–600	3–60	10–245	1.8–7	3–10	1.5–4
8.	18,400	29,500	23,500	17,000	4500–5400	3500–5000	3000–4600	7000–10,000	4700–6500	
9.			33,000	24,000	5500–8000	7500	3000–7200	6500–8400		8900–9800
10.	24,400–26,600	39,000–41,100	31500	28,000–29,800	6000–8000	7000–9200	5500–7000	7000–20,000		10,500–22,000
11.	1400			1300	165–225	450–575	375–500	700–1000		1100–1500
12.					150–300					
13.	1000–1700	2500–2600	1200	1150–1200	170–250	210–670	230–450	310–780	420–1150	950–1000
					50	400	320			
					35					

14.	0.6–0.8	1.24–1.7	0.9	0.7–0.9	0.4–1.4	0.4–1.4	0.5–1.0	1.0–2.2	0.50–0.85	1.4–2.0
15.			125	125	R80–102	R85–110	R78–99	R92–115	R82–100 066–78	R102–111
16.			2.9–4.6	3.8–4.1	81–100	42–80	28–50	21–62		27–32
17.	466–504	522–527	527	315–325	120–140	132–180	135–170	235–288		300–330
					225–250	210–290	200–270	290–320		330
18.					2.8	7.6	6.9	5.5–6.2		8.4–8.8
19.	1.58	1.78–1.79	1.54	1.54–1.57	0.900–0.910	0.97–1.27	0.97–1.25	0.97–1.14	0.99–1.35	1.22–1.23
20.	0.28	0.17	0.16	0.14	0.01–0.03	0.01–0.03	0.02–0.05	0.01–0.05	0.01–0.06	0.05–0.06
										0.09–0.10
21.			505	455	600	500	410–500			500–510
	Amoco Polymers; RTP	Amoco Polymers; RTP	Amoco Polymers; RTP	Amoco Polymers; RTP	American Polymers; Amoco Chemical; Aristech Chem.; Bamberger Polymers; ComAlloy; Dow Plastics; Epsilon; Equistar; Exxon; Federal Plastics; Ferro; Fina; Huntsman; M.A. Polymers; Montell NA; Network Polymers; Phillips; RSG Polymers; A. Schulman; Shuman; Solvay Polymers; Union Carbide; Wash Penn	Adell; Albis; Amoco; Bamberger Polymers; ComAlloy; DSM; Exxon; Federal Plastics; Ferro; M.A. Polymers; Montell NA; MRC; Network Polymers; Polfil; RSG Polymers; RTP; A. Schulman; Spartech Polycom; Thermofil; Wash Penn	Adell; Albis; Bamberger Polymers; ComAlloy; DSM; Federal Plastics; Ferro; M.A. Polymers; Montell NA; Network; Polymers; Polifil; RSG Polymers; RTP; A. Schulman; Spartech Polycorn; Thermofil; Wash, Penn	Adell; Albis; Amoco Polymers; Bamberger Polymers; ComAlloy; DSM; Federal Plastics; Ferro; LNP; M.A. Polymers; Montell NA; MRC; Network Polymers; Polifil; RSG Polymers; RTP; A. Schulman; Spartech Polycom; Thermofil; Wash Penn	Network Polymers; Polifil; RTP; A. Schulman; Spartech Polycom; Washington Penn	Adell; Albis; Amoco Polymers; ComAlloy; DSM; Ferro; LNP; M.A. Poliymers; Montell NA; MRC; Network; Polymers; Polifil; RTP; A. Schulman; Thermofil

			Polypropylene (Cont'd)					
			Homopolymer (Cont'd)					Copolymer
Materials	Properties	ASTM Test Method	20–30% Long Glass Fiber-reinforced	40% Long Glass Fiber-reinforced	30% Random Glass Mat	Impact-modified, 40% Mica-filled	EMI Shielding (Conductive); 30% PAN Carbon Fiber	Unfilled
Processing	1a. Melt flow (gm./10 min.)	D1238						0.6–100
	1. Melting temperature, °C.							
	T_m(crystalline)		168	163	168	168	168	150–175
	T_g (amorphous)							−20
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 360–440	I: 370–410	C: 420–440	I: 350–470	I: 360–470	I: 375–550 E: 400–500
	3. Molding pressure range, 10^3 p.s.i.			6–12	1–2			10–20
	4. Compression ratio			3–4				2–2.4
	5. Mold (linear) shrinkage, in./in.	D955	0.0025–0.004	0.001–0.003	0.002–0.003	0.007–0.008	0.001–0.003	0.010–0.025
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	7500–14,100	10,500–15,600	12,000	4500	6800	4000–5500
	7. Elongation at break, %	D638[b]	2.1–2.2	1.7	3	4	0.5	200–500
	8. Tensile yield strength, p.s.i.	D638[b]			12,000			3000–4300
	9. Compressive strength (rupture or yield), p.s.i.	D695	6500–14,400	10,400–15,900				3500–8000
	10. Flexural strength (rupture or yield), p.s.i.	D790	10,000–22,800	20,800–25,200	20,000	7000	9000	5000–7000
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	750–900	970–1120	670	700	1750	130–180
	12. Compressive modulus, 10^3 p.s.i.	D695						
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	550–800	920–1000	620	600	1650	130–200
	200° F.	D790						40
	250° F.	D790						30
	300° F.	D790						

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	3.5–7.8	8.0–10.04	12.2	0.7	1.1	1.1–14.0
	15. Hardness	Rockwell	D785	R105–117					R65–96
		Shore/Barcol	D2240/ D2583						Shore D70–73
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696			15			68–95
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	250–295	300	310	205	245	130–140
		66 p.s.i.	D648	305					185–220
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	2.35					3.5–4.0
Physical	19. Specific gravity		D792	1.04–1.17	1.21	1.1	1.23	1.04	0.890–0.905
	20. Water absorption ($^1/_6$-in. thick specimen), %	24 hr.	D570	0.05				0.12	0.03
		Saturation	D570						
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149						600
			SUPPLIERS[a]	DSM; LNP; Montell NA; RTP; Ticona	LNP; Montell NA; RTP; Ticona	Azdel	Albis; ComAlloy; DSM; Federal Plastics; Ferro; M.A. Polymers; Polifil; A. Schulman; Spartech Polycom	ComAlloy; DSM; LNP; RTP	American Polymers; Amoco Chemical; Aristech Chem.; Bamberger Polymers; ComAlloy; Dow Plastics; Epsilon; Equistar; Exxon; Federal Plastics; Ferro; Fina; Huntsman; M.A. Polymers; Montell NA; Network Polymers; NOVA Chemicals; Phillips; RSG Polymers; A. Schulman; Shuman; Solvay Polymers; Spartech Polycom; Union Carbide; Wash, Penn

	Polypropylene (Cont'd)			**Polystyrene and Styrene Copolymers**						
	Copolymer (Cont'd)			Polystyrene Homopolymers			Rubber-modified		Styrene Copolymers	
									Syrene-Acrylonitrile (SAN)	
	Unfilled, Impact-modified	10-20% Glass Fiber-reinforced	10-40% Talc-filled	High and Medium Flow	Heat-resistant	20% Long and Short Glass Fiber-reinforced	Flame-retarded, UL-V0	High-impact	Molding and Extrusion	Olefin Rubber modified
1a.		0.1–20	0.1–30					5.8	1.4	
1.	150–168	160–168								
	−20			74–105	100–110	115		9.3–105	100–200	−55/110
2.	I: 390–500 E: 400–500	I: 350–480	I: 350–470 E: 425–475	C: 300–400 I: 350–550 E: 350–500	C: 300–400 I: 350–500 E: 350–500	I: 400–550	I: 400–450 E: 375–425	I: 350–525 E: 375–500	C: 300–400 I: 360–550 E: 360–450	I: 480–530 E: 435–460
3.	10–20		15–20	5–20	5–20	10–20	6–15	10–20	5–20	1–2
4.	2–2.4		2–2.5	3	3–5		3	4	3	2.7–3.2
5.	0.010–0.025	0.003–0.01	0.009–0.017	0.004–0.007	0.004–0.007	0.001–0.003	0.003–0.006	0.004–0.007	0.003–0.005	0.005–0.007
6.	3500–5000	5000–8000	3000–3775	5200–7500	6440–8200	10,000–12,000	2650–4100	1900–6200	10,000–11,900	5100
7.	200–700	3.0–4.0	20–50	1.2–2.5	2.0–3.6	1.0–1.3	30–50	20–65	2–3	15–30
8.	1600–4000		2800–4100		6440–8150		3100–4400	2100–6000	9920–12,000	5000–6000
9.	3500–6000	5500–5600		12,000–13,000	13,000–14,000	16,000–17,000			14,000–15,000	
10.	4000–6000	7000–11,000	4500–5100	10,000–14,600	13,000–14,000	14,000–18,000	4500–7500	3300–10,000	11,000–19,000	7700–8900
11.	50–150			330–475	450–485	900–1200	240–300	160–370	475–560	300
12.				480–490	495–500				530–580	
13.	60–160	355–510	160–400	380–490	450–500	950–1100	280–330	160–390	500–610	280–300

14. 2.2–No break	0.95–2.7	0.6–4.0	0.35–0.45	0.4–0.45	0.9–2.5	1.9–3.3	0.95–7.0	0.4–0.63	13–15
15. R50–60	R100–103	R83–88	M60–75	M75–84	M80–95; R119	R38–65	R50–82; L–60	M80, R83, 75	R100–102
Shore D45–55									
16. 68–95			50–83	68–85	39.6–40	45	44.2	65–68	80
17. 115–135	260–280	100–165	169–202	194–217	200–220	180–205	170–205	203–220	197–200
167–192	305	195–260	155–204	200–224	220–230	176–181	165–200	220 – 224	
18. 3.5–4.0			3.0	3.0	5.9			3.0	
19. 0.880–0.905	0.98–1.04	0.97–1.24	1.04–1.05	1.04–1.05	1.20	1.15–1.17	1.03–1.06	1.06–1.08	1.02
20. 0.03	0.01	0.02	0.01–0.03	0.01	0.07–0.01	0.0	0.05–0.07	0.15–0.25	0.09
			0.01–0.03	0.01	0.3			0.5	
21. 500			500–575	500–525	425	550		425	420
American Polymers; Amoco Polymers; ComAlloy; Dow; Plastics; Epsilon Equistar; Exxon; Federal Plastics; Huntsman; LG Chemical; M.A. Polymers; Montell NA; Network. Polymers; Phillips; A. Schulman; Solvay Engineered Polymers; Solvay Polymers; Spartech Polycom; Wash, Penn	Adell; Albis; ComAlloy; DSM; Federal Plastics; Ferro; LG Chemical; LNP; M.A. Polymers; Montell NA; Polifil; RTP; A. Schulman; Solvay Engineered Polymers; Spartech Polycom; Thermofil; Wash, Penn	Adell; Albis; Bamberger Polymers; ComAlloy; DSM; Federal Plastics; Ferro; LG Chemical; M.A. Polymers; Montell NA; Polifil; RTP; A. Schulman; Solvay Engineered Polymers; Spartech Polycom; Wash, Penn	American Polymers; Bamberger Polymers; BASF; Chevron; Deltech Polymers; Dow Plastics; Federal Plastics; Fina; Huntsman; LG Chemical; Mobil; Network Polymers; RSG Polymers; A. Schulman	American Polymers; BASF; Chevron; Deltech Polymers; Dow Plastics; Federal Plastics; Fina; Huntsman; LG Chemical; Mobil; Network Polymers; A. Schulman	DSM; Ferro; LG Chemical; LNP; M.A. Polymers; Mobil; RTP	BASF; Dow Plastics; Huntsman; LG Chemical; Mobil Network Polymers; RTP; A Schulman	American Polymers; Bamberger Polymers; BASF; Bayer Corp.; Chevron; Dow Plastics; Federal Plastics; Fina; Huntsman; LG Chemical; Mobil; NOVA Chemicals; RSG Polymers; RTP; A. Schulman; Shuman	Albis; American Polymers; BASF; Bamberger Polymers; Bayer Corp.; Dow Plastics; Federal Plastics; Huntsman; LG Chemical; Network Polymers; RSG Polymers; A. Schulman	Dow Plastics; Huntsman; Network Polymers

Materials			**Polystyrene and Styrene Copolymers** (Cont'd)					
			Styrene Copolymers (Cont'd)					
			Styrene-Acrylonitrile (SAN) (Cont'd)		Acrylate-Styrene-Acrylonitrile (ASA)		Styrene-Maleic Anhydride (SMA)	
	Properties	ASTM Test Method	20% Glass Fiber-reinforced	Clear Styrene-Butadiene Copolymers (SBC)	ASA extrusion, Blow Molding, Injection Molding Grades	Clear Styrene-Butadiene Copolymers	Molding and Extrusion	Impact-modified
Processing	1a. Melt flow (gm./10 min.)	D1238		6–18		7–15		
	1. Melting temperature, °C. T_m (crystalline)							
	T_g (amorphous)		120			108	114	
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 400–550	I: 375–425 E: 375–427	E: 380–450 I: 400–470	I: 380–450 E: 380–440	I: 430–510 E: 400–500	I: 450–550 E: 425–525
	3. Molding pressure range, 10^3 p.s.i.		10–20		9–15		12–17	12–17
	4. Compression ratio				2.8–3.0			2.5–2.7
	5. Mold (linear) shrinkage, in./in.	D955	0.001–0.003	0.002–0.008	0.004–0.006	0.004–0.010	0.004–0.006	0.004–0.006
Mechanical	6. Tensile strength at break, p.s.i.	D638^b	15,500–18,000		4000–7500		8100	4500–5500
	7. Elongation at break, %	D638^b	1.2–1.8	20–180	25–40	20–180	1.8–30	10–35
	8. Tensile yield strength, p.s.i.	D638^b		1900–4500	5200–5600	1900–4400	5200–8100	4500–6400
	9. Compressive strength (rupture or yield), p.s.i.	D695	17,000–21,000					
	10. Flexural strength (rupture or yield), p.s.i.	D790	20,000–22,700	2700–6400	6000–8000	2700–6400	8000–14,200	7600–13,000
	11. Tensile modulus, 10^3 p.s.i.	D638^b	1200–1710				340–390	270–360
	12. Compressive modulus, 10^3 p.s.i.	D695						
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	1000–1280	150–240	220–341	153–215	320–470	280–490
	200° F.	D790						
	250° F.	D790						
	300° F.	D790						

	14. Izod impact. ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.0–3.0	0.3–1.5 NB	9–11	0.4–1.4 NB	0.4–2.0	2.5–6
	15. Hardness	Rockwell	D785	M89–100; R122		R85–90		R106–109	R75–109
		Shore/Barcol	D2240/ D2583		Shore D 60–65				
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	23.4–41.4	−65	59		80	47–88
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	210–230	140–170	185–190	143–170	−214–245	198–235
		66 p.s.i.	D648	220		200–210			
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	6.6					
Physical	19. Specific gravity		D792	1.22–1.40	1.00–1.01	1.05–1.06	1.01	1.05–1.08	1.05–1.09
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.1–0.2	0.08	0.2–0.3	0.08	0.1	0.1–0.5
		Saturation	D570	0.7					
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	500		490	300		415–480
	SUPPLIERS[a]			ComAlloy; DSM; Ferro; LG Chemical; LNP; Network Polymers; RTP; Thermofil	Phillips	BASF; Bayer Corp.; Diamond Polymers; GE Plastics; LG Chemical; Network Polymers	Network Polymers	Bayer Corp; DSM; NOVA Chemicals;	Bayer Corp.; NOVA Chemicals

	Polystyrene and Styrene Copolymers (Cont'd)						Polyurethane			
	Styrene Copolymers (Cont'd)						Thermoset		Thermoplastic	
	SMA (Cont'd)	High Heat-resistant Copolymers					Casting Resins			
	20% Glass Fiber-reinforced	Injection Molding	Impact-modified	20% Glass Fiber-reinforced	Styrene Methyl Methacrylate	EMI Shielding (Conductive); 20% PAN Carbon Fiber	Liquid	Unsaturated	Unreinforced Molding	30% Long Glass Fiber-reinforced
1a.			1.0–1.8							
1.							Thermoset	Thermoset	75–137	240
					100–105					
2.	I: 400–550	I: 450–550	I: 425–540 E: 400–500	I: 425–550	I: 375–475	I: 430–500	C: 43–250		I: 370–500 E: 370–510	I: 440–500
3.	10–20				5–20		0.1–5		6–15	10–20
4.					2.5–3.5				3	3
5.	0.002–0.003	0.005	0.003–0.006	0.003–0.004	0.002–0.006	0.0005–0.003	0.020		0.004–0.010	0.002–0.006
6.		7100–8100	4600–5800	10,000–14,000	8100–10,100	14,000	175–10,000	10,000–11,000	4500–9000	24,200
7.	2–3	1.7–1.9	10–20	1.4–3.5	2.1–5.0	1	100–1000	3–6	60–550	3.0
8.	8100–11,000								7,800–11,000	
9.		11,400–14,200					20,000			24,600–25,700
10.	16,300–17,000		8500–10,500	16,300–22,000	14,100–16,000	20,700	700–4500	19,000	10,200–15,000	35,300
11.	750–880	440–490	280–330	850–900	440–520	2000	10–100		190–300	1100
12.					440–480		10–100			
13.	720–800	450–490	320–370	800–1050	450–460	1900	10–100	610	4–310	1100

14.	2.1–2.7	0.4–0.6	1.5–4.0	2.1–2.6	0.3–0.4	0.7	25 to flexible	0.4	1.5–1.8-No break	6.2–7.5
15.	R73		R75–95		M80–85				R>100; M48	
							Shore A10-	Barcol 30–35	Shore 75A–70D	
							13, D90			
16.		65–67	67–79	20	40–72		100–200		0.5–0.8	
17.	229–245	226–249	230–260	231–247	205–210	220	Vanes over wide range	190–200	158–260	185
						230			115–275	
18.							5			
19.	1.21–1.22	1.07–1.10	1.05–1.08	1.20–1.22	1.08–1.13	1.14	1.03–1.5	1.05	1.12–1.24	1.43
20.	0.1	0.1	0.1	0.1	0.11–0.17	0.1	0.2–1.5	0.1–0.2	0.15–0.19	
									0.5–0.6	
21.							300–500		400	
	Bayer Corp.; DSM; NOVA Chemicals; RTP	NOVA Chemicals	Bayer Corp.; NOVA Chemicals	ComAlloy; DSM; LNP, M.A. Polymers; NOVA Chemicals; RTP	Network Polymerrs; NOVA Chemicals	DSM; LNP; RTP	Bayer Corp.; Cabot; Conap; Dow Plastics; Emerson & Cuming; ITW Devcon; Polyurethane Specialties; Union Carbide	Dow Plastics; Emerson& Cuming; Polyurethane Specialties	Bayer Corp.; BF Goodrich; Dow Plastics	RTP; Ticona

Materials			**Polyurethane** (Cont'd)		**Polyvinylidene Chloride Copolymers**			**Silicone**	
			Thermoplastic (Cont'd)			Barrier Film Resins		Casting Resins	Liquid Injection Molding
	Properties	ASTM Test Method	Long Glass-reinforced Molding Compound	EMI Shielding (Conductive); 30% PAN Carbon Fiber	Injection Molding	Un-plasticized	Plasticized	Flexible (Including RTV)	Liquid Silicone Rubber
Processing	1a. Melt flow (2m./10 min.)	D1238							
	1. Melting temperature, °C.								
	T_m (crystalline)		75		172	160	172	Thermoset	Thermoset
	T_g (amorphous)				−15	0.2	−15		
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 450–500	I: 360–450	C: 260–350 I: 300–400 E: 300–400	E: 320–390	E: 340–400		I: 360–420
	3. Molding pressure range, 10^3 p.s.i.				5–30	3–30	5–30		1–2
	4. Compression ratio				2.5	2–2.5	2–2.5		
	5. Mold (linear) shrinkage, in./in.	D955	0.001	0.001–0.002	0.005–0.025	0.005–0.025	0.005–0.025	0.0–0.006	0.0–0.005
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	27,000–33,000	13,000	3500–5000	2800	3500	350–1000	725–1305
	7. Elongation at break, %	D638[b]	2	20	160–240	350–400	250–300	20–700	300–1000
	8. Tensile yield strength, p.s.i.	D638[b]	27,000–33,000		2800–3800		4900		
	9. Compressive strength (rupture or yield), p.s.i	D695			2000–2700				
	10. Flexural strength (rupture or yield), p.s.i.	D790	45,000–57,000	9000	4200–6200				
	11. Tensile modulus, 10^3 p.s.i.	D638[b]	1700–2500	500	50–80	50–80	50–80		
	12. Compressive modulus, 10^3 p.s.i.	D695			55–95				
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790	1500–2200	500	55–95				
	200° F.	D790							
	250° F.	D790							
	300° F.	D790							

	14. Izod impact, ft.-lb./in. of notch (1/8-in. thick specimen)		D256A	8–16	10	0.4–1.0	0.3–1.0	0.3–1.0		
	15. Hardness	Rockwell	D785			M60–65	R98–106	R98–106		
		Shore/Barcol	D2240/ D2583						Shore A10–70	Shore A20–70
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	0.6–0.8		190	190	190	10–19	10–20
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	200–260	180	130–150	130–150	130–150		
		66 p.s.i.	D648	230–370						
	18. Thermal conductivity, 10^{-4} cal.cm./sec.-cm.^{2}-°C.		C177			3	3	3	3.5–7.5	
Physical	19. Specific gravity		D792		1.33	1.65–1.72	1.65–1.70	1.68–1.72	0.97–2.5	1.06–1.14
	20. Water absorption (1/8-in. thick specimen), %	24 hr.	D570			0.1	0.1	0.1	0.1	
		Saturation	D570							
	21. Dielectric strength (1/8-in. thick specimen), short time, v./mil		D149			400–600		400–600	400–550	
SUPPLIERS[a]				Dow Plastics; RTP	LNP; RTP	Dow Plastics	Dow Plastics	Dow Plastics	Bayer Corp.; Dow Coming; Emerson & Cuming; GE Silicones	Bayer Corp.

	Silicone (Cont'd)			**Sulfone Polymers**						
	Molding and Encap-sulating Compounds	Silicone/poly-amide Pseudo-interpenetrating Networks'		Polysulfone						
	Mineral- and/or Glass-filled	Silicone/ Nylon 66	Silicone/ Nylon 12	Injection Molding, Flame-retarded, Extrusion	Mineral-filled	Extrusion/ Injection Molding Grade	20% Glass Fiber-reinforced	EMI Shielding (conductive); 30% Carbon Fiber	Injection Molding Platable Grade	Polyaryl-sulfone
1a.				3.5–9	7–8.5	3–20			12–18	10–30
1.	Thermoset	Interpenetrating Network	Interpenetrating Network							
				187–190	190	190	190	190		220
2.	C: 280–360 I: 330–370 T: 330–370	I: 460–525	I: 360–410	I: 625–750 E: 600–700	I: 675–775	I: 610–735 E: 600–680	1: 660–715	I: 550–700	I: 690–750	I: 630–800 E: 620–750
3.	0.3–6	8–15	7–12	5–20	10–20			10–20	5–100	5–20
4.	2.0–8.0			2.5–3.5	2.5–3.5			2.5–3.5	2	
5.	0.0–0.005	0.004–0.007	0.005–0.007	0.0058–0.007	0.004–0.005	0.005–0.007	2.8×10^{-3}	0.0005–0.001	0.0025	0.007–0.008
6.	500–1500	10,100–12,500	5200–7400		9500–9800		16,700	23,000–23,500	1100	9000
7.	80–800	5–20	10	50–100	2–5	40–100	2.4	1.5–2	2.3	40–60
8.				10,200–11,600		11,500				10,400–12,000
9.				13,900–40,000				25,000		
10.		14,000–15,900	8000–8300	15,400–17,500	14,300–15,400	17,500	21,000	31,000–35,000	7700	12,400–16,100
11.				360–390	550–650	390	1020	2150–2800		310–385
12.				374						
13.		360–410	200–216	390	600–750	370	850	1900–2300	881	330–420
				370	570–710					
				350	550–690					
				310	510–650					

14.		0.8–0.9	0.6–0.7	1.0–1.3	0.65–1.0	1.0–1.2	1.5	1.2–1.8		1.6–12
15.				M69	M70–74	M69	M83	M80		
	Shore A10–80									
16.	20–50			56	34–39	31	25	6		31–49
17.	> 500			345	345–354	340	363	360–365	410	400
				358		360	369	365–380		
18.	7.18			6.2						
19.	1.80–2.05	1.12–1.13	1.01–1.02	1.24–1.25	1.48–1.61	1.24	1.40	1.36–1.7	1.68	1.29–1.37
20.	0.15	0.6–0.8	0.12–0.15	03		0.3		0.15–0.25		
	0.15–0.40			0.8	0.5–0.6	0.8	0.6			1.1–1.85
21.	200–550			425	450				380	370–380
	Cytec Fiberite; Dow Coming; GE Silicones	LNP	LNP	Amoco Polymers; BASF	Amoco Polymers; RTP	Amoco Polymers; BASF	Amoco Polymers; BASF; ComAlloy; RTP	DSM; Ferro; LNP; RTP	Amoco Polymers	LNP; RTP

Materials				Sulfone Polymers						
				Polyethersulfone				Modfied Polysulfone		
		Properties	ASTM Test Method	Unfilled	10% Glass fiber-reinforced	20% Glass Fiber-reinforced	EMI Shielding (Conductive); 30% Carbon Fiber	Poly-phenyl Sulfone	Poly-phenyl Sulfone, Unrein-forced	Mineral-filled
Processing	1a.	Melt Flow (gm./10 min.)	D1238		12	10		14–20	11.5–17.0	
	1.	Melting Temperature, °C. T_m (crystalline)								
		T_g (amorphous)		220–230	225	220–225	225	225	220	
	2.	Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		C: 645–715 I: 590–750 E: 625–720	I: 660–715	C: 610–750 I: 630–735 E: 570–650	I: 600–750	I: 680–735	680–735	I: 575–650
	3.	Molding pressure range, 10^3 p.s.i.		6–20	50–100	6–100	10–20	10–20		5–20
	4.	Compression ratio		2–2.5	2:1	2.0–3.5	2.5–3.5	2.2		2.5–3.5
	5.	Mold (linear) shrinkage, in./in.	D955	0.006–0.007	0.5	0.002–0.005	0.0005–0.002	0.007	0.007	0.006–0.007
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	9800–13,800	16,000	15,200–20,000	26,000–30,000	10,100	10,100	
	7.	Elongation at break, %	D638[b]	6–80	4.1	2–3.5	1.3–2.5	60–120	60–120	50–100
	8.	Tensile yield strength, p.s.i.	D638[b]	12,200–13,000		18,000–18,800				10,500
	9.	Compressive strength (rupture or yield), p.s.i.	D695	11,800–15,600		19,500–24,000	22,000			
	10.	Flexural strength (rupture or yield), p.s.i.	D790	17,000–18,700	21,000; 24,500	23,500–27,600	36,000–38,000	13,200	13,200	16,500
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	350–410	555; 740	825–1130	2120–2900	340	340	400
	12.	Compressive modulus, 10^3 p.s.i.	D695							
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	348–380	590; 650	750–980	2000–2600	350	350	480
		200° F.	D790			812–850				370
		250° F.	D790	330		840				340
		300° F.	D790	280		580–842				320

	14. Izod impact, ft.-lb./in. of notch ($^{1}/_{8}$-in. thick specimen)		D256A	1.4-No break	0.9; 1.3	1.1–1.7	1.2–1.6	13	13.0	1.1
	15. Hardness	Rockwell	D785	M85–88	M94	M96–99	R123			M74
		Shore/Barcol	D2240/ D2583							
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	55	34	23–32	10	17	5.6	53
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	383–397	437	408–426; 437	415–420	405	405	325
		66 p.s.i.	D648	410	423	410–430	420–430			
	18. Thermal conductivity, 10^{-4} cal.cm./sec.-cm.^{2}-°C.		C177	3.2–4.4						
Physical	19. Specific gravity		D792	1.37–1.46	1.43; 1.45	1.51–1.53	1.47–1.48	1.29–1.3		1.30
	20. Water absorption ($^{1}/_{8}$-in. thick specimen), %	24 hr.	D570	0.12–1.7		0.15–0.4	0.29–0.35	0.37	0.37	
		Saturation	D570	1.8–2.5	1.9	1.65–2.1; 1.7		1.1		0.8
	21. Dielectric strength ($^{1}/_{8}$-in. thick specimen), short time, v./mil		D149	400	440	375–500		360	380	460
			SUPPLIERS[a]	Amoco Polymers; BASF	Amoco Polymers; BASF; RTP	Amoco Polymers; BASF; DSM; LNP; RTP	DSM; LNP; RTP	Amoco Polymers	Amoco Polymers	RTP

	Thermoplastic Elastomers								
	Polyolefin							Silicone-based, Pesudo-Interpenetrating Networks,	
	Low and Medium Hardness	High Hardness	Copolyester Ether	Polyester	Polyether/ Amide block Copolymers	Block Copolymers of Styrene and Butadiene or Styrene and Isoprene	Block Copolymers of Styrene and Ethylene and/or Butylene	Silicone/ Polyamide	Silicone/ Polyester
1a.	0.4–20.0	0.4–10.0	05–20 @190–240	3–12 @190–240		0.5–20			
1.			150–223	148–230	148–209			Interpenetrating network	Interpenetrating network
	165	163–165	−3						
2.	C: 350–450 I: 360–475 E: 380–450	C: 370–450 I: 350–480 E: 380–475	E: 400–500 I: 435–500	I: 340–500 E: 340–500	C: 365–480 I: 340–482 E: 340–460	C: 250–325 I: 300–425 E: 370–400	C: 300–380 I: 350–480 E: 330–380	I: 360–410 I: 355–580 E: 320–365	I: 360–450 E: 380–450
3.	4–19	6–10	1–15	1–15	8–12	0.3–3	1.5–20	5–25	6–14
4.	2–3.5	2–3.5	2–4	3–3.5		2.0–4.0	2.5–5.0	3–5	2.5–4
5.	0.015–0.020	0.007–0.021	0.004–0.02	0.003–0.018		0.001–0.022	0.003–0.022	0.004–0.007	0.004–0.015
6.	650–2500	950–4000	1000–10,000	1000–6800	2000–7000	100–4350	600–3000	5200–12,500	5000
7.	150–780	20–600	200–1000	170–900	350–680	20–1350	600–640	5–275	950–1050
8.		1600–4000	1370–1750	1350–3900	3000–3500	3700–4400			
9.		22–39							
10.					1100–1900	5100–6400	0.1–100	2200–15,900	1700
11.	1.1–16.4	0.34–34.1	16–18	1.1–130	2–60	0.8–235			18
12.				7.5–48		3.6–120			
13.	1.5–30	2.7–300	18	5–175	2.9–66	4–215	0.1–100	35–410	25

14.	No break	5.0–16.0 No break	NB (-30C)	2.5-No break	4.3-No break	No break	No break;	No break 0.6–0.9	No break
15.				104					
	Shore A64–92	Shore D40–70	55/95 (D/A); 30–85	Shore D35–72	Shore A75-D72	Shore A20–95 D63–75	Shore A5–95	Shore D60	Shore D49–51
16.		36–110	150	85–190	210–230	67–140			
17.					45–135	< 0–170			
				111–284	158–257	< 0–190			
18.	4.5–5.0		5–6	3.6–4.5		3.6			
19.	0.88–0.98	0.90–1.15	1–1.3	1.10–1.28	1.0–1.03	0.90–1.2	0.9–1.2	1.01–1.21	1.21–1.16
20.	0.01	0–0.28	0.4–50	0.2–3.6	1.01–1.36	0.009–0.39	0.1–0.42	0.5–0.15	0.3–0.8
21.	410–445	390–465	350	350–600		300–520	450–800		
	AlphaGary; DuPont; Exxon; M.A. Polymers; Montell NA; Network Polymers; A. Schulman; Solutia; Solvay Engineered Polymers; Teknor Apex; Union Carbide; Vi-Chem	AlphaGary; Equistar; M.A. Polymers; Montell NA; Network Polymers; A. Schulman; Solutia; Solvay Engineered Polymers; Teknor Apex; Vi-Chem; Wash. Penn	DuPont; Eastman	DuPont; Ticona	Creanova; Elf Atochem N.A.; EMS	Fina; Firestone Synthetic Rubber; Network Polymers; A. Schulman; Shell	AlphaGary; Dow Plastics; Network Polymers; Shell; Teknor Apex	Creanova; LNP	Creanova; LNP

Materials			Thermoplastic Elastomers (Cont'd)				
			Silicone-based, Pseudo-Interpenetrating Networks' (Cont'd)				Polyurethane
					Silicone/Polyurethane		Molding and Extrusion Compounds
	Properties	ASTM Test Method	Sillicone/ Polyolefin	Silicone/ Polystyrene Ethyene Butadiene-styrene	Aromatic and Aliphatic Polyether and Polyester Urethane, unfilled	Aromatic Polyether Urethane, 15% Carbon Fiber-reinforced	Polyester Low and Medium Hardness
Processing	1a. Melt flow (gm./10 min.)	D1238					
	1. Melting temperature, °C. T_m (crystalline)		Interpenetrating Network	Interpenetrating network	Interpenetrating network	Interpenetrating network	
	T_g (amorphous)				150–225		120–180
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		I: 340–425	I: 390–490 E: 325–480	I: 325–450 E: 325–475	I: 410–475	I: 340–435 E: 340–410
	3. Molding pressure range, 10^3 p.s.i.		6–11	6–20	5–15	6–15	0.8–1.4
	4. Compression ratio		2.5–3.5	2–3.5	2.5–3.5	2.5–3.5	
	5. Mold (linear) shrinkage, in./in.	D955	0.010–0.020	0.005–0.040	0.010–0.020	0.011–0.014	0.008–0.015
Mechanical	6. Tensile strength at break, p.s.i.	D638[b]	475–1000	1000–3300	2100–6500	18,500	3300–8400
	7. Elongation at break, %	D638[b]	120–1000	500–1000	400–1300	5	410–620
	8. Tensile yield strength, p.s.i.	D638[b]					
	9. Compressive strength (rupture or yield), p.s.i.	D695					
	10. Flexural strength (rupture or yield), p.s.i.	D790			7000–8000	18,000	
	11. Tensile modulus, 10^3 p.s.i.	D638[b]			9–19		
	12. Compressive modulus, 10^3 p.s.i.	D695					
	13. Flexural modulus, 10^3 p.s.i. 73° F.	D790			2–27	800	4000–6990
	200° F.	D790					
	250° F.	D790					
	300° F.	D790					

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	No break	No break	No break	1.6	
	15. Hardness	Rockwell	D785					
		Shore/Barcol	D2240/ D2583	Shore A57–85	Shore A50–84	Shore A55–87; D55–60	Shore D70	Shore A55–94
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696					
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648					
		66 p.s.i.	D648					
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177					
Physical	19. Specific gravity		D792	0.96–0.97	0.90–0.97	1.04–1.19	1.24	1.17–1.25
	20. Water absorption ($^1/_8$-in. thick specimen), %	24 hr.	D570	0.01	0.05–0.3	0.3–0.6	0.4	
		Saturation	D570					
	21. Dielectric strength (1/8-in. thick specimen), short time, v./mil		D149					
SUPPLIERS[a]				LNP	Creanova; LNP	Creanova	LNP	BASF: Bayer Corp.; Dow Plastics; BF Goodrich; A. Schulman

	Thermoplastic Elastomers (Cont'd)					**Vinyl Polymers and Copolymers**			
	Polyurethane (Cont'd)			Elastomeric Alloys		PVC and PVC-acetate, MC, Sheets, Rods, and Tubes			
	Molding and Extrusion Compounds (Cont'd)								
	Polyester (Cont'd)		Polyether						
	High Hardness	Low and Medium Hardness	High Hardness	Low and Medium Hardness	High Hardness	Rigid	Rigid, Tin-stabilized	Flexible, Unfilled	Flexible, Filled
1a.		Thermoset							
1.				165	165				
	120–160	120–160	120–160			75–105		75–105	75–105
2.	I: 400–440 E: 370–410	I: 350–430 E: 340–410 C: 72–120	I: 400–435 E: 380–440	I: 350–450	I: 350–450	C: 285–400 I: 300–415	I: 380–400	C: 285–350 I: 320–385	C: 285–350 I: 320–385
3.	0.8–1.4	0.6–1.2	1–1.4	6–10	6–10	10–40		8–25	1–2
4.				2.5–3.5	2.5–3.5	2.0–2.3	2.0	2.0–2.3	2.0–2.3
5.	0.005–0.015	0.006–0.015	0.008–0.012	1.5–2.5	1.5–2.5	0.002–0.006		0.010–0.050	0.008–0.035 0.002–0.008
6.	4000–11,000	158–6750	6000–7240	650–3200	2300–4000	5900–7500		1500–3500	1000–3500
7.	110–550	475–1000	340–600	300–750	250–600	40–80		200–450	200–400
8.					1600	5900–6500	5140–7560		
9.						8000–13,000		900–1700	1000–1800
10.						10,000–16,000	6300–13,600		
11.				0.7–5.0	16–100	350–600	310–435		
12.									
13.	9150–64,000	2480–6190	4000–44,900	1.5–6.6	15–50	300–500	305–420		

14.				No fracture	No fracture	0.4–22	2.1–20.0	Varies over wide range	Varies over wide range
15.	Shore D46–78	Shore A13–92	Shore D55–75	Shore 55–95A	Shore 32–72D	Shore D65–85	Shore D69–78	Shore A50–100	Shore A50–100
16.				82	82	50–100	1.0–18.1	70–250	
17.						140–170			
							69–163		
						135–180			
							161–166		
18.						3.5–5.0		3–4	3–4
19.	1.15–1.28	1.02	1.14–1.21	0.90–1.39	0.90–1.31	1.30–1.58		1.16–1.35	1.3–1.7
							1.32–1.45		
20.	0.3					0.04–0.4		0.15–0.75	0.5–1.0
21.		470	470	400–600	400–600	350–500		300–400	250–300
	BASF; Bayer Corp.; Dow Plastics; BF Goodrich; A. Schulman	BASF; Bayer Corp.; Cabot; Dow Plastics; BF Goodrich; A. Schulman	BASF; Bayer Corp.; Dow Plastics; BF Goodrich; A. Schulman	AlphaGary; Goodyear; M.A. Hanna; Montell NA; Network Polymers; Novatec; A. Schulman; Solutia; Vi-Chem	AlphaGary; M.A. Hanna; Montell NA; Network Polymers; A. Schulman; Solutia	AlphaGary; Colorite; CONDEA Vista; Creanova; Formosa; Georgia Gulf; Keysor-Century; LG Chemical; Novatec; OxyChem; Rimtec; RSG Polymers; Shintech; Synergistic; Union Carbide; Vi-Chem	AlphaGary; Colorite; CONDEA Vista; Georgia Gulf; Keysor-Century; Oxychem; Rimtec; Shintech; Synergistic	AlphaGary; Colorite; CONDEA Vista; Creanova; Keysor-Century; LG Chemical; Novatec; Rimtec; A. Schulman; Shintech; Shuman; Synergistic; Teknor Apex; Union Carbide; Vi-Chem	AlphaGary; Colorite; CONDEA Vista; Creanova; Keysor-Century; Novatec; Rimtec; Shintech; Synergistic; Teknor Apex; Union Carbide; Vi-Chem

Materials				**Vinyl Polymers and Copolymers** (Cont'd)		
				Molding and Extrusion Compounds		
		Properties	ASTM Test Method	Chlorinated Polyvinyl Chloride	Vinyl Butyral, Flexible	PVC/Acrylic Blends
Processing	1a.	Melt flow (gm./10 min.)	D1238			
	1.	Melting temperature, °C. T_m (crystalline)				
		T_g (amorphous)		110–127	49	
	2.	Processing temperature range, °F. (C = Compression; T = transfer; I = Injection; E = extrusion)		C: 350–400 I: 395–440 E: 360–430	C: 280–320 I: 250–340	I: 360–390 E: 390–410
	3.	Molding pressure range, 10^3 p.s.i.		15–40	0.5–3	2–3
	4.	Compression ratio		1.5–2.8		2–2.5
	5.	Mold (linear) shrinkage, in./in.	D955	0.003–0.007		0.003
Mechanical	6.	Tensile strength at break, p.s.i.	D638[b]	6500–9000	500–3000	6400–7000
	7.	Elongation at break, %	D638[b]	4–100	150–450	35–100
	8.	Tensile yield strength, p.s.i.	D638[b]	6000–8200		
	9.	Compressive strength (rupture or yield), p.s.i.	D695	9000–22,000		6800–8500
	10.	Flexural strength (rupture or yield), p.s.i.	D790	11,500–17,000		10,300–11000
	11.	Tensile modulus, 10^3 p.s.i.	D638[b]	326–475		340–370
	12.	Compressive modulus, 10^3 p.s.i.	D695	212–600		
	13.	Flexural modulus, 10^3 p.s.i. 73° F.	D790	334–450	350–380	
		200° F.	D790			
		250° F.	D790			
		300° F.	D790			

	14. Izod impact, ft.-lb./in. of notch ($^1/_8$-in. thick specimen)		D256A	1.0–10.0	Varies over wide range	1–12
	15. Hardness	Rockwell	D785	R109–117	A10–100	R106–110
		Shore/Barcol	D2240/ D2583	82–88		
Thermal	16. Coef. of linear thermal expansion, 10^{-6} in./in./°C.		D696	52–78		44–79
	17. Deflection temperature under flexural load, °F.	264 p.s.i.	D648	194–234	167–185	
		66 p.s.i.	D648	215–247	172–189	
	18. Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C.		C177	3.3		
Physical	19. Specific gravity		D792	1.39–1.58	1.05	1.26–1.35
	20. Water absorption (1/8-in. thick specimen), %	24 hr.	D570	0.02–0.16	1.0–2.0	0.09–0.16
		Saturation	D570			
	21. Dielectric strength ($^1/_8$-in. thick specimen), short time, v./mil		D149	600–625	350	480
			SUPPLIERS[a]	BF Goodrich; Elf Atochem N.A.; Georgia Gulf	Solutia; Union Carbide	AlphaGary

Notes for Appendix B

a. See list below for addresses of suppliers.

b. Tensile test method varies with material; D638 is standard for thermoplastics; D651 for rigid thermosetting plastics; D412 for elastomeric plastics; D882 for thin plastics sheeting.

c. Dry, as molded (approximately 0.2 percent moisture content).

d. As conditioned to equilibrium with 50 percent relative humidity.

e. Test method in ASTM D4092.

f. *Pseudo* indicates that the thermosetting and thermoplastic components were in the form of pellets or powder prior to fabrication.

g. Dow Plastics samples are unannealed.

Names and Addresses of Suppliers Listed in Appendix B

Adell Plastics, Inc.
4530 Annapolis Rd.
Baltimore, MD 21227
800–638-5218, 410-789-7780
Fax: 410-789-2804

Ain Plastics, Inc.
249 E. Sandford Blvd.
P.O. Box 151-M
Mt. Vernon, NY 10550
800-431-2451, 914-668-6800
Fax: 914–668–8820

Albis Corp.
445 Hwy. 36 N.
RO. Box 711 ß
Rosenberg, TX 77471
800–231-5911, 713-342-3311
Fax: 713-342-3058
Telex: 166-181

Alliedsignal Inc.
Alliedsignal Engineered Plastics
P.O. Box 2332, 101 Columbia Rd.
Morristown, NJ 07962-2332
201-455-5010
Fax: 201-455-3507

ALM Corp.
55 Haul Rd.
Wayne, NJ 07470
201-694-4141
Fax: 201-831-8327

Alpha/Owens-Corning
P.O. Box 610
Collierville, TN 38027-0610
901-854-2800
Fax: 901-854-1183

AlphaGary Corp.
170 Pioneer Dr.
P.O. Box 808
Leominster, MA 01453
800-232-9741, 508-537-8071
Fax: 508-534-3021

American Polymers
P.O. Box 366
53 Milbrook St.
Worcester, MA 01606
508-756-1010
Fax: 508-756-3611

Ametek, Inc.
Haveg Div.
900 Greenbank Rd.
Wilmington, DE 19808
302-995-0400
Fax: 302-995-0491

Amoco Chemical Co.
200 E. Randolph Dr.
Mail Code 7802
Chicago, IL 60601-7125
800-621-4590, 312-856-3200
Fax: 312-856-4151

Applied Composites Corp.
333 N. Sixth St.
St. Charles, IL 60174
708-584-3130
Fax: 708-584-0659

Applied Polymer Systems, Inc.
P.O. Box 56404
Flushing, NY 11356-4040
718-539-4425
Fax: 718-460-4159

Arco Chemical Co.
3801 West Chester Pike
Newtown Square, PA 19073
800-345-0252 (PA Only),
215-359-2000

Aristech Chemical Corp.
Acrylic Sheet Unit
7350 Empire Dr.
Florence, KY 41042
800-354-9858
Fax: 606-283-6492

Ashley Polymers
5114 Ft. Hamilton Pkwy.
Brooklyn, Ny 11219
718-851-8111
Fax: 718-972-3256
Telex: 42-7884

AtoHaas North America Inc.
100 Independence Mall W
Philadelphia, PA 19106
215-592-3000
Fax: 215-592-2445

Ausimont USA, Inc.
Crown Point Rd & Leonards Lane
P.O. Box 26
Thorofare, NJ 08086
800-323-2874, 609-853-8119
Fax: 609-853-6405

Bamberger, Claude P., Molding
Compounds Corp.
111 Paterson Plank Rd.
P.O. Box 67
Carlstadt, NJ 07072
201-933-6262
Fax: 201-933-8129

Bamberger Polymers, Inc.
1983 Marcus Ave.
Lake Success, NY 11042
800-888-8959, 516-328-2772
Fax: 516-326-1005
Telex: 6711357

BASF Corp., Plastic Materials
3000 Continental Dr. N.
Mount Olive, NJ 07828-1234
201-426-2600

Bayer Corp.
100 Bayer Rd.
Pittsburgh, PA 15205-9741
800-662-2927, 412-777-2000

BFGoodrich Adhesive Systems Div.
123 W Bartges St.
Akron, OH 44311-1081
216-374-2900
Fax: 216-374-2860

BFGoodrich Specialty Chemicals
9911 Breckville Rd.
Cleveland, OH 44141-3247
800-331-1144, 216-447-5000
Fax: 216-447-5750

Boonton Plastic Molding Co.
30 Plain St.
Boonton, NJ 07005-0030
201-334-4400
Fax: 201-335-0620

Borden Packaging Div.
Borden Inc.
One Clark St.
North Andover, MA 01845
508-686-9591

BP Chemicals (Hitco) Fibers and Materials
700 E. Dyer Rd.
Santa Ana, CA 92705
714-549-1101

BP Chemicals, Inc.
4440 Warrensville Center Rd.
Cleveland, OH 44128
800-272-4367, 216-586-5847
Fax: 216-586-5839

BP Performance Polymers Inc.
Phenolic Business
60 Walnut Ave.
Suite 100
Clark, NJ 07066
908-815-7843
Fax: 908-815-7844

Budd Chemical Co.
Pennsville-Auburn Rd.
Carneys Point, NJ 08069
609-299-1708
Fax: 609-299-2998

Budd Co.
Plastics Div.
32055 Edward Ave.
Madison Heights, MI 48071
810-588-3200
Fax: 810-588-0798

Bulk Molding Compounds Inc.
3N497 N. 17th St.
St. Charles, IL 60174
708-377-1065
Fax: 708-377-7395

Cadillac Plastic & Chemical Co.
143 Indusco Ct.
P.O. Box 7035
Troy, MI 48007-7035
800-488-1200, 810-583-1200
Fax: 810-583-4715

Cast Nylons Ltd.
4300 Hamann Pkwy
Willoughby, OH 44092
800-543-3619, 216-269-2300
Fax: 216-269-2323

Chevron Chemical Co.
Olefin & Derivatives
P.O. Box 3766
Houston, TX 77253
800-231-3828, 713-754-2000

Ciba-Geigy Corp., Ciba Additives
540 White Plains, Rd.
P.O. Box 20005
Tarrytown, NY 10591-9005
800-431-2360, 914-785-2000
Fax: 914-785-4244

Color-Art Plastics, Inc.
317 Cortlandt St.
Belleville, NJ 07109-3293
201-759-2400

CornAlloy International Co.
481 Allied Dr.
Nashville, TN 37211
615-333-3453
Fax: 615-834-9941

Conap, Inc.
1405 Buffalo St.
Olean, NY 14760
716-372-9650
Fax: 716-372-1594

Consolidated Polymer Technologies, Inc.
11811 62nd St. N.
Largo, FL 34643
800-541-6880, 813-531-4191
Fax: 813-530-5603

Cook Composites & Polymers
P.O. Box 419389
Kansas City,
MO 64141-6389
800-821-3590,
816-391-6000
Fax: 816-391-6215

Cosmic Plastics, Inc.
27939 Beale Ct.
Valencia, CA 91355
800-423-5613, 805-257-3274
Fax: 805-257-3345

Custom Manufacturers
858 S. M-18
Gladwin, MI 48624
800-860-4594, 517-426-4591
Fax: 517-426-4049

Custom Molders, Crop.
2470 Plainfield Ave.
Scotch Plains, NJ 07076
800-233-5880
Fax: 908-233-5949

Custom Plastic Injection
Molding Co. Inc.
3 Spielman Rd.
Fairfield, NJ 07004
201-227-1155

Cyro Industries
100 Enterprise Dr., 7th fl.
Rockaway, NJ 07866
201-442-6000

CYTEC Industries Inc.
5 Garret Mt. Plaza
West Paterson, NJ 07424
800-438-5615, 201-357-3100
Fax: 201-357-3065

CYTEC Industries Inc.
12600 Eckel Rd.
P.O. Box 148
Perrysburgh, OH 43551
800-537-3360, 419-874-7941
Fax: 419-874-0951

Diamond Polymers
1353 Exeter Rd.
Akron, OH 44306
216-773-2700
Fax: 216-773-2799

Dow Chemical Co.
Polyurethanes
2040 Willard H. Dow Center
Midland, MI 48674
800-441-4369

Dow Corning Corp.
P.O. Box 0994
Midland, MI 48686-0994
517-496-4000
Fax: 517-496-4586

Dow Corning STI
47799 Halyard Dr.
Suite 99
Plymouth, MI 48170
313-459-7792
Fax: 313-459-0204

Dow Plastics
P.O. Box 1206
Midland, Mi 48641-1206
800-441-4369

DSM Copolymer, Inc.
P.O. Box 2591
Baton Rouge, LA 70821
800-535-9960, 504-355-5655
Fax: 504-357-9574

DSM Engineering Plastics
2267 W Mill Rd.
P.O. Box 3333
Evansville, IN 47732
800-333-4237, 812-435-7500
Fax: 812-435-7702

DSM Thermoplastic Elastomers, Inc.
29 Fuller St.
Leominster, MA 01453-4451
800-524-0120, 508-534-1010
Fax: 508-534-1005

DuPont Engineering Polymers
1007 Market St.
Wilmington, DE 19898
800-441-7515, 302-999-4592
Fax: 302-999-4358

Eagle-Picher Industries, Inc.
C & Porter Sts.
Joplin, MO 64802
417-623-8000
Fax: 417-782-1923

Eastman Chemical Co.
P.O. Box 511
Kingsport, TN 37662
800-327-8626

Elf Atochem North America, Inc.
Fluoropolymers
2000 Market St.
Philadelphia, PA 19103
800-225-7788, 215-419-7000
Fax: 215-419-7497

Elf Atochem North America, Inc.,
Organic Peroxides
2000 Market St.
Philadelphia, PA 19103
800-558-5575, 215-419-7000
Fax: 215-419-7591

Emerson & Cuming, Inc./Grace
Specialty Polymers
77 Dragon Ct.
Woburn, MA 01888
800-832-4929, 617-938-8630
Fax: 617-935-0125

Epic, Inc.
654 Madison Ave.
New York, NY 10021
212-308-7039
Fax: 212-308-7266

Epsilon Products Co.
Post Rd. and Blueball Ave.
P.O. Box 432
Marcus Hook, PA 19061
610-497-8850
Fax: 610-497-4694

EVAL Co. of America
1001 Warrenville Rd.
Suite 201
Lisle, IL 60532-1359
800-423-9762, 708-719-4610
Fax: 708-719-4622

Exxon Chemical Co.
13501 Katy Freeway
Houston, TX 77079-1398
800-231-6633, 713-870-6000
Fax: 713-870-6970

Federal Plastics Corp.
715 South Ave. E.
Cranford, NJ 07016
800-541-4424, 908-272-5800
Fax: 908-272-9021

Ferro Corp.
Filled & Reinforced Plastics Div.
5001 O'Hara Dr.
Evansville, IN 47711
812-423-5218
Fax: 812-435-2113

Ferro Corp., World Headquarters
1000 Lakeside Ave.
P.O. Box 147000
Cleveland, OH 44114-7000
216-641-8580
Fax: 216-696-6958
Telex: 98-0165

Fina Oil & Chemical Co.
Chemical Div.
P.O. Box 2159
Dallas, TX 75221
800-344-3462, 214-750-2806
Fax: 214-821-1433

Firestone Canada
P.O. Box 486
Woodstock, Ontario, Canada, N45 7Y9
800-999-6231, 519-421-5649
Fax: 519-537-6235

Firestone Synthetic Rubber & Latex Co.
P.O. Box 26611
Akron, OH 44319-0006
800-282-0222
Fax: 216-379-7875
Telex: 67-16415

Formosa Plastics Corp. USA
9 Peach Tree Hill Rd.
Livingston, NJ 07039
201-992-2090
Fax: 201-716-7208

Franklin Polymers, Inc.
P.O. Box 481
521 Yale Ave.
Pitman, NJ 08071-0481
800-238-7659, 609-582-6115
Fax: 609-582-0525

FRP Supply Div.
Ashland Chemical Co.
P.O. Box 2219
Columbus, OH 43216
614-790-4272
Fax: 614-790-4012
Telex: 24-5385 ASHCHEM

GE Plastics
One Plastics Ave.
Pittsfield, MA 01201
800-845-0600, 413-448-7110

GE Silicones
260 Hudson River Rd.
Waterford, NY 12188
800-255-8886
Fax: 518-233-3931

General Polymers Div., Ashland Chemical Co.
P.O. Box 2219
Columbus, OH 43216
800-828-7659
Fax: 614-889-3195

George, P. D., Co.
5200 N. Second St.
St. Louis, MO 63147
314-621-5700

Georgia Gulf Corp.
PVC Div.
P.O. Box 629
Plaquemine, LA 70765-0629
504-685-1200

Glastic Corp.
4321 Glenridge Rd.
Cleveland, OH 44121
216-486-0100
Fax: 216-486-1091

GLS Corp.
Thermoplastic Elastomers Div.
740B Industrial Dr.
Cary, IL 60013
800-457-8777 (not IL), 708-516-8300
Fax: 708-516-8361

Goodyear Tire & Rubber Co.
Chemical Div.
1485 E. Archwood Ave.
Akron, OH 44316-0001
800-522-7659, 216-796-6253
Fax: 216-796-2617

Grace Specialty Polymers
77 Dragon Ct.
Woburn, MA 01888
617-938-8630

Haysite Reinforced Plastics
5599 New Perry Hwy
Erie, PA 16509
814-868-3691
Fax: 814-864-7803

Hercules Inc.
Hercules Plaza
Wilmington, DE 19894
800-235-0543, 302-594-5000
Fax: 412-384-4291

Hercules Moulded Products
R.R. 3
Maidstone, Ontario, Canada NOR 1K0
519-737-6693
Fax: 519-737-1747

Hoechst Celanese Corp.
Advanced Materials Group
90 Morris Ave.
Summit, NJ 07901
800-526-4960, 908-598-4000
Fax: 908-598-4330
Telex: 13-6346

Hoechst Celanese Corp.
Hostalen GUR Business Unit
2520 S. Shore Blvd.
Suite 110
League City, TX 77573
713-334-8500

Huls America Inc.
80 Centennial Ave.
Piscataway, NJ 08855-0456
908-980-6800
Fax: 908-980-6970

Huntsman Chemical Corp.
2000 Eagle Gate Tower
Salt Lake City, UT 84111
800-421-2411, 801-536-1500
Fax: 801-536-1581

Huntsman Corp.
P.O. Box 27707
Houston, TX 77227-7707
713-961-3711
Fax: 713-235-6437
Telex: 227031 TEX UR

Hysol Engineering Adhesives
Dexter Distrib. Programs
One Dexter Dr.
Seabrook, NH 03874-4018
800-767-8786, 603-474-5541
Fax: 603-474-5545

ICI Acrylics Canada Inc.
7521 Tranmere Dr.
Mississauga, Ontario, Canada LSS 1L4

800-387-4880, 905-673-3345
Fax: 905-673-1459

ICI Acrylics Inc.
10091 Manchester Rd.
St. Louis, MO 63122
800-325-9577, 314-966-3111
Fax: 314-966-3117

ICI Americas Inc.
Tatnall Bldg.
P.O. Box 15391
3411 Silverside Rd.
Wilmington, DE 19850-5391
800-822-8215, 302-887-5536
Fax: 302-887-2089

ICI Fiberite
Molding Materials
501 W. Third St.
Winona, MN 55987-5468
507-454-3611
Fax: 507-452-8195
Telex: 507-454-3646

ICI Polyurethanes Group
286 Mantua Grove Rd.
West Deptford, NJ 08066-1732
800-257-5547, 609-423-8300
Fax: 609-423-8580

ITW Adhesives
37722 Enterprise Ct.
Farmington Hills, MI 48331
800-323-0451, 313-489-9344
Fax: 313-489-1545

Jet Composites Inc.
405 Fairall St.
Ajax, Ontario, Canada L1S 1R8
416-686-1707
Fax: 416-427-9403

Jet Plastics
941 N. Eastern Ave.
Los Angeles, CA 90063
213-268-6706
Fax: 213-268-8262

Keysor-Century Corp.
26000 Springbrook Rd.
P.O. Box 924
Santa Clarita, CA 91380-9024
805-259-2360
Fax: 805-259-7937

Kleerdex Co.
100 Gaither Dr.
Suite B
Mt. Laurel, NJ 08054
800-541-7232, 609-866-1700
Fax: 609-866-9728

Laird Plastics
1400 Centrepark
Suite 500
West Palm Beach, FL 33401
800-610-1016, 407-684-7000
Fax: 407-684-7088

LNP Engineering Plastics Inc.
475 Creamery Way
Exton, PA 19341
800-854-8774, 610-363-4500
Fax: 610-363-4749

Lockport Thermosets Inc.
157 Front St.
Lockport, LA 70374
800-259-8662, 504-532-2541
Fax: 504-532-6806

M.A. Industries Inc.
Polymer Div.
303 Dividend Dr.
P.O. Box 2322
Peachtree City, GA 30269
800-241-8250, 404-487-7761

Mitsui Petrochemical Industries Ltd.
3-2-5 Kasumigasekl, Chiyoda-ku
Tokyo, Japan 100
03-3593-1630
Fax: 03-3593-0979

Mitsui Plastics, Inc.
11 Martine Ave.
White Plains, NY 10606
914-287-6800
Fax: 914-287-6850

Mitsui Toatsu Chemicals, Inc.
2500 Westchester Ave.
Suite 110
Purchase, NY 10577
914-253-0777
Fax: 914-253-0790

Mobile Chemical Co.
1150 Pittsford-Victor Rd.
Pittsford, NY 14534
716-248-1193
Fax: 716-248-1075

Mobil Polymers
P.O. Box 5445
800 Connecticut Ave.
Norwalk, CT 06856
203-854-3808
Fax: 203-854-3840

Monmouth Plastics Co.
800 W Main St.
Freehold, NJ 07728
800-526-2820, 908-866-0200
Fax: 908-866-0274

Monsanto Co.
800 N. Lindbergh Blvd.
St. Louis, MO 63167
314-694-1000
Fax: 314-694-7625
Telex: 650-397-7820

Montell Polyolefins
Three Little Falls Centre
2801 Centerville Rd.
Wilmington, DE 19850-5439
800-666-8355, 302-996-6000
Fax: 302-996-5587

Morton International Inc.
Morton Plastics Additives
150 Andover St.
Danvers, MA 01923
508-774-3100
Fax: 508-750-9511

Network Polymers, Inc.
1353 Exeter Rd.
Akron, OH 44306
216-773-2700
Fax: 216-773-2799

Nova Polymers, Inc.
P.O. Box 8466
Evansville, IN 47716-8466
812-476-0339
Fax: 812-476-0592

Novacor Chemicals Inc.
690 Mechanic St.
Leominster, MA 01453
800-225-8063, 508-537-1111
Fax: 508-537-5685

Novacor Chemicals Inc.
Clear Performance Plastics
690 Mechanic St.
Leominster, MA 01453
800-243-4750, 508-537-1111
Fax: 508-537-6410

Novatec Plastics & Chemicals Co. Inc.
P.O. Box 597
275 Industrial Way W
Eatontown, NJ 07724
800-782-6682, 908-542-6600

Nylon Engineering
12800 University Dr.
Suite 275
Ft. Myers, FL 33907
813-482-1100
Fax: 813-482-4202

Occidental Chemical Corp.
5005 LBJ Freeway
Dallas, TX 75244
214-404-3800

Patent Plastics Inc.
638 Maryville Pike S.W.
P.O. Box 9246
Knoxville, TN 37920
800-340-7523, 615-573-5411

Paxon Polymer Co.
P.O. Box 53006
Baton Rouge, LA 70892
504-775-4330

Performance Polymers Inc.
803 Lancaster St.
Leominster, MA 01453
800-874-2992, 508-534-8000
Fax: 508-534-8590

Perstorp Compounds Inc.
238 Nonotuck St.
Florence, MA 01060
413-584-2472
Fax: 413-586-4089

Perstorp Xytec, Inc.
9350 47th Ave. S.W.
P.O. Box 99057
Tacoma, WA 98499
206-582-0644
Fax: 206-588-5539

Phillips Chemical Co.
101 ARB Plastics Technical Center
Bartlesville, OK 74004
918-661-9845
Fax: 918-662-2929

Plaskolite, Inc.
P.O. Box 1497
Columbus, OH 43216
800-848-9124, 614-294-3281
Fax; 614-297-7287

Plaskon Electronic Materials, Inc.
100 Independence Mall West
Philadelphia, PA 19106
800-537-3350, 215-592-2081
Fax: 215-592-2295
Telex: 845-247

Plaslok Corp.
3155 Broadway
Buffalo, NY 14227
800-828-7913, 716-681-7755
Fax: 816-681-9142

Plastic Engineering & Technical Services, Inc.
2961 Bond
Rochester Hills, MI 48309
313-299-8200
Fax: 313-299-8206

Plastics Mfg. Co.
2700 S. Westmoreland St.
Dallas, TX 75223
214-330-8671
Fax: 214-337-7428

Polymer Resources Ltd.
656 New Britain Ave.
Farmington, Ct 06032
800-423-5176, 203-678-9088
Fax: 203-678-9299

Polymers International Inc.
P.O. box 18367
Spartanburg, SC 29318
803-579-2729
Fax: 803-579-4476

Polyply Composites Inc.
1540 Marion
Grand Haven, MI 49417
616-842-6330
Fax: 616-842-5320

PPG Industries, Inc.
Chemicals Group
One PPG Place
Pittsburgh, PA 15272
412-434-3131
Fax: 412-434-2891

Premix, Inc.
Rte. 20 & Harmon Rd.
P.O. Box 281
North Kingsville, OH 44068
216-224-2181
Fax: 216-224-2766

Prime Alliance, Inc.
1803 Hull Ave.
des Moines, IA 50302
800-247-8038, 515-264-4110
Fax: 515-264-4100

Prime Plastics, Inc.
2950 S. First St.
Clinton, OH 44216
216-825-3451

Progressive Polymers, Inc.
P.O. Box 280
4545 N. Jackson
Jacksonville, TX 75766
800-426-4009, 903-586-0583
Fax: 903-586-4063

Quantum Composites, Inc.
4702 James Savage Rd.
Midland, MI 48642
800-462-9318, 517-496-2884
Fax: 517-496-2333

Reichhold Chemicals, Inc.
P.O. Box 13582
Research Triangle Park, NC 27709
800-448-3482, 919-990-7500
Fax: 919-990-7711

Reichhold Chemicals, Inc.
Emulsion Polymer Div.
2400 Ellis Rd.
Durham, NC 27703-5543
919-990-7500
Fax: 919-990-7711

Resinoid Engineering Corp.
P.O. Box 2264
Newark, OH 43055
614-928-6115
Fax: 614-929-3165

Resinoid Engineering Corp.
Materials Div.
7557 N. St. Louis Ave.
Skokie, IL 60076
708-673-1050
Fax: 708-673-2160

Rhone-Poulenc
Rte. 8
Rouseville Rd.
P.O. Box 98
Oil City, PA 16301-0098
814-677-2028
Fax: 814-677-2936

Rimtec Corp.
1702 Beverly Rd.
Burlington, NJ 08016
800-272-0069, 609-387-0011
Fax: 609-387-0282

Rogers Corp.
One Technology Dr.
Rogers, CT 06263
203-774-9605
Fax: 203-774-9630

Rogers Corp.
Molding Materials Div.
Mill and Oakland Sts.
P.O. Box 550
Manchester, CT 06045
800-243-7158, 203-646-5500
Fax: 203-646-5503

Ronald Mark Associates, Inc.
P.O. Box 776
Hillside, NJ 07205
908-558-0011
Fax: 908-558-9366

Rostone Corp.
P.O. Box 7497
Lafayette, IN 47903
317-474-2421
Fax: 317-474-5870

Rotuba Extruders, Inc.
1401 Park Ave. S.
Linden, NJ 07036
908-486-1000
Fax: 908-486-0874

R.S.G. Polymers Corp.
P.O. Box 1677
Valrico, FL 33594
813-689-7558
Fax: 813-685-6685

RTP Co.
580 E. Front St.
P.O. Box 5439
Winona, MN 55987-0439
800-433-4787, 507-454-6900
Fax: 507-454-2041

Schulman, A., Inc.
3550 W Market St.
Akron, OH 44333
800-547-3746, 216-668-3751
Fax: 216-668-7204
Telex: SCHN 6874 22

Shell Chemical Co.
One Shell Plaza
Rm. 1671
Houston, TX 77002
713-241-6161

Shell Chemical Co.
Polyester Div.
4040 Embassy Pkwy
Suite 220
Akron, Oh 44333
216-798-6400
Fax: 216-798-6400

Shintech Inc.
Weslayan Tower
24 Greenway Plaza
Suite 811
Houston, TX 77046
713-965-0713
Fax: 713-965-0629

Shuman Co.
3232 South Blvd.
Charlotte, NC 28209
704-525-9980
Fax: 704-525-0622

Solvay Polymers, Inc.
P.O. Box 27328
Houston, TX 77227-7328
800-231-6313, 713-525-4000
Fax: 713-522-2435

Sumitomo Plastics America, Inc.
900 Lafayette St.
Suite 510
Santa Clara, CA 95050-4967
408-243-8402
Fax: 408-243-8405

Synergistics Industries (NJ) Inc.
10 Ruckle Ave.
Farmingdale, NJ 07727
908-938-5980
Fax: 908-938-6933

Syracause Plastics, Inc.
400 Clinton St.
Fayetteville, NY 13066
315-637-9881
Fax: 315-637-9260

Teknor Apex Co.
505 Central Ave.
Pawtucket, RI 02861
800-554-9892, 401-725-8000
Fax: 401-724-6250

Tetrafluor, Inc.
2051 E. Maple Ave.
El Segundo, CA 90245
310-322-8030
Fax: 310-640-0312

Texapol Corp.
177 Mikron Rd.
Lower Nazareth Comm. Park
Bethlehem, PA 18017
800-523-9242, 610-759-8222
Fax: 610-759-9460

Thermofil, Inc.
6150 Whitmore Lake Rd.
Brighton, MI 48116-1990
800-444-4408, 810-227-3500
Fax: 810-227-3824

Union Carbide Corp.
39 Old Ridgebury Rd.
Danbury, CT 06817-0001
800-335-8550, 203-794-5300

Vi-Chem Corp.
55 Cottage Grove St. S.W.
Grand Rapids, MI 49507
800-477-8501, 616-247-8501
Fax: 616-247-8703

Vista Chemical Co.
900 Threadneedle
P.O. Box 19029
Houston, TX 77079
713-588-3000

Washington Penn Plastic Co.
2080 N. Main St.
Washington, PA 15301
412-228-1260
Fax: 412-228-0962

Wellman Extrusion
P.O. Box 130
Ripon, WI 54971-0130
800-398-7876, 414-748-7421
Fax: 414-748-6093

Westlake Polymers Corp.
2801 Post Oak Blvd.
Suite 600
Houston, TX 77056
800-545-9477, 713-960-9111
Fax: 713-960-8761

APPENDIX C

Important Properties of Elastomers

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

C.1 Rubber—Molded, Extruded

APPENDIX C.1a

Type →	Polybutadiene	Styrene-butadiene	Isoprene	Isobutylene Isoprene	Nitrile	Hydrogenated Nitrile
ASTM Designation →	BR	SBR	NR, IR	IIR	NBR	HNBR
PHYSICAL PROPERTIES						
Specific Gravity	0.91	0.94	0.92–1.037	0.92	0.98	1.1–1.3
Ther Cond (Btu/hr/sq ft/F/ft)	—	0.143	0.082	0.053	0.143	—
Coef of Ther Exp (cubical) (10^{-5} per °F)	37.5	37	37	32	39	—
Colorability	—	Good	—	Good	Excellent	Good
MECHANICAL PROPERTIES						
Hardness, Durometer	45A–80A	30A–90D	30A–100A	30A–100A	30A–100A	55A–60D
Ten Str (10^3 psi)	2.0–2.5	1.8–3.0	2.5–4.6	>2.0	1.0–3.5	1.5–6.0
Modulus (100%) (psi)	300–1500	300–1500	480–850	50–500	490	300–2900
Elongation (%)	450	450–500	300-750	300–800	400–600	150–550
Compression Set, Method B (%)	10–30	5–30	10–30	25[a]	5–20	10
Resilience (%)						
Yerzley (ASTM 945)	50–90	20–90	80	30	—	—
Rebound (Bashore)	—	10–60	—	—	—	—
Hysteresis Resistance	Good	Fair-Good	Excellent	—	—	Fair-Good
Flex Cracking Resistance	Excellent	Good	Excellent	—	—	Good
Tear Resistance	Good	Fair	Good-Excellent	Good	Good	Good
Abrasion Resistance	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Impact Resistance	Good	Excellent	Excellent	Good	Good	Excellent
ELECTRICAL PROPERTIES						
Vol Res (ohm-cm)	—	$5.0–8.4 \times 10^{13}$	—	2.0×10^{16}	3.5×10^{10}	—
Dielectric Str (v/mil)	400–600	600–800	400–600	600–900	250	—
Dielectric Constant						
60 Hz	—	—	—	2.31	—	—
1 MHz	3.3	—	2.9	2.25	—	—

THERMAL PROPERTIES						
Service Temperature (F)						
Min for Cont Use	−150	−75	−75	−50	−60	−40
Max for Cont Use	200	250	160	300	250	300
ASTM D200/SAE J-200, Type, Class	Not rated	B, A	B, A	B, A	C, H	D, H
ENVIRONMENTAL RESISTANCE						
Ozone	Poor	Poor	Poor	Excellent	Poor	Excellent
Oxidation	Good	Good	Good	Excellent	Fair-Good	Excellent
Weathering	Fair	Fair	Fair	Excellent	Good	Excellent
Water	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Radiation	Poor	Fair-Good	Fair	Poor	Fair-Good	Good
Alkalies	Fair-Good	Fair-Good	Fair-Good	Excellent	Fair-Good	Fair-Good
Aliphatic Hydrocarbons	Poor	Poor	Poor	Fair	Excellent	Excellent
Aromatic Hydrocarbons	Poor	Poor	Poor	Fair-Good	Good	Good
Halogenated Hydrocarbons	Poor	Poor	Poor	Poor	Poor	Poor
Alcohol	Good	Good	Good	Very good	Very good	Fair
Animal, Vegetable Oils	Poor-Good	Poor	Poor-Good	Good	Excellent	Excellent
Acids						
Dilute	Fair-Good	Fair-Good	Fair-Good	Excellent	Excellent	Good-Excellent
Concentrated	Fair-Good	Fair-Good	Fair-Good	Good	Excellent	Fair-Good
Synthetic Lubricants (diester)	Poor-Fair	Poor	Poor-Fair	Fair	Poor	Fair-Poor
Hydraulic Fluids						
Silicates	Poor-Good	Poor-Good	Poor-Good	Fair	Fair	Fair
Phosphates	Poor-Good	Poor-Good	Poor-Good	Good	Poor	Poor
Permeability to Gases	Low	Low	Low	Very low	Very low	Extremely low
Limiting Oxygen Index	—	—	—	18–19	17–20	17–20

APPENDIX C.1a (*Continued*)

Type →	Polybutadiene	Styrene-butadiene	Isoprene	Isobutylene Isoprene	Nitrile	Hydrogenated Nitrile
ASTM Designation →	BR	SBR	NR, IR	IIR	NBR	HNBR
USES	Pneumatic tires; heels, soles; gaskets, seals, belting, sponge, stocks; used in blends with other rubbers for better resilience, abrasion resistance, low temp properties	Same as natural rubber and polybutadiene	Pneumatic tires, tubes; power transmission belts; gaskets; shock absorption, seals against air, moisture, sound, dirt; sponge stock; heels, soles, containment linings	Trucks and auto tire inner tubes; curing bags for tire vulcanization and molding; steam hose, diaphragms, flexible elec insul, shock, vibration absorption	Gasoline, chemical, oil hose; tubing, gaskets, seals, 0-rings; heels, soles; conveyor belting, printing goods and binders for friction materials	Belts, hoses, seals, rollers, blow-out preventors, vibration mounts, tubing

[a] 70 hr at 257 F.

Source: Reprinted with permission from *1994 Materials Selector Issue*: *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

APPENDIX C.1b

Type →	Chloroprene	Polysulfide	Ethylene Propylene	Chlorinated Polyethylene	Chlorosulfonated Polyethylene
ASTM Designation →	CR	PTR	EPM, EPDM	CM	CSM
PHYSICAL PROPERTIES					
Specific Gravity	1.23–1.25	1.35	0.86	1.16–1.32	1.11–1.28
Ther Cond (Btu/hr/sq ft/F/ft)	0.11	—	0.15	—	0.065
Coef of Ther Exp (cubical) (10^{-5} per °F)	34	—	32	—	27
Colorability	Fair	Fair	Good-Excellent	Excellent	Excellent
MECHANICAL PROPERTIES					
Hardness, Durometer	30A–95A	20A–80A	30A–90A	50A–95-A	40A–95A
Ten Str (10^3 psi)	0.5–3.5	0.5–1.5	0.5–3.5	0.9–3.0	0.5–3.5
Modulus (100%) (psi)	100–3000	—	100–3000	700–2200	100–3000
Elongation (%)	100–800	210–450	100–700	100–700	100–700
Compression Set, Method B (%)	20–60[b]	29–38	20–60[b]	5–30	35–80[a]
Resilience (%)					
Yerzley (ASTM 945)	50–80	—	40–75	—	30–70
Rebound (Bashore)	50–80	—	40–75	15–40	30–70
Hysteresis Resistance	Very good	—	Good	Good	Fair-Good
Flex Cracking Resistance	Very good	—	Very good	Excellent	Very good
Tear Resistance	Good	Poor-Fair	Fair-Good	Good	Fair
Abrasion Resistance	Excellent	Poor-Fair	Good-Excellent	Excellent	Excellent
Impact Resistance	Excellent	Poor-Fair	Very good	Excellent	Very good
ELECTRICAL PROPERTIES					
Vol Res (ohm-cm)	2.0×10^{13}	5×10^{13}	2×10^{16}–1×10^{17}	—	1×10^{14}
Dielectric Str (v/mil)	400–600	—	500–1000	—	650
Dielectric Constant					
60 Hz	8.0	7.3[c]	2.25–3.0	—	7.0
1 MHz	6.7	6.8[d]	2.2–2.85	—	6.0[e]
THERMAL PROPERTIES					
Service Temperature (F)					
Min for cont Use	−60	−50	−70	−60	−50
Max for Cont Use	225	>250	300	300	275

APPENDIX C.1b (*Continued*)

Type →	Chloroprene	Polysulfide	Ethylene Propylene	Chlorinated Polyethylene	Chlorosulfonated Polyethylene
ASTM Designation →	CR	PTR	EPM, EPDM	CM	CSM
ASTM D200/SAE J-200, Type, Class	B, E	A, K	D, A	C, E	C, E
ENVIRONMENTAL RESISTANCE					
Ozone	Very good	Excellent	Outstanding	Outstanding	Outstanding
Oxidation	Very good	Excellent	Excellent	Outstanding	Outstanding
Weathering	Very good	Excellent	Outstanding	Good	—
Water	Good	Good	Excellent	Good	Good
Radiation	Good	Fair	Excellent	Excellent	Very good
Alkalies	Excellent	Good	Good-Excellent	Excellent	Excellent
Aliphatic Hydrocarbons	Good	Excellent	Poor-Good	Excellent	Good
Aromatic Hydrocarbons	Fair	Excellent	Poor	Poor	Fair
Halogenated Hydrocarbons	Poor	Fair-Good	Fair-Poor	—	Poor
Alcohol	Good	Very good	Poor-Good	Excellent	Good
Animal, Vegetable Oils	Good	Excellent	Fair	Very good	Good
Acids					
Dilute	Excellent	Good	Excellent	Outstanding	Excellent
Concentrated	Fair-Good	Poor	Fair-Good	Excellent	Very good
Synthetic Lubricants (diester)	Poor	Good	Fair-Good	Poor	Poor
Hydraulic Fluids					
Silicates	Poor-Good	Poor-Good	Fair-Good	Good	Poor
Phosphates	Poor	Poor-Fair	Good-Excellent	Good	Poor
Permeability to Gases	Low-Medium	Very low	Medium	Low	Low
Limiting Oxygen Index	38–45	—	10–20	30–35	30–36

USES	Belts, hose, extruded goods, coatings; molded and sheet goods; adhesives, automotive gaskets, seals; chemical tank linings	Seals, gaskets, diaphragms, valve seat disks, flexible mountings, hose in contact with solvents, balloons, boats, life vests, rafts	Elec insul jacketing; footwear, sponge, proofed fabrics; auto weather strip, hose, belts; auto, appliance parts; parts req outstanding ozone, heat res	Hose, tubing, belting, molded goods	Flex chemical and petroleum tube and hose, rools, tank linings, high temp belts; wire and cable; shoe soles and heels; flooring; building products

[a] 22 hr at 212F. [b] 70 hr at 212F. [c] 1 KC. [d] 1 MC. [e] Estimated.

Source: Reprinted with permission from *1994 Materials Selector Issue*: *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

Type →	Ethylene/ Acrylic	Epichlorohydrin	Polynorborene	Polyacrylate	Silicone
ASTM Designation →		CO, ECO		ACM, ANM	VMQ
PHYSICAL PROPERTIES					
Specific Gravity	1.08–1.12	1.27–1.49	0.96	1.09	1.1–1.6
Ther Cond (Btu/hr/sq ft/F/ft)	—	—	—	—	0.13
Coef of Ther Exp (cubical) (10^{-5} per °F)	—	—	—	—	45
Colorability	—	Good	Excellent	Good	Excellent
MECHANICAL PROPERTIES					
Hardness, Durometer	64A	30A–95A	15–100A	40A–90A	20A–90A
Ten Str (10^3 psi)	1.95	2–3	1.0–4.0	1.8–2.0	1.5
Modulus (100%) (psi)	800[a]	150–2000	100–1500	100–1500	—
Elongation (%)	450	2000–800	100–600	100–400	100–800
Compression Set, Method B (%)	—	20[b]	10–600	10–60	10–30
Resilience (%)					
Yerzley (ASTM 945)	—	50–80	—	—	30–60
Rebound (Bashore)	20	45–75	—	—	—
Hysteresis Resistance	—	Good	Excellent	—	Fair-Good
Flex Cracking Resistance	Excellent	Very good	Good	Fair	Fair-Excellent
Tear Resistance	Excellent	Good	Good	Fair-Good	Fair-Good
Abrasion Resistance	Excellent	Fair-Good	Excellent	Good	Poor
Impact Resistance	—	Good	Excellent	Poor	Good
ELECTRICAL PROPERTIES					
Vol Res (ohm-cm)	1.9×10^{12}	—	—	7×10^{12}	1×10^{14}–1×10^{16}
Dielectric Str (v/mil)	7.30	—	—	800	400–700
Dielectric Constant					
60 Hz	—	—	—	—	2.95–4.0
1 MHz	—	—	—	—	2.95–4.0
THERMAL PROPERTIES					
Service Temperature (F)					
Min for Cont Use	−30	−15 to −80	−60	−40	−178
Max for Cont Use	350	325	250	350	500

ASTM D200/SAE J-200, Type, Class	E, E	C, H	B, E	D, H	G, E
ENVIRONMENTAL RESISTANCE					
Ozone	Outstanding	Excellent	Poor	Excellent	Excellent
Oxidation	Excellent	Excellent	Good	Excellent	Excellent
Weathering	Excellent	Excellent	Fair	Excellent	Excellent
Water	Excellent	Good	Excellent	Fair-Poor	Excellent
Radiation	—	Excellent	Fair-Good	Fair	Fair-Good
Alkalies	Excellent	Good	Fair-Good	Poor	Poor-Fair
Aliphatic Hydrocarbons	Good	Excellent	Poor	Excellent	Poor-Good
Aromatic Hydrocarbons	Good	Very good	Poor	Poor	Poor-Good
Halogenated Hydrocarbons	Good	Good	Poor	Poor	Fair
Alcohol	Fair	Good	Good	Poor	Fair
Animal, Vegetable Oils	Excellent	Excellent	Fair-Good	Very Good	Good
Acids					
Dilute	Excellent	Good	Fair-Good	Fair	Very good
Concentrated	Poor	Poor	Fair-Good	Fair	Good
Synthetic Lubricants (diester)	—	Fair-Good	Good	Good	Good
Hydraulic Fluids					
Silicates	Good	Very good	Fair-Good	Good	Poor
Phosphates	Good	Poor-Fair	Fair-Good	Poor	Good
Permeability to Gases	—	Low	Very low	Medium	High
Limiting Oxygen Index	48[c]	25–33		—	20–30
USES	Automotive ignition wire jackets, spark plug boots, coolant and power steering hose, motor mounts, timing belts, transmission seals	Diaphragms, print rolls, belts, oil seals, molded mechanical goods, gaskets, hose for petroelum handling; low temp parts	Gaskets, body and engine mount, shock absorbing sponges, heels, soles, electrical and appliance parts, low-temperature parts, racing tires	Oil hose, white or pastel colored goods, auto gaskets, O-rings (especially for res to extreme pressure and to lubricants, oil containing sulfur)	High and low temperature electric insulation seals, gaskets, diaphragms, duct work, O-rings, tubing for food and medical uses, solid or liquid injection grades available.

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[a] At 200%. [b] 70 hr at 212 F.

Source: Reprinted with permission from *1994 Materials Selector Issue*: *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

APPENDIX C.1d

Type →	Fluorosilicone	Fluoroelastomer	Perfluoro-elastomer	Polyurethanes	Propylene Oxide	Recycled Rubber (EPDM, SBR)
ASTM Designation →	FVMQ	FKM	FFKM	AU, EU	PO	—
PHYSICAL PROPERTIES						
Specific Gravity	1.4	1.8–1.9	1.9–2.0	1.02–1.25	1.01	0.59–1.30
Ther Cond (Btu/hr/sq ft/F/ft)	0.13	0.06–1.3	0.09	0.09–0.10	—	—
Coef of Ther Exp (cubical) (10^{-5} per °F)	45	—	13	5–25	—	—
Colorability	Very good	Very good	—	Good-Excellent	Good	—
MECHANICAL PROPERTIES						
Hardness, Durometer	40A–80A	55A–95A	75–80A	10A–80D	40A–80A	30–60A
Ten Str (10^3 psi)	0.7–1.5	1.5–2.0	2.3–2.4	0.8–8.0	>2	0.044–0.22
Modulus (100%) (psi)	—	200–2000	1050–1400	25–5000	—	—
Elongation (%)	200–500	150–450	135–150	250–800	500–670	70–150
Compression Set, Method B (%)	10–20	15–30[a]	25–45	10–45[b]	—	—
Resilience (%)						
Yerzley (ASTM 945)	—	40–70	—	5–75	—	—
Rebound (Bashore)	22–35	40–70	—	20–65	—	—
Hysteresis Resistance	Good	Good	—	Fair-Good	Very good	—
Flex Cracking Resistance	Good	Good	—	Good-Excellent	Very good	—
Tear Resistance	Fair-Good	Fair-Very good	—	Outstanding	Excellent	—
Abrasion Resistance	Poor	Good	—	Exc-Outst	Good	—
Impact Resistance	Fair	Good	—	Exc-Outst	Excellent	—
ELECTRICAL PROPERTIES						
Vol Res (ohm-cm)	10^{12}–10^{15}	2×10^{13}	—	0.3×10^{10}–4.7×10^{13}	—	—
Dielectric Str (v/mil)	400–700	500	>450	330–700	—	—
Dielectric Constant						
60 Hz	5–7	5.0–10.0[c]	—	4.7–9.53	—	—
1 MHz	5–7	—	—	5.9–8.51	—	—
THERMAL PROPERTIES						
Service Temperature (F)						
Min for Cont Use	−70	−60	−40	−65	−80	—
Max for Cont Use	400	500	600	250	<250	—

ASTM D200/SAE J-200, Type, Class	F, K	H, K	>J, K	B, G	Not rated	—
ENVIRONMENTAL RESISTANCE						
Ozone	Excellent	Outstanding	Outstanding	Excellent	Excellent	—
Oxidation	Excellent	Outstanding	Outstanding	Excellent	Excellent	—
Weathering	Excellent	Excellent	Outstanding	Good	Excellent	—
Water	Excellent	Very Good	Excellent	Good-Excellent	Excellent	—
Radiation	Fair-Excellent	Fair-Good	Very Good	Good-Excellent	Poor	—
Alkalies	Very good	Fair-Good	Excellent	Poor-Fair	Very good/Exc	—
Aliphatic Hydrocarbons	Excellent	Excellent	Excellent	Excellent	Fair	—
Aromatic Hydrocarbons	Excellent	Excellent	Excellent	Fair-Good	Poor-Fair	—
Halogenated Hydrocarbons	Excellent	Good	Excellent	Poor-Fair	Poor-Fair	—
Alcohol	Good-Excellent	Very Good	Excellent	Poor-Good	Fair-Good	—
Animal, Vegetable Oils	Good	Excellent	Excellent	Excellent	Good	—
Acids						
Dilute	Excellent	Fair-Excellent	Excellent	Fair	Fair	—
Concentrated	Excellent	Fair-Excellent	Excellent	Poor	Poor	—
Synthetic Lubricants (diester)	Outstanding	Good-Excellent	Excellent	Poor-Good	Fair-Good	—
Hydraulic Fluids						
Silicates	Outstanding	Excellent	Excellent	Fair	Fair-Good	—
Phosphates	Poor	Good-Excellent	Excellent	Poor	Poor	—
Permeability to Gases	Medium	Low	Low	Medium	High	—
Limiting Oxygen Index	—	50–100	—	15–20	—	—
USES	Parts req res to high temp solv or oils; seals, gaskets, O-rings, diaphragms Solid or liquid injection grades available.	O-rings, shift seals, gaskets, fuel hose, ducting and connectors, diaphragms, carburetor needle tips, lined valves, packings, roll coverings	High temperature, inert seals for chemical processing and transport, mixed-solvent systems, petroleum refining, semiconductor processing, etc.	Fork-lift truck and airplane tail wheels; back-up wheels for turbine blade grinders; hydraulic accum; heels; rolls, gaskets, seals, mechanical goods	Electrical insulation, molded mechanical goods	Sport surfaces, roofing, walkways, landfill and building membranes, flooring systems, underlayment

[a] 22 hr 392 F. [b] 22 hr at 158 F. [c] 1000 cycles

Source: Reprinted with permission from 1994 *Materials Selector Issue: Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

C.2 Thermoplastic Elastomers

APPENDIX C.2

Type →	Olefinics	Styrenics	Copolymers	Amide Urethanes	Polyester Urethanes	Polyether Ester	Copolyether Polyester
PHYSICAL PROPERTIES							
Specific Gravity	0.84–1.07	0.9–1.2	1.01–1.4	1.18–1.23	1.10–1.20	1.16–1.25	1.22–1.44
Ther Cond (Btu/hr/sq ft/F/ft)	0.08–0.09	0.09	—	0.14–0.19	0.09–0.17	0.154	—
Coef of Ther Exp (cubical) 10^{-5} per °F	6–12	7.2–7.7	6–12	—	5.4–9.5	11–36	—
Colorability	Excellent	Excellent	Outstanding	Excellent	Excellent	Excellent	Excellent
MECHANICAL PROPERTIES							
Hardness, Durometer	35A–95A	45A–95A	60A–75D	70A–80D	80A–65D	35–72D	35–72D
Ten Str (1000 psi)	0.65–4.46	0.5–3.2	3.6–5.0	5.0–8.0	3.0–8.0	1.9–8.7	1.0–4.0
Modulus (100%) (psi)	200–2200	100–800	60–6400	650–5400	650–3400	1100–9500	—
Elongation (%)	50–1000	600–800	—	390–750	350–650	350–685	380–900
Compression Set, Method B (%)	45–92	32–59	—	27–50	25–90	41–67	—
Resilience (%)							
Yerzley (ASTM 945)	—	71–75	—	—	—	—	—
Rebound (Bashore)	35–50	—	—	35	25–50	40–60	—
Hysteresis Resistance	Fair	—	Excellent	Fair	Fair-Good	Good	—
Flex Cracking Resistance	Fair	—	Excellent	Good-Excellent	Excellent	Excellent	—
Tear Resistance	Good-Excellent	Good	Excellent	Good-Excellent	Exc-Outstanding	Excellent	600–1340 lb/in.
Abrasion Resistance	Fair-Good	—	Excellent	Exc-Outstanding	Exc-Outstanding	Excellent	—
Impact Resistance	Exc-Outstanding	Excellent	Outstanding	Excellent	Exc-Outstanding	Excellent	No Break
ELECTRICAL PROPERTIES							
Vol. Res (ohm-cm)	1×10^{16}	2×10^{16}	10^3–10^{13}	2.1×10^{12}–4.7×10^{13}	0.88×10^{12}	2.25×10^{13}	—
					-11×10^{12}	-4.5×10^{14}	—
Dielectric Str (V/mil)	600	400–510	—	330–460	440–730	525–900	—
Dielectric Constant							
60 Hz	2.41	2.5	—	5.75–6.34	6.0	—	—
1 Mhz	2.41	2.5	—	4.53–5.15	4.21	4.6	—

THERMAL PROPERTIES							
Service Temperature (F)							
Min for Cont Use	−60	−65	−80	−65	−65	−60	—
Max for Cont Use	250	300	300	212	180	300	—
ENVIRONMENTAL RESISTANCE							
Ozone	Good-Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	—
Oxidation	Good	—	Excellent	Excellent	Good-Excellent	Excellent	Fair
Weathering	Exc-Outstanding	—	Excellent	Good	Good	Good	Fair
Water	Excellent	Good	Excellent	Good	Good-Excellent	Excellent	Excellent
Radiation	Good	—	Very Good	Good	Good-Excellent	Excellent	Excellent
Alkalies	Good-Excellent	Good	Poor-Good	Poor-Fair	Poor-Fair	Good-Excellent	Fair
Aliphatic Hydrocarbons	Fair-Good	Poor	Good	Excellent	Excellent	Good-Excellent	Good
Aromatic Hydrocarbons	Poor	Poor	Good	Fair-Good	Fair-Good	Excellent	Good
Halogenated Hydrocarbons	Poor	Poor	Good	Fair	Poor-Fair	Poor	Good
Alcohol	Fair-Good	Good	Good-Excellent	Poor-Fair	Fair-Good	Good	Excellent
Animal, Vegetable Oils	Fair-Good	—		Excellent	Excellent	Excellent	Good
Acids							
Dilute	Good-Excellent	Good	Good	Fair	Fair	Good	Good
Concentrated	Good-Excellent	Fair	Good	Poor	Poor	Poor	Poor
Synthetic Lubricants (diester)	Good	—	Good	Poor	Poor-Good	Excellent	—
Hydraulic Fluids							
Silicates	Fair-Good	—	Good	Poor	Fair	Excellent	Good
Phosphates	Fair-Good	—	Good	Poor	Poor	Good	—
Permeability to gases	Low	—	Low	Medium	Medium	Medium	Medium
Limiting Oxygen Index	17–20	—	—	—	15–20	20[a]	—
USES	Cable jacketing, sheeting, tubing, blown film, tires, gaskets, seals	Tubing, sheeting, disposable medical products, sealants, shoe soles, asphalt modification	Electrical, automotive, sporting goods, materials, handling	Tubing, film, seals, gaskets, shoe soles, automotive fascia, O-rings, diaphragms, casters	Tubing, film, cable jacketing, seals, gaskets, diaphragms, O-rings, bladders, wheels, casters	Tubing, hose film, gears, wire and cable jacketing, gaskets, belting, sheeting, all terrain vehicle tracks, automotive body panels.	Gaskets, seals, bellows, wire coating, tubing, connectors, automotive fascia

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[a] 30 with additives

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APPENDIX D

Important Information Regarding Coatings

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

D.1 Organic Coatings

APPENDIX D.1a

	Solvent-Base								Water Borne		
		Rubber							Solution		
Type →	Poly-ethylene	Chlorinated Rubber	Chloro-prene	Chlorosul-fonated Polyethy-lene	Fluoro-carbon	Urethane	Vinyl	Vinyl-Alkyd (Approx 1:1)	Alkyd	Polyester (Oil-free)	Acrylic (Thermo-setting)
CHEMICAL RESISTANCE											
ExteriorDurability	P	E	E	E	E	E	E	E	E	E	E
Salt Spray	VG	E	E	E	E	E	E	E	E	E	E
Solvents—Alcohols	E	E	E	—	E	E	F	G	F	G	P
Solvents—Gasoline	P	G	G	G	E	E	G	G	G	E	G
Solvents—Hydrocarbons	—	—	G	G	E	E	—	—	G	E	F
Solvents—Esters, Ketones	G	P	P	P	—	E	P	P	—	—	—
Solvents—Chlorinated	P	P	P	P	G	G	P	P	—	—	—
Beverages, Food	—	—	—	—	—	—	—	—	F	G	VG
Salts	E	E	E	E	E	E	E	G	VG	G	VG
Ammonia	E	G	G	G	E	F	E	P	P	P	P
Alkalis	P, G	E, E	E, E	E, E	E, E	E, G	E, E	G, P	P, P	P	G, F
Acids—Mineral	—	E, E, E	E, G, G	E, E, G	E, E, E	E, G, F	E, E, G	VG, G, P	F, P, P	E	G, F, P
Acids—Oxidizing	VG, VG, VG	E, E, F	F, P, P	G, G, F	E, E, E	G, F, P	E, VG, G	P, P, P	P, P, P	P	F, P, P
Acids—Organic (acetic, formic, etc.)	VG, F, P	G, P, P	G, F, F	G, F, F	G, G, G	G, F, F	E, P, P	G, F, P	P, P, P	P	P, P, P
Acids—Organic (oleic, stearic, etc.)	G	F	G	G	G	E	E	E	F	F	F
Acid—Phosphoric	VG	G	VG	G	G	E	E	F	P	F	P
Water (salt, fresh)	E	E	E	E	G	E	E	E	F	G	E
PHYSICAL PROPERTIES											
Sward Rocker Hard. (8th day)	—	24	<10	<10	<10	35–65	20	26	22–28	22–28	24–32
Flexibility	E	VG	E	E	G	E	E	E	E	G	E
Abrasion Res, cycles[a]	—	> 5000	5000	5000	1000	> 7500	> 5000	250A	3500	3500	2500
Max Svc Temp, F	225	200	200	250	550	300	150	180	200	200	180
Toxicity	None	Slight	None	—	Slight	Slight	None	None	None	None	None

Impact Res	E	G	E	E	E	E	E	E	F-G	G-E	F-G
Dielec Properties	E	E	G	VG	G	E	E	G	G	G	VG
Adhesion to—											
Ferrous Metals	E	F	VG	VG	VG	E	G	VG	—	—	—
Nonferrous Metals	E	VG	VG	VG	VG	E	VG	G	—	—	—
DECORATIVE PROPERTIES											
Choice of Colors[b]	U	U	L	U	U	U	U	U	U	U	U
Color Retention[c]	E	G	G	E	G	E	E	E	G	E	E
Initial Gloss	E	VG	P	P	E	E	G	E	E	E	E
Gloss Retention	E	G	F	F	F	E	E	E	E	G	E
APPLICATION											
Ease of Application	E	G	VG	VG	VG	E	F	VG	—	—	—
Metal Surface Prep	No primer	Primer	No Primer	Primer	Primer	Primer	Primer	Primer	—	—	—
Solvent for Appl[d]	None	Hyd	Hyd	Hyd	Blend	Blend	Blend	Blend	—	—	—
Methods[b]	SL	U	U	U	L	U	L	U	—	—	—
Cure[e]	B	A or B	A or B	A or B	A or B	A or B	A or B	A	—	—	—
Bake Drying Time	10–15 min (450 F)	15 min (300 F)	15 min (300 F)	15 min (300 F)	—	15 min (300 F)	15 min (300 F)	—	—	—	—
Air Drying Times											
Touch	—	45 min	15 min	15 min	5 min	45 min	5 min	15 min	—	—	—
Handle	—	2 hr	30 min	30 min	15 min	1–2 hr	15 min	30 min	—	—	—
Re-Coat	—	4–6 hr	4 hr	4 hr	12 hr	4–6 hr	15 min	4–6 hr	—	—	—
Hard	—	4–6 hr	4 hr	4 hr	12 hr	18 hr	4–6 hr	12 hr	—	—	—
Corr Res	—	24 hr	7–10 days	7–10 days	12 hr	5–7 days	24 hr	24 hr	—	—	—
Coverage sq ft/gal/mil	560	450	300–400	250–350	200	—	250	200	—	—	—
Coat Thk (avg), mil	3–10	1.5	2–10	2	1.0	1–4	1.0	1.0	—	—	—

RATING KEY: E, excellent; VG, very good; G, good; F, fair; P, poor. Two ratings are for 20% and concentrated solutions, respectively. Three ratings are for 10%, 10–30% and concentrated solutions, respectively.

[a] Taber GS-10 wheel. [b] Key: L, limited (i.e., pure white cannot be formulated); SL, slightly limited (difficluty in formulating whites and pastels); U, unlimited (any color can be formulated). [c] Based on white coatings with titanium dioxide pigment. [d] Key: Hyd, hydrocarbons; Alc, alcohols. [e] Key: A, air dried; B, can be baked.

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APPENDIX D.1b

Powder														
Emulsion			Colloidal											
Epoxy-amine	Epoxy-ester	Acrylic	Acrylic (Thermoplastic)	Acrylic (Thermoplastic)	Cellu-losics	Epoxies	Chlori-nated Polyether	Polyamide (Nylon 11, 12)	Fluoro-carbon, PTFE	Thermo-plastic Polyester	Thermoset Polyester	Poly-ethylene	Vinyl (PVC)	Poly-propylene
G	E	E	E	E	G	F	F	G	E	VG	—	F	E	F
VG	E	E	E	E	G	E	E	VG	E	G	E	G	E	E
G	F	P	P	G–E	F	E	E	G	E	E	—	E	E	G
E	E	G	G	G–E	G	E	VG	E	E	E	—	VG	E	E
E	VG	F	F	F	G	E	E	E	E	G	E	VG	G	F
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
E	VG	VG	VG	VG	G	E	E	VG	E	—	—	E	E	E
E	E	VG	VG	VG	VG	E	E	VG	E	G	E	E	E	E
G	P	P	P	F–G	P	F	E	G	E	F	P	E	E	E
E, E	E, E	G, F	G, F	F	F	VG	VG	G	E	P	—	VG	E	E
E, VG,G	G, F, P	G, F, P	G, F, P	F	—	—	—	—	—	—	—	—	—	—
G, P, P	F, P, P	F, P, P	F, P, P	F	P	G	VG	P	E	P	—	P	G	VG
F, E, P	F, P, P	P, P, P	P, P, P	F	P	G	E	P	E	G	—	VG	P	E
G	E	F	F	F	F	E	E	VG	E	G	—	VG	E	E
G	P	P	P	F	P	G	E	—	E	—	—	VG	E	VG
G	VG	E	E	G	VG	VG	E	G	E	G	—	VG	E	E
36	30	20–24	24–32	24–32	—	—	—	—	—	—	—	—	—	—
E	E	F–G	G	F–G	G	E	F	VG	G	F	E	E	E	G
> 5000	> 5000	2500	2500	2500	—	—	—	—	—	—	—	—	—	—

400	300	180	180	180	180	350+	250	180+	500	200	450	160	200+	225
None	None	None	None	None	—	—	—	—	—	—	—	—	—	—
G	E	F–G	F–G	VG	E	E	G	E	E	G	E	F	E	G
VG	VG	VG	VG	VG	VG	E	VG	G	E	F	E	E	VG	E
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
U	U	U	U	U	U	U	L	G	L	U	—	L	U	G
F	G	E	E	E	E	VG	G	VG	G	G	—	VG	VG	G
E	E	E	E	E	—	—	—	—	—	—	—	—	—	—
F	G	E	E	E	—	—	—	—	—	—	—	—	—	—

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D.2 *Organic Coatings—Solvent Base*

APPENDIX D.2a

	Alkyd								Cellulose		
Type ⟶	Alkyd	Alkyd-Amine	Alkyd-Phenolic	Alkyd-Silicone	Alkyd-Urea	Styrenated Alkyd	Acrylic	Bitu-minous	Nitro-cellulose	Butyrate	Ethyl Cellulose
CHEMICAL RESISTANCE											
Exterior Durability	E	E	E	E	E	G	E	F	E	E	E
Salt Spray	E	VG	E	E	G	G	E	E	E	E	E
Solvents–Alcohols	F	G	G	G	G	G	P	P	G	G	P
Solvents–Gasoline	G	E	E	E	E	F	G	P	G	G	P
Solvents–Hydrocarbons	G	E	E	G	E	F	F	P	F	F	F
Solvents–Esters, Ketones	P	P	F	P	F	P	P	P	P	P	P
Solvents–Chlorinated	P	P	P	P	P	P	P	P	P	P	P
Beverages, Food	F	G	VG	G	G	VG	VG	E	G	G	E
Salts	VG	E	E	VG	E	E	VG	G	G	VG	G
Ammonia	P	P	P	P	P	P	P	—	P	P	G
Alkalis	P, P	VG, G	F, P	G, F	G, G	G, VG	G, F	E	P, P	P, P	G, G
Acids–Mineral	F, P, P	G, F, P	VG, G, F	G, P, P	G, P, P	G, F, P	G, F, P	G, –, –	E, G, F	G, F, P	G, F, P
Acids–Oxidizing	P, P, P	F, P, P	G, F, P	P, P, P	F, P, P	F, P, P	F, P, P	—	P, P, P	P, P, P	F, P, P
Acids–Organic (acetic, formic, etc.)	P, P, P	P, P, P	F, P, P	P, P, P	P, P, P	P, P, P	P, P, P	E, –, –	P, P, P	P, P, P	G, –, –
Acids–Organic (oleic, stearic, etc.)	F	G	VG	G	F	F	F	P	F	F	—
Acid–Phosphoric	P	P	P	P	P	P	P	E	E	P	—
Water (salt, fresh)	F	G	G	G	F	G	E	E	G	E	E
PHYSICAL PROPERTIES											
Sward Rocker-Hard (8th day)	24	30	34	16–30	28	28	24	—	30–50	26	25–30
Flexibility	E	VG	G	VG	VG	G	E	E	E	E	E
Abrasion Res, cycles[a]	3500	> 5000	> 5000	4000	> 5000	> 5000	2500	—	2500	2500	—
Max Svc Temp, F	200	250	250	450	225	200	180	200	180	180	300
Toxicity	None	Slight	None	None	Slight	Slight	None	—	None	None	None
Impact Res	VG	E	G	G	E	G	E	E	E	E	E
Dielec Properties	G	G	VG	E	G	G	VG	—	F	G	E

Adhesion to—											
Ferrous Metals	E	E	E	VG	E	F	VG	E	VG	VG	P
Nonferrous Metals	F	E	E	VG	VG	F	VG	E	G	G	G
Old Paints	VG	G	G	E	G	VG	P	—	P	P	P
DECORATIVE PROPERTIES											
Choice of Colors[b]	U	U	SL	U	U	U	U	L	U	U	U
Color Retention[c]	G	VG	P	E	VG	G	E	—	E	E	E
Initial Gloss	E	E	VG	E	E	E	E	P	E	E	E
Gloss Retention	E	G	F	E	F	G	E	—	VG	E	VG
APPLICATION											
Ease of Application	E	Bake req	E	E	Bake req	E	VG	P-VG	VG	VG	VG
Metal Surface Prep	Primer	No primer	No primer	Primer	No primer	No primer	Primer	No primer	Primer	Primer	Primer
Solvent for Appl[d]	Hyd	Hyd	Hyd	Hyd	Hyd	Hyd	Hyd	—	Blend	Blend	Blend
Method[b]	U	U	U	U	U	U	U	U	U	U	U
Cure[e]	A or B	B	A or B	A or B	B	A or B	A	A	A	A	A
Bake Drying Time	30 min (275 F)	20 min (320 F)	30 min (350 F)	30 min (350 F)	20 min (320 F)	15 min (300 F)	—	—	—	—	—
Air Drying Times											
Touch	2 hr	—	20 min	45 min	—	10 min	5 min	2 hr	5 min	5 min	5 min
Handle	4 hr	—	60 min	2 hr	—	30 min	15 min	24 hr	15 min	15 min	15 min
Re-Coat	4 hr	—	6 hr	4-6 hr	—	4 hr	15 min	—	15 min	15 min	15 min
Hard	12 hr	—	6 hr	12 hr	—	4 hr	12 hr	24 hr	12 hr	12 hr	12 hr
Corr Res	48 hr	—	48 hr	12 hr	—	48 hr	24 hr	—	24 hr	24 hr	—
Coverage, sq ft/gal/mil	450	450	450	500	450	400	350	—	300	200	300
Coat Thk (avg), mil	1.5	1.5	1.5	0.6	1.5	1.5	1.0	3-250	1.0	1.0	1.0

RATINGS KEY: E, excellent; VG, very good; G, Good; F, fair; P, poor. Two ratings are for 20% and concentrated solutions, respectively. Three ratings are for 10%, 10-30% and concentrated solutions, respectively.

[a] Taber GS-10 wheel. [b] Key: L, limited (i.e., pure white cannot be formulated); SL, slightly limited (difficulty in formulating whites and pastels); U, unlimited (any color can be formulated). [c] Based on white coatings with titanium dioxide pigment. [d] Key: Hyd, hydrocarbons; Alc, alcohols. [e] Key: A, air dried; B, can be baked.

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APPENDIX D.2b

Epoxy													
Epoxy-Amine	Epoxy-Ester	Epoxy-Furane	Epoxy-Melamine	Epoxy-Phenolic	Epoxy-Urea	Chlorinated Polyether	Chlorinated Poly-propylene	Fluoro-Carbon	Furane	Phenolic	Poly-amide (Nylon)	Polyester	Silicone
G	E	E	E	E	VG	E	E	E	G	E	P	E	E
VG	E	E	E	E	E	E	E	E	G	E	F	E	E
G	F	E	E	E	E	E	E	E	E	E	G	G	F
E	E	E	E	E	E	E	F	E	E	E	G	E	F
E	VG	E	E	E	E	E	F	E	E	E	—	E	G
VG	F	G	VG	E	VG	E	P	P	G	F	—	P	P
G	F	E	E	E	E	E	P	E	E	F	—	P	P
E	VG	E	E	E	E	E	G	E	E	E	—	G	F
E	E	E	E	E	E	E	E	E	E	E	—	G	G
G	P	E	P	F	P	E	G	E	E	P	G	P	P
E, E	E, E	E	E, E	E, E	E, E	E	VG, VG	E, E	E	P, P	G, G	P	E, F
E, VG, G	G, F P	G	E, VG, G	E, E, E	E, VG, F	E, E, E	E, G, G	E, E, E	E	G, F, P	P, P, P	E	G, G, P
G, P, P	F, P, P	F	G, P, P	E, VG, P	F, P, P	E, G, F	E, E, G	E, E, E	P	G, F, P	—	P	P, P, P
F, F, P	F, P, P	F, G	G, F, P	E, E, VG	F, P, P	E, E, E	G, P, P	E, E, E	F, G	G, F, P	P, P, P	P	P, P, P
G	E	E	E	E	E	E	G	E	E	E	VG	F	G
G	P	E	G	E	G	E	G	E	E	F	—	F	F
G	VG	E	G	E	G	E	E	E	E	E	F	G	E
36	30	24	36	44	34	—	24	<10	38	38	—	30	16
F	E	E	VG	VG, E	VG	F	VG	G	F	G	G	G	F
> 5000	> 5000	—	> 5000	> 5000	> 5000	> 5000	> 5000	1000	—	> 5000	—	3500	2500
400	300	350	400	400	400	250	200	550	300	350	300	200	1000
None	None	None	None	None	None	None	None	Slight	None	None	—	None	None
G	E	G	VG	VG	G	F	G	E	F	G	VG	F	F
VG	VG	G	VG	VG	VG	E	E	E	F	E	G	G	E

E	E	E	E	E	E	VG	E	VG	F	E	VG	F	F
E	E	E	E	E	E	G	VG	VG	F	E	VG	F-P	E
G	VG	E	P	P	P	P	E	P	E	G	—	P	E
U	U	L	SL	L	SL	L	U	U	L	L	L	U	U
F	G	G	G	P	G	E	G	G	G	P	—	E	E
E	E	G	VG	VG	VG	E	E	E	E	VG	F	E	E
F	G	G	F	F	F	F	G	F	F	F	—	G	E
catal req	E	E	Bake req	Bake req	Bake req	F	G	VG	E	E	G	F	E
No primer	Primer	None	No primer	No primer	No primer	Primer	Primer	Primer	Primer	No primer	No primer	Primer	Primer
Blend	Hyd	Ketone	Blend	Blend	Blend	—	Hyd	Blend	Ketone	Alc, Hyd	—	Styrene	Hyd
U	U	U	L	L	L	L	U	L	U	U	L	L	U
A	A or B	B	B	B	B	B	A or B	A or B	A or B	A or B	A	A or B	A or B
—	30 min (320 F)	30 min (350 F)	30 min (350 F)	30 min (400 F)	30 min (350 F)	15 + min (425 F)	15 min (300 F)	3–15 min (450–600)	30 min (300 F)	30 min (350 F)	—	15 min (300 F)	1 hr (450 F)
60 min	1 hr	—	—	—	—	—	15 min	5 min	1 hr	10 min	—	1 hr	45 min
2 hr	2 hr	—	—	—	—	—	30 min	15 min	4 hr	30 min	—	1 hr	2 hr
6–8 hr	8 hr	—	—	—	—	—	4–6 hr	12 hr	6 hr	30 min	—	1 hr	4–6 hr
12 hr	8 hr	—	—	—	—	—	4–6 hr	12 hr	24 hr	4 hr	—	12 hr	12 hr
7–10 days	5 days	—	—	—	—	—	24 hr	12 hr	48 hr	24 hr	—	7–10 days	12 hr
500	450	450	500	450	500	—	450	200	400	350	—	800	350
1.8	1.5	0.5–1.0	1.8	1.8	1.8	25–30	1.5	1.0	3–5	1.5	2-30	2-50	1.0

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D.3 Application Methods for Coatings

APPENDIX D.3

Method	Advantages	Limitations	Typical applications
Spray	Fast, adaptable to varied shapes and sizes. Equipment cost is low.	Difficult to completely coat complex parts and to obtain uniform thickness and reproducible coverage.	Motor frames and housings, electronic enclosures, circuit boards, electronic modules.
Dip	Provides thorough coverage, even on complex parts such as tubes and high-density electronic modules.	Viscosity and pot life of dip must be monitored. Speed of withdrawal must be regulated for consistent coating thickness.	Small- and medium-sized parts,castings, moisture and fungus proofing of modules, temporary protection of finished machined parts.
Brush	Brushing action provids good "wetting" of surface, resulting in good adhesion. Cost of equipment is lowest.	Poor thickness control; not for precise applications. High labor cost.	Coating of individual components, spot repairs, or maintenance.
Roller	High-speed continuous process; provides excellent control on thickness.	Large runs of flat sheets or coil stock required to justify equipment cost and setup time. Equipment cost is high.	Metal decorating of sheet to be used to fabricate cans, boxes.
Impregnation	Results in complete coverage of intricate and closely spaced parts. Seals fine leaks or pores.	Requires vacuum or pressure cycling or both. Special equipment usually required.	Coils, transformers, field and armature windings, metal castings, and sealing of porous structures.
Fluidized bed	Thick coatings can be applied in one dip. Uniform coating thickness on exposed surfaces. Dry materials are used, saving cost of solvents.	Requires preheating of part to above fusion temperature of coating. This temperature may be too high for some parts.	Motor stators; heavy-duty electrical insulation on castings, metal substrates for circuit boards, heat sinks.
Screen-on	Deposits coating in selected areas through a mask. Provides good pattern deposition and controlled thickness.	Requires flat or smoothly curved surface. Preparation of screens is time-consuming.	Circuit boards, artwork, labels, masking against etching solution, spot insulation between circuitry layers or under heat sinks or components.

Electrocoating	Provides good control of thickness and uniformity. Parts wet from cleaning need not be dried before coating.	Limited number of coating types can be used; compounds must be specially formulated ionic polymers. Often porous, sometimes nonadherent.	Primers for frames and bodies, complex castings such as open work, motor end bells.
Vacuum deposition. . .	Ultrathin, pinhole-free films possible. Selective deposition can be made through masks.	Thermal instability of most plastics; decomposition occurs on products. Vacuum control needed.	Experimental at present. Potential use is in microelectronics, capacitor dielectrics.
Electrostatic spray	Highly efficient coverage and use of paint on complex parts. Successfully automated.	High equipment cost. Requires specially formulated coatings.	Heat dissipators, electronic enclosures, open-work grills and complex parts.

Source: Izzo, C. P., “Protective and Decorative Coatings’’, *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

D.4 *Specific Test Methods for Coatings*

APPENDIX D.4

Test	ASTM	Fed. STD. 141a, Method	MIL-STD-202, Method	Fed. STD. 406, Method	Others
Abrasion	D 968	6191 (Falling Sand) 6192 (Taber)	—	1091	Fed. Std. 601, 14111
Adhesion	—	6301.1 (Tape Test, Wet) 6302.1 (Microknife)	—	1111	Fed. Std. 601, 8031
	D 2197	6303.1 (Scratch Adhesion) 6304.1 (Knife Test)			
Arc resistance	D 495	—	303	4011	
Dielectric constant	D 150	—	301	4021	Fed. Std. 101, 303
Dielectric strength (breakdown voltage)	D 149 D 115	—	—	4031	Fed. Std. 601, 13311
Dissipation factor	D 150	—	—	4021	
Drying time	D 1640 D 115	4061.1			
Electrical insulation resistance	D 229	—	302	4041	MIL-W-81044, 4.7.5.2
	D 257	—	—	—	
Exposure (exterior)	D 1014	6160 (On Metals) 6161.1 (Outdoor Rack)			
Flash point	D 56, D 92	4291 (Tag Closed Cup) 4294 (Cleveland Open Cup)	—	—	Fed. Std. 810, 509
	D 1310 (Tag Open Cup)				
Flexibility	—	6221 (Mandrel) 6222 (Conical Mandrel)	—	1031	Fed. Std. 601, 11041

Fungus resistance	D 1924	—	—	—	MIL-E-5272, 4.8 MIL-STD-810, 508.1 MIL-T-5422, 4.8
Hardness	—	6211 (Print Hardness)			
	D 1474	6212 (Indentation)			
Heat resistance	D 115				
	D 1932	6051			
Humidity	D 2247	6071 (100% RH)	103	—	MIL-E-5272, Proc. 1
		6201 (Continuous Condensation)	106A	—	Fed. Std. 810, 507
Impact resistance	—	6226 (G.E. Impact)	1074		
Moisture-vapor permeability	E 96				
	D 1653	6171	7032		
Nonvolatile content	—	4044			
Salt spray (fog)	B 117	6061	101C	6071	MIL-STD-810, 509.1 MIL-E-5272, 4.6 Fed. Std. 151, 811.1 Fed. Std. 810, 509
Temperature-altitude	—	—	—	—	MIL-E-5272, 4.14 MIL-T-5422, 4.1 MIL-STD-810, 504.1
Thermal conductivity	D 1674 (Cenco Fitch) C 177 (Guarded Hot Plate)	—	—	—	MIL-I-16923, 4.6.9
Thermal shock	—	—	107	—	MIL-E-5272, 4.3 MIL-STD-810, 503.1
Thickness (dry film)	D 1005	6181 (Magnetic Gage)	—	2111, 2121	Fed. Std. 151, 520, 521.1
	D 1186	6183 (Mechanical Gage)	—	2131, 2141, 2151	

Test	ASTM	Fed. STD. 141a, Method	MIL-STD-202, Method	Fed. STD. 406, Method	Others
Viscosity	D 1545	4271 (Gardner Tubes)			
	D 562	4281 (Krebs-Stormer)			
	D 1200	4282 (Ford Cup)			
	D 88	4285 (Saybolt)			
		4287 (Brookfield)			
Weathering (accelerated)	D 822	6151 (Open Arc)	—	6024	
		6152 (Enclosed Arc)			

A more complete compilation of test methods is found in J. J. Licari, *Plastic Coatings for Electronics*, McGraw-Hill Book Company, New York, 1970.

The major collection of complete test methods for coatings is *Physical and Chemical Examination of Paints, Varnishes, Lacquers, and Colors*, by Gardner and Sward, Gardner Laboratory, Bethesda, MD. This has gone through many editions.

Source: Izzo, C. P., "Protective and Decorative Coatings", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

D.5 NEMA Standards for Magnet Wire Insulation

APPENDIX D.5a

Manufacturer	Plain Enamel	Polyvinyl Formal	Polyvinyl Formal Modified	Polyvinyl Formal with Nylon Overcoat	Polyvinyl Formal with Butyral Overcoat	Polyamide	Acrylic	Epoxy
Thermal class	105°C	105°C	105°C	105°C	105°C	105°C	105°C	130°C
NEMA Standard[6]	MW 1	MW 15	MW 27	MW 17	MW 19	MW 6	MW 4	MW 9
Anaconda Wire & Cable Co.	Plain enamel	Formvar	Hermetic Formvar	Nyform	Cement coated Formvar	—	—	Epoxy epoxy-cement coated
Asco Wire & Cable Co.	Enamel	Formvar	—	Nyform	Formbond	Nylon	Acrylic	Epoxy
Belden Manufacturing Co.	Beld-enamel	Formvar	—		Nyclad		—	Epoxy
Bridgeport Insulated Wire Co.			Formvar		Quick bond	Quick-Sol	—	—
Chicago Magnet Wire Corp.	Plain enamel	Formvar		Nyform	Bondable Formvar	Nylon	Acrylic	Epoxy
Essex Wire Corp.	Plain enamel	Formvar	Formetex	Nyform	Bondex		Ensolex/ ESX	Epoxy
General Cable Corp.	Plain enamel	Formvar	Formetic	Formlon	Formeze		Solderable acrylic	Epoxy
General Electric Co.	—	Formex	—	—	—	Nylon	—	—
Haveg-Super Temp Div	—	—	—	—	—	—	—	—
Hitemp Wires Co. Division Simplex Wire & Cable Co.	—	—	—	—	—	—	—	—

APPENDIX D.5a (*Continued*)

Manufacturer	Plain Enamel	Polyvinyl Formal	Polyvinyl Formal Modified	Polyvinyl Formal with Nylon Overcoat	Polyvinyl Formal with Butyral Overcoat	Polyamide	Acrylic	Epoxy
Hudson Wire Co.	Plain enamel	Formvar	—	Nyform	Formvar AVC	Ezsol	—	—
New Haven Wire & Cable, Inc.	Plain enamel	—	—	—	—	—	—	—
Phelps Dodge Magnet Wire Corp.	Enamel	Formvar	Hermeteze	Nyform	Bondeze	—	—	—
Rea Magnet Wire Co., Inc.	Plain enamel	Formvar	Hermetic Formvar special	Nyform	Koilset	Nylon		Epoxy
Viking Wire Co., Inc.	Enamel	Formvar	—	Nyform	F-Bondall	Nylon	—	—

Courtesy of Rea Magnet Wire Co., Inc.

Source: Izzo, C. P., "Protective and Decorative Coatings", *Handbook of Plastics, Elastomers, and Composites* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

APPENDIX D.5b

Manufacturer	Teflon	Polyurethane	Polyurethane with Friction Surface	Polyurethane with Nylon Overcoat	Polyurethane with Butyral Overcoat	Polyurethane with Nylon and Butyral Overcoat	Polyester	Polyester with Overcoat	Polyimide	Polyester Polyimide	Ceramic, Ceramic-Teflon, Ceramic-Silicon
Thermal class	200°C	105°C	105°C	130°C	105°C	130°C	155°C	155°C	220°C	180°C	180°C+
NEMA Standard[6]	MW 10	MW 2	—	MW 28	MW 3 (PROP)	MW 29 (PROP)	MW 5	MW 5	MW 16	—	MW 7
Anaconda Wire & Cable Co.		Analac	—	Nylac	Cement-coated analac	Cemente coated nylac	—	Anatherm D, Anatherm 200	Al 200 M.L.	Anatherm N Anamid M (amid -imide)	
Asco Wire & Cable Co.		Poly	—	Nypol	Asco bond-P	Asco bond	Ascotherm	Isotherm 200	M.L.	Ascomid	
Belden Manufacturing Co.		Beldure	—	Beldsol	—	—	Isonel	Polythermaleze	M.L.		
Bridgeport Insulated Wire Co.		Polyurethane	Uniwind	Polynylon	Polybond	—	Isonel 200				
Chicago Magnet Wire Corp.		Soder brite	—	Nysod	Bondable polyurethane	—	Polyester 155				
Essex Wire Corp.		Soderex	—	Soderon	Soderbond	Soderbond N	Thermalex F	Polyther malex/ PTX 200	Allex		
General Cable Corp.		Enamel "G"	—	Genlon	—	—	Gentherm	Polythermaleze 200			

APPENDIX D.5b (*Continued*)

Manufacturer	Teflon	Poly-urethane	Poly-urethane with Friction Surface	Poly-urethane with Nylon Overcoat	Poly-urethane with Butyral Overcoat	Poly-urethane with Nylon and Butyral Overcoat	Polyester	Polyester with Overcoat	Poly-imide	Polyester Polyimide	Ceramic, Ceramic-Teflon, Ceramic-Silicon
General Electric Co		—	—	—	—	—	Alkanex				
Haveg-Super Temp Div	Teflon	—	—	—	—	—	Isonel				
Hitemp Wires Co. Division Simplex Wire & Cable Co.	Temprite										
Hudson Wire Co.		Hudsol	Gripon	Nypoly	Hudsol AVC	Nypoly AVC	Isonel 200	Isonel 200-A	M.L.	Isomid	
New Haven Wire & Cable, Inc.		Impsol	—	Impsolon	—	—	—	Imp-200			
Phelps-Dodge Magnet Wire Corp.		Sodereze	Gripeze	Nyleze	—	S-Y Bondeze	—	Polyther-maleze 200 II	M.L		
Rea magnet Wire Co., Inc.		Solvar	—	Nylon solvar	Solvar koilset	—	Isonel 200	Polyther-maleze 200	Pyre M.L.	Isomid	Ceroc
Viking Wire Co., Inc.		Polyure-thane		Poly-nylon	P-Bondall	—	Isonel 200	Iso-poly	M.L.	Isomid Isomid-P	

Source: Izzo, C. P., “Protective and Decorative Coatings”, *Handbook of Plastics, Elastomers, and Composites* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

APPENDIX E

Important Properties of Laminates

*E.1 Description of NEMA Laminate Grades**

Paper-Base Grades with Phenolic Resin

- *Grade X:* These laminates are used for mechanical applications and are affected by humidity. They are not usually used in electrical applications as an insulating material. The impact strength is low. Rolled tubes machine easily and have low dissipation factors. Rods are not available.
- *Grade XP:* This grade is intended for hot punching at 212°F or higher, but laminates less than 0.062 in may be punched at room temperature. Grade XP has lower physical properties than Grade X but is somewhat better in resistance to humidity. Rods and tubes are not made from this material.
- *Grade XPC:* These laminates can be punched or cut at room temperature. They have lower flexural strength than grade XP and are less rigid. Rods and tubes are not made from this material.
- *Grade XX:* These laminates can be used as electrical insulations. They do not punch well but are easily machined. Rolled tubes can be threaded, but they are not as strong as Grade X. Moisture resistance is somewhat better than Grade X. Molded tubes resist humidity better than the rolled tubes, but seams have lower electric strength. Rods are available.

[*] Sampson, R. N., "Laminates and Reinforced Plastics Materials and Processes", *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

- *Grade XXP:* This is punchable type of Grade XX. Laminates must be punched hot (>212°F). The electrical properties are better than Grade XX. Rods and tubes are not available.
- *Grade XXX:* This is an excellent electrical laminate, and it resists humidity and creep. Rolled tubes have electrical properties superior to other grades. Molded tubes and rods are similar in properties to the laminate.
- *Grade XXXP:* This is a punchable grade of XXX. Hot punching (>212°F) is required. Electrical properties are better than Grade XXX. The material can be used when high resistivities are needed at high humidity. Rods and tubes are not available.
- *Grade XXXPC:* This grade is punchable at room temperature and has properties similar to Grade XXXP. Rods and tubes are not available.
- *Grade ES-1:* This grade and the other ES grades are used as name-plate stock. The surface layer is black or other colors and the center core is white melamine paper. Engraving exposes the white section.
- *Grade ES-2:* This material has a white surface and a black core made from phenolic impregnated paper.
- *Grade ES-3:* This grade is similar to ES-1, with various colored surfaces and a black core.

Fabric-Base Grades with Phenolic Resin Binder

- *Grade C:* Laminates are molded from cotton fabrics weighing more than 4 oz per square yard. The material is used for pulleys, gears and other applications requiring impact resistance, but marginal electrical properties limit its use in electrical devices. Both rods and rolled tubes are available.
- *Grade CE:* This grade is similar to Grade C in construction, but a different resin system provides improved electrical properties and humidity resistance. Electrical characteristics are similar to Grade XX. However, its use at voltages greater than 600 is not intended. Molded tubes are available, but the seams are weak electrically. The properties of rods are the same as laminates.
- *Grade L:* This mechanical grade can be machined with better edges and surfaces than the other cotton-based grades. The material is not intended for electrical applications.
- *Grade LE:* These laminates can be used in electrical applications and are stronger than grade XX. However, like Grade CE, they should not be used as primary electrical insulations, and voltages are limited to less than 600. Rolled and molded tubes and rods are available.

Asbestos-Base Grade

- *Grade AA:* Laminates of this grade are more heat resistant than the preceding grades. The material is not used in electrical devices, and the laminates expand in humid environments.

Glass-Base Grades

- *Grade G-3 (glass fabric with phenolic resin binder):* These laminates have good mechanical properties and are used in nonelectrical applications. The impact resistance is excellent as is the resistance to heat. Rods and rolled tubes are available.

- *Grade G-5 (glass fabric with melamine resin binder):* This grade is an excellent electrical insulation and widely used in marine electrical devices, particularly where arc resistance is needed. The material is hard and abrasion resistant and does not burn readily. Electrical applications are limited to conditions below 120°F. Rods and rolled tubes are available.
- *Grade G-7 (glass fabric with silicon resin binder):* This material has excellent heat resistance and arc resistance. It resists burning and has good electrical properties. Its physical properties are excellent.
- *Grade G-9 (glass fabric with moisture-resistant melamine resin binder):* This material retains its electrical properties better than class G-5 under wet conditions. Other characteristics are similar to G-5. Rods and tubes are available.
- *Grade G-10 (glass fabric with epoxy resin binder):* Laminates of G-10 have very high mechanical strengths at room temperature. Electrical properties are also very good. Rods and rolled tubes are available.
- *Grade G-11 (glass fabric with heat-resistant epoxy resin binder):* This material is similar to Grade G-10 but can be used at higher temperatures. Rods and rolled tubes are available.

Nylon-Cloth Grade with Phenolic Resin Binder

- *Grade N-1:* Based on nylon fabrics, these laminates are used for electrical insulation at humid conditions where their impact resistance is good. They creep readily, particularly at elevated temperatures.

Flame-Resistant Grades

- *Grade FR-1:* This grade has a phenolic resin binder and paper reinforcement. It is similar to Grade XP but burns less readily. Rods and tubes are not available.
- *Grade FR-2:* This grade is similar to Grade XXXPC but is fire retardant.
- *Grade FR-3:* These laminates are reinforced with paper and impregnated with an epoxy resin. The fire resistance equals or exceeds V-1, and electrical properties are good. The flexural strength exceeds that of Grade XXXPC.
- *Grade FR-4:* This grade is the most common grade used in printed wiring applications. It is made with epoxy resin and glass fabric reinforcement and has properties similar to G-10 but with a flame resistance of V-0. Rods and rolled tubes are available.
- *Grade FR-5:* This grade is made with epoxy resin and glass fabric and is similar to Grade G11 but with a flame resistance of V-0. Rods and tubes are available.

Composite-Base Laminates

- *Grade CEM-1:* These materials consist of a glass fabric surface and a cellulose paper core impregnated with a flame-resistant epoxy resin. Designed for punchability and ease of drilling and machining, they are used in printed wiring applications.
- *Grade CEM-3:* This grade is made with a glass fabric surface and a glass mat core impregnated with an epoxy resin. It can be punched and machined. Its properties are similar to those of FR-4.

E.2 Properties of NEMA Laminate Grades

Appendix E.2a

	NEMA grade								
Properties	X	XX	XXX	XP	XPC	XXP	XXXP-C	C	CE
Tensile strength,10^3lb/in^2									
Lengthwise	20	16	15	12	10.5	11	12.4	10	8
Crosswise	16	13	12	9	8.5	8.5	9.5	8	7
Compressive strength, 10^3lb/in^2									
Flatwise	36	34	32	25	22	25	25	37	39
Edgewise	19	23	25.5					23.5	24.5
Flexural strength, 10^3 lb/in^2 (1/8 in-thick)									
Lengthwise	25	15	13.5	14	16	14	12	17	16.5
Crosswise	22	14	11.8	12	10	12	10.5	16	14
Modulus of elasticity in flexure, 10^6 lb/in^2									
Lengthwise	1.8	1.4	1.3	1.2	1	0.9	1	1	0.9
Crosswise	1.3	1.1	1	0.9	0.8	0.7	0.7	0.9	0.8
Shear strength, 10^3 lb/in^2	12	11	10	8		11	11	12	11
Izod impact, ft-lb/in of notch									
Flatwise	4	1.3	1				3.2	2.3	
Edgewise	0.5	0.35	0.35				1.7	1.4	
Rockwell hardness, M scale	110	105	110	95	75	100	95	103	103
Specific gravity	1.36	1.34	1.32	1.33	1.34	1.32	1.3	1.36	1.36
Coeff. Of thermal expansion, cm/cm/°C $\times 10^{-5}$	2	2	2	2	2	2	2	2	2
Water absorption, %/24 h									
1/16-in	6	2	1.4	3.6	5.5	1.8	0.75	4.4	2.3
1/8-in	3.3	1.3	0.95	2.2	3	1.1	0.55	2.5	1.6
1/2-in	1.1	0.55	0.45					1.2	0.75

Dielectric strength, V/mil; perpendicular to laminations; short time test									
1/16-in	700	700	650	650	600	700	650	200	500
1/8-in	500	500	470	470	425	500	470	150	360
Dissipation factor, 1 megacycle									
Condition A	0.06	0.045	0.038	0.06		0.04	0.038	0.1	0.1
Dielectric constant, 1 megacycle									
Condition A	6	5.5	5.3	6		5	4.6		5.3
Insulation resistance, MΩ									
Condition: 96 h/90% relative humidity, 95°F		60	1000			500	50,000		
Maximum constant operating temperature, °F	285	285	285	285		285	275	265	265
Temp. indices, NEMA, °C									
Electrical	130	130–140	130–140	130	130	130–140	125	85–115	85–115
Mechanical	130	130–140	130–140	130	130	130–140	125	85–125	85–125
Flame resistance classification, UL 94	94HB	94HB	94HB	94HB	94HB, V-0	94HB	94HB	94HB	94HB
Bond strength, lb	700	800	950					1800	1800
Thickness, in									
Minimum	0.010	0.010	0.015	0.010	0.020	0.015	0.031	0.031	0.03
Maximum	2	2	2	0.250	0.250	0.250	0.250	10	2
Standard colors	Natural (variable tan) and black	Natural (variable tan) and black	Natural (variable tan) and black	Natural (variable tan) and black	Natural (variable tan) and black	Natural (variable tan) and black	Natural (variable tan)	Natural (variable tan) and black	Natural (variable tan) and black
Standard finishes	Semigloss	Glossy, semigloss	Glossy, semigloss	Semigloss	Semigloss	Semigloss	Semigloss	Semigloss	Semigloss

Source: Sampson, R. N., "Laminates and Reinforced Plastics Materials and Processes", *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

APPENDIX E.2b

	NEMA grade													
Properties	L	LE	N-1	G-3	G-5	G-7	G-9	G-10	G-11	GPO-1	GPO-2	GPO-3	GPO-1P	GPO-2P
Tensile strength,10^3lb/in^2														
Lengthwise	13	12	8.5	23	37	23	37	40	40	9	9	9	8	8
Crosswise	9	8.5	8	20	30	18.5	30	35	35					
Compressive strength, 10^3lb/in^2														
Flatwise	35	37		50	70	45	70	60	60	30	30	30	20	20
Edgewise	23.5	25		17.5	25	14	25	35	35	20	20	20		
Flexural strength, 10^3 lb/in^2 (1/8 in-thick)														
Lengthwise	16	16	10	18	55	20	55	55	55	18	18	18	16	16
Crosswise	14	14	9.5	16	45	18	35	45	45	18	18	18	16	16
Modulus of elasticity in flexure, 10^6 lb/in^2														
Lengthwise	1	1	0.6	1.5	1.7	1.4	2.5	2.7	2.8	1.2	1.2	1.2	1.2	1.2
Crosswise	0.85	0.85	0.5	1.2	1.5	1.2	2	2.2	2.3	1.0	1.0	1.0	1.0	1.0
Shear strength, 10^3 lb/in^2		11.5	14			17	20	19	19	14	14	14	10	10
Izod impact, ft-lb/in of notch														
Flatwise	1.35	1.8	4			8.5	12	7	7	8	8	8	5	5
Edgewise	1.10	1	2.0			5.5	5.5	5.5	5.5					
Rockwell hardness, M scale	105	105	105	100	120	100	120	111	112	100	100	100	100	100
Specific gravity	1.35	1.33	1.15	1.65	1.90	1.68	1.9	1.80	1.80	1.5–1.9	1.5–1.9	1.7–1.95	1.5–1.9	1.5–1.9
Coeff. Of thermal expansion, cm/cm/°C × 10^{-5}	2	2	8	2	2	1	1	0.9	0.9	2	2	2	2	2
Water absorption, %/24 h	2.5	1.95	0.6	2.7	2.7	0.55	0.8	0.25	0.25	1.0	0.8	0.6	1.0	0.8
1/16-in	1.6	1.3	0.4	2.0	2.0	0.35	0.7	0.15	0.15	0.7	0.6	0.5	0.7	0.6
1/8-in	0.9	0.7	0.35	1.5	1.5	0.20	0.4	0.1	0.1	0.35	0.25	0.25		
1/2-in														

Dielectric strength, V/mil; perpendicular to laminations; short time test														
1/16-in	200	500	600	700	350	400	400	700	700	300	300	300	300	300
1/8-in		360	450	600	260	350	350	550	550					
Dissipation factor, 1 megacycle														
Condition A		0.055	0.038			0.003	0.017	0.025	0.025	0.03			0.03	
Dielectric constant, 1 megacycle														
Condition A		5.8	3.9			4.2	7.2	5.2	5.2	4.3			4.3	
Insulation resistance, MΩ		30	50,000		100	2500	10,000	200,000	200,000					
Condition: 96 h/90% relative humidity, 95°F														
Maximum constant operating temperature, °F	265	265				465	285	285	300					
Temp. indices, NEMA, °C														
Electrical	85–115	85–115		140		170		130	140–170		130	120		
Mechanical	85–125	85–125		170	140	220	140	140	160–180		160	140		
Flame resistance classification, UL 94	94HB	94HB	94HB		94V-0	94V-0	94V-0	94HB	94HB		94V-0			
Bond strength, lb	1600	1600	1000	850	1570	850	1700	2000	1600	850	850	850		
Thickness, in														
Minimum	0.010	0.015	0.010			0.010	0.010	0.010	0.010	0.031	0.031	0.031	0.062	0.062
Maximum	2	2	1			2	3.5	1	1	2	2	2	0.188	0.188
Standard colors	Natural (variable tan) and black	Natural (variable tan) and black	Natural (variable tan)			Natural (white to tan)	Grayish brown	Natural (green to tan)	Natural (green to tan)	Natural (tan)				
Standard finishes	Semigloss	Semigloss	Semigloss			Semigloss	Semigloss	Semigloss	Semigloss					

Source: Sampson, R. N., “Laminates and Reinforced Plastics Materials and Processes”, *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

APPENDIX E.2c

Properties	NEMA grade						
	GPO-3P	FR-2	FR-3	FR-4	FR-5	CEM-1	CEM-3
Tensile strength, 10^3 lb/in^2							
Lengthwise	8	12.5	14	40	40		
Crosswise		9.5	12	35	35		
Compressive strength, 10^3 lb/in^2							
Flatwise	20	25	29	60	60		
Edgewise				35	35		
Flexural strength, 10^3 lb/in^2 (1/8 in-thick)							
Lengthwise	16	12	20	55	55	35	40
Crosswise	16	10.5	16	45	45	28	32
Modulus of elasticity in flexure, 10^6 lb/in^2							
Lengthwise	1.2	1.1	1.5	2.7	2.7		2.3
Crosswise	1.0	0.9	1	2.2	2.2		2.1
Shear strength, 10^3 lb/in^2	10		11	19	19	15	14
Izod impact, ft-lb/in of notch							
Flatwise	5			7	7	1.6	1.6
Edgewise				5.5	5.5	1.2	1.4
Rockwell hardness, M scale	100	97	100	110	110		
Specific gravity	1.7–1.95	1.33	1.36	1.85	1.85		1.75
Coeff. of thermal expansion, cm/cm/°C $\times 10^{-5}$	2	2	2	1	0.9		
Water absorption, %/24 h							
1/16-in	0.6	0.75	0.65	0.25	0.25	0.3	0.25
1/8-in	0.5	0.55	0.5	0.15	0.15		
1/2-in				0.1	0.1		

Dielectric strength, V/mil; perpendicular to laminations; short time test							
1/16-in		650	600	700	700	400	
1/8-in		470	475	550	550		
Dissipation factor, 1 megacycle							
Condition A		0.038	0.035	0.025	0.025	0.035	0.025
Dielectrical constant, 1 megacycle							
Condition A		4.6	4.6	5.2	5.2	4.62	5.2
Insulation resistance, MΩ							
Condition: 96 h/90% relative humidity, 95°F		20,000	100,000	200,000	200,000	100,000	200,000
Maximum constant operating temperature, °F			265	285	300		265
Temp. indices, NEMA, °C							
Electrical		75–105	90–110	130	140–170	130	130
Mechanical		75–105	90–110	140	160–180	140	140
Flame resistance classification, UL94		94V-0	94V-0	94V-0	94V-0	94V-0	94V-0
Bond strength, lb			950	2000	1600		
Thickness, in							
Minimum	0.062	0.031	0.031	0.002	0.002	0.031	0.031
Maximum	0.188	0.250	0.250	1	1	0.093	0.093
Standard colors		Natural	Natural (grey to tan)	Natural (green to tan)	Natural (green to tan)	Natural (variable to tan)	Natural (variable green)
Standard finishes		Semigloss	Semigloss	Semigloss	Semigloss	Semigloss and dull	Semigloss and dull

Source: Sampson, R. N., "Laminates and Reinforced Plastics Materials and Processes", *Handbook of Plastics, Elastomers, and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

APPENDIX F

Composite Ply Orientation–Symmetry and Balance. Examples of Typical Callouts*

A shorthand code for ply fiber orientations has been adapted for use in design layouts and studies.

Figure a illustrates the ply lay-up descriptions. Each ply is shown by a number representing the direction of the fibers in degrees, with respect to a reference (x) axis. Zero degree fibers of both tape and fabric are normally aligned with the largest axial load.

Individual adjacent plies are separated by a slash in the code if their angles are different. See Figure b.

The plies are listed in sequence, from one laminate face to the other, starting with the ply first on the tool and indicated by the code arrow with brackets indicating the beginning and end of the code.

Adjacent plies of the same angle or orientation are shown by a numberical subscript. See Figure c.

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*Source: Peters, S. T., "Advanced Composite Materials and Processes", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

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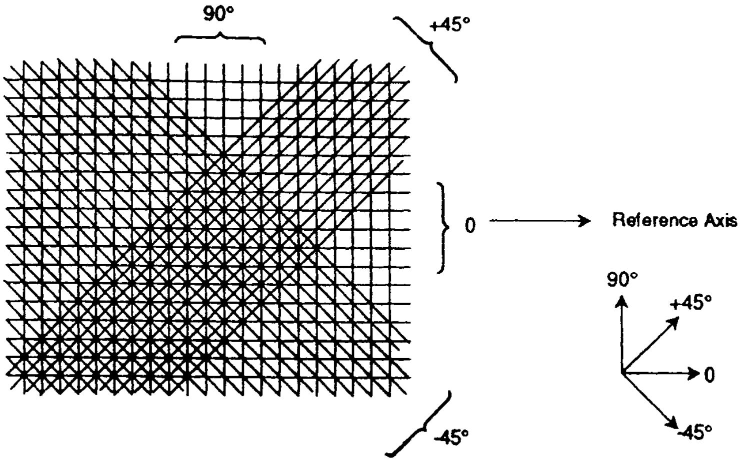
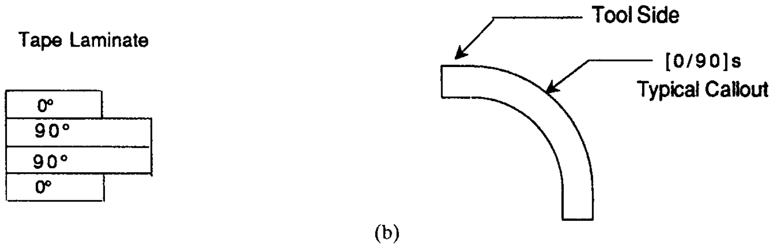


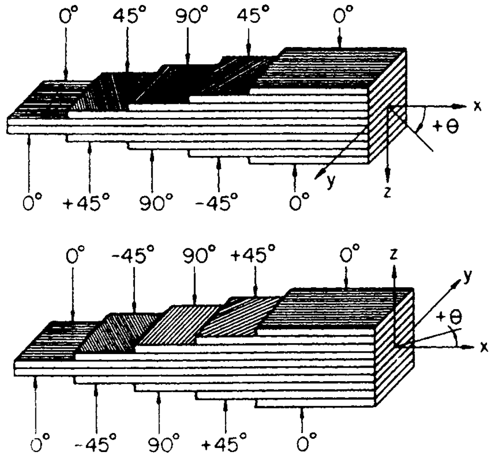
(a)



(b)

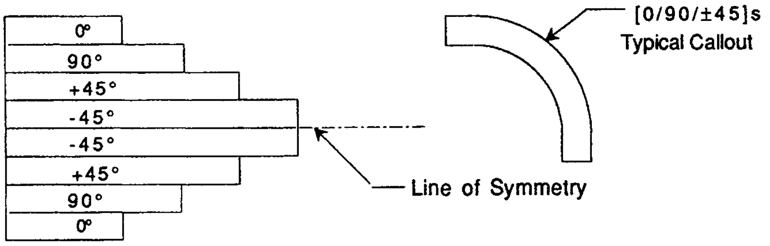
(c)

When tape plies are oriented at angles equal in magnitude but opposite in sign, (+) and (−) are used. Each (+) and (−) sign represents one ply. A numerical subscript is used only when there are repeating angles of the same sign. Positive and negative angles should be consistent with the coordinate system chosen. An orientation shown as positive in one right-handed coordinate system may be negative in another. If the y and z-axis directions are reversed, the +/−45 deg plies are reversed. See Figure d.



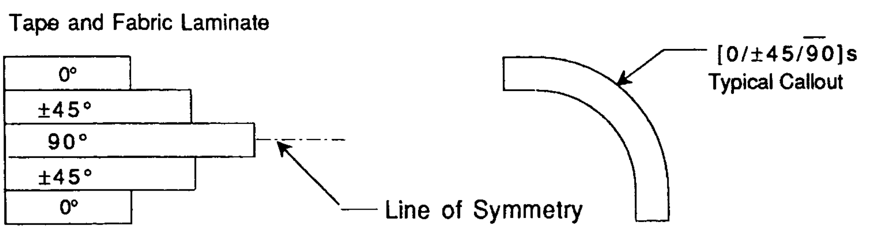
(d)

Symmetric laminates with an even number of plies are listed in sequence, starting at one face and stopping at the midpoint. A subscript S following the bracket indicates that only one half of the code is shown. See Figure e.

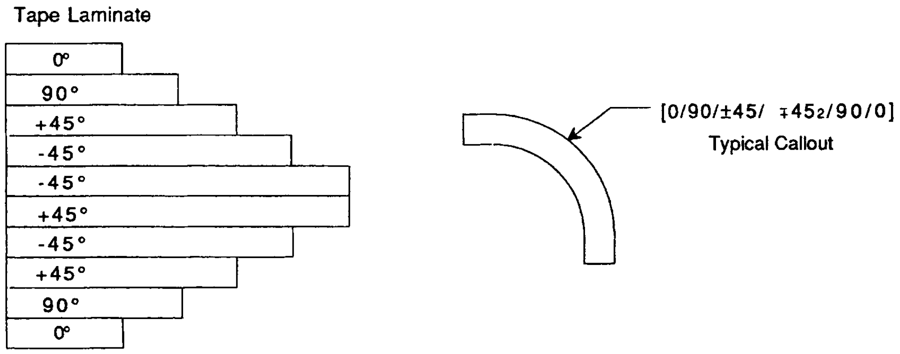


(e)

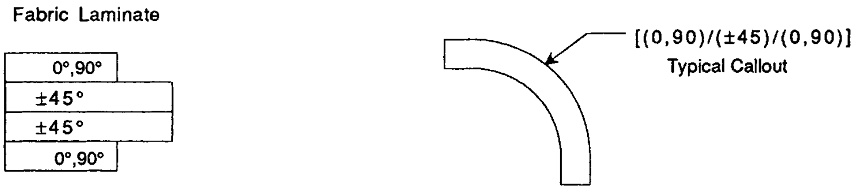
Symmetric laminates with an odd number of plies are coded as a symmetric laminate except that the center ply, listed last, is overlined to indicate that half of it lies on either side of the plane of symmetry. See Figures f–h.



(f)


Tape Laminate
0°
90°
+45°
-45°
-45°
+45°
-45°
+45°
90°
0°
[0/90/±45/ ∓45₂/90/0]
Typical Callout

(g)


Fabric Laminate
0°,90°
±45°
±45°
0°,90°
[(0,90)/(±45)/(0,90)]
Typical Callout

(h)

APPENDIX G

Important Information Regarding Processing of Plastics

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
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G.1 Plastics and Rubber Fabrication Processes

APPENDIX G.1a

Form ↓	The Process	Advantages	Limitations.
PLASTICS			
Injection Molding	Similar to die casting of metals. A thermoplastic molding compound is heated to plasticity in a cylinder at a controlled temperature and forced under pressure through sprues, runners and gates into a mold; the resin solidifies rapidly, the mold is opened, and the parts ejected; with certain modifications, thermosetting materials can be used for small parts.	Extremely rapid production rate and hence low cost per part; little finishing required; excellent surface finish; good dimensional accuracy; ability to produce variety of relatively complex and intricate shapes.	High tool and die costs; high scrap loss; limited to relatively small parts; not practical for small runs.
Extrusion	Thermoplastic molding powder is fed through a hopper to a chamber where it is heated to plasticity and driven, usually by a rotating screw, through a die having the desired cross section; extruded lengths are either used as-is or cut into sections; with modifications, thermosetting materials can be used.	Very low tool cost; material can be placed where needed; great variety of complex shapes possible; rapid production rate.	Close tolerances difficult to achieve; openings must be indirection of extrusion; limited to shapes of uniform cross section (along length).
Sheet Molding (Thermoforming)	VACUUM FORMING—Heat-softened sheet is placed over a male or female mold; air is evacuated form between sheet and mold, causing sheet to conform to contour of mold. Modifications include vacuum snapback forming, plus assist, drape forming, etc.	Simple procedure; inexpensive; good dimensional accuracy; ability to produce large parts with thin sections.	Limited to parts of low profile.
	BLOW OR PRESSURE FORMING—The reverse of vacuum forming in that positive air pressure rather than vacuum is applied to form sheet to mold contour.	Ability to produce deep drawn parts; ability to use sheet too thick for vacuum forming; good dimensional accuracy; rapid production rate.	Relatively expensive; molds must be highly polished.
	MECHANICAL FORMING—Sheet metal equipment (presses, benders, rollers, creasers, etc.) forms heated sheet by mechanical means. Localized heating is used to bend angles; where several bends are required, heating elements are arranged in series.	Ability to form heavy and/or tough materials; simple; inexpensive; rapid production rate.	Limited to relatively simple shapes.
Blow Molding	An extruded tube (parison) of heated plastics is placed within the two halves of a female mold and expanded against the sides of the mold by air pressure; the most common method uses injection molding equipment with a special mold.	Low tool and die cost; rapid production rate; ability to produce relatively complex hollow shapes in one piece.	Limited to hollow or tubular parts; wall thickness difficult to control.

Slush, Rotational, Dip Molding	Powder (polyethylene) or liquid material (usually vinyl plastisol or organosol) is poured into a closed mold, the mold is heated to fuse a specified thickness of material adjacent to mold surface, excess material is poured out, and the semifused part placed in an oven for final curing. A variation, rotational molding, provides completely enclosed hollow parts.	Low cost molds; relatively high degree of complexity; little shrinkage.	Relatively slow production rate; choice of materials limited.
Compression Molding	Material to be molded is placed in a matched-metal-die mold cavity and the mold closed. The part is formed by compressing the material under heat and pressure until the resin is cured or sufficiently cool to allow removal. Suitable for sheet (SMC) or bulk molding compounds (BMC), preforms, wet resin applied to reinforcement in the mold (wet system molding) or reinforced thermoplastic sheet (hot stamping).	Rapid production rates, little waste of material, low finishing costs, large parts possible. High reinforcement content yields high-strength parts. High volume process	Not suitable for intricate parts, undercuts, or delicate inserts. Close tolerances difficult to achieve. High equipment costs.
Transfer Molding	A change of material, often preheated, is placed in a chamber (pot) connected to the closed cavity of a heated matched-metal-die mold. The material is hydraulically forced into the mold by a plunger through a series of runners/gates. Part removed after resin cures.	Thin sections and delicate inserts are easily molded; flow of material is more easily controlled than in compression molding; good dimensional accuracy; rapid production rate.	Molds are more elaborate than compressionmolds, and more expensive; loss of material in of cull and sprue; size parts limited.
Liquid Resin Molding	Resin and catalyst held separately, are rapidly metered, mixed and delivered into a closed mold cabvity, filling the cavity before reaction is complete. Often combined with precut-or preformed-fiber reinforcement placed in the mold first, yielding a composite part as the mixture impregnates the reinforcement. Variations known as resin transfer molding (RTM), and reaction injection molding (RIM).	Capable of forming large parts with fast cycle times at low capital equipment and energy costs. Low volatile emissions compared to open-mold processes.	Class A surfaces difficult to obtain. Considered an intermediate volume process.
Hand Lay-Up	The lay-up, which consists of a mixture of reinforcement (usually glass cloth or fibers) and resin (usually thermosetting), is placed in mold by hand, rolled to improve consolidation, and allowed to harden without heat or pressure.	Los cost; no limitations on size or shape of part.	Parts are sometimes erratic in performance and appearance; limited to polyesters, epoxies and some phenolics.
Spray-Up	Resin system and chopped fibers are sprayed simultaneously from two guns against a mold; after spraying, layer is rolled flat with a hand roller. Either room temperature or oven cure.	Low cost; relatively high production rate; high degree of complexity possible.	Requires skilled workers; lack of reproducibility.

Source: Reprinted with permission from 1994 Materials Selector Issue, *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

APPENDIX G.1b

Form ↓	The Process	Advantages	Limitations
PLASTICS			
Vacuum Bag Molding	Similar to hand lay-up except a flexible film is placed over lay-up and a vacuum drawn between film and mold (about 12 psi).	Greater densification allows higher glass contents resulting in higher strengths.	Limited to polyesters, expoxies and some phenolics.
Autoclave Molding	After hand lay-up, winding, or other fabrication technique, mold and composite part are placed in an autoclave. Heat and pressure are applied via steam, consolidating and curing part. Usually combined with a vacuum-bag bleeder and release cloth. Hydroclave uses water as the pressure media. Thermoclave process uses powdered silicone rubber which acts as a fluid under heat/pressure.	High pressures provide increased laminate consolidation and improved removal of volatiles, for high-strength parts.	Equipment and operating expenses are high. Parts limited to cavity size of autoclave.
Pultrusion	Reinforcing filaments saturated with thermosetting resin are pulled through an orifice in a heated die. Polymerization of the resin occurs as the wet bundle passes through the die, forming a continuous, rigid profile corresponding to the orifice shape.	Capable of producing complex profiles in unlimited length. High fiber content up to 75% yields high-strength structural parts. Low labor content.	Limited to constant cross-section profiles. Can't make a curved product.
Pulforming	Variation of pultrusion producing continuously reinforced products other than profiles. By pulling fibers through a rotation wagon-wheel-type die, curved shapes are formed. Recirculating molds which clamp around the wet fiber package allow continuous forming of various shapes.	Unlike pultrusion, curved shapes (leaf springs) and non-constant cross section parts (hammer handles) can be formed continuously.	Complex tooling arrangements. Dies are expensive.
Tape Placement	Thermoset or thermoplastic, fiber-reinforced unidirectional tape is laid automatically by a programmed dispensing machine to form a desired shape. A gantry system provides the necessary lay-down motions of the tape head, producing either flat or contoured surfaces.	Lay-down rates substantially higher than . hand lay up, with improved placement accuracy and reduced human error.	High cost of equipment. Intrinsically stiff tapes limit the complexity of finished parts.
Fiber Placement	Similar to automated tape placement using resin-impregnated fiber rovings. Rovings are automatically placed on a complex mold surface which can include both positive and negative surfaces. Can also be applied to surfaces of rotation like filament winding.	Fiber roving flexibility allows more-complex shapes than tape placement. Negative surfaces can be formed.	Unlike filament winding, rovings are placed and not wound under tension, diminishing consolidation and structural properties such as tensile strength.
Filament Winding	Glass filaments, usually in the form of rovings, are saturated with resin and machine wound onto mandrels having the shape of desired finished part; finished part is cured at either room temperature or in an oven, depending on resin used and size of part.	Provides precisely oriented reinforcing filaments; excellent strength-to-weight ratio; good uniformity.	Limited to shapes of positive curvature; drilling or cutting reduces strength.

Casting	Plastic material (usually thermosetting except for the acrylics) is heated to a fluid mass, poured into mold (without pressure), cured, and removed from mold	Low mold cost; ability to produce large parts with thick sections; little finishing required; good surface finish	Limited to relatively simple shapes
Cold Molding	Method is similar to compression molding in that material is charged into a split, or open, mold; it differs in that it uses no heat—only pressure. After the part is removed from mold, it is placed in an oven to cure to final state	Because of special materials used, parts have excellent electrical insulating properties and resistance to moisture and heat; low cost; rapid	Poor surface finish; poor dimensional accuracy; molds wear rapidly; relatively expensive finishing; materials must be mixed and used immediately
RUBBER			
Compression Molding	An excess amount of uncured compound is placed in mold cavity; mold is closed and heat and pressure applied, forcing compound to fill mold cavity; heat cures (vulcanizes) compound and mold is opened to remove hardened parts	Good surface finish; parts can be made in almost any hardness, shape and size; relatively low cost; little waste; most compounds suitable.	Close tolerances difficult to achieve; flash has to be removed; extreme intricacy difficult; slow production rate.
Transfer, Injection Molding	Similar to compression molding except that mold is closed empty and rubber compound is forced into it through sprues, runners and gates.	Very good dimensional accuracy; no flash removal; ability to produce extremely intricate parts; good finish and uniformity; rapid production rate.	High mold costs; not all rubber compounds can be used; high scrap loss due to sprues, runners, etc.
Extrusion	Similar to plastic extrusion in that heated material is forced through a die having desired cross section. However, vulcanizatin does not take place in mold cavity; extruded lengths are cured n a steam vulcanizer and either used as-is or cut into sections.	Very low cost operation; great variety of complex shapes possible; rapid production rate.	Close tolerances difficult to achieve; limited to parts of uniform cross section (along length); openings must be in direction of extrusion.
Die Cut	Parts are stamped or cut from vulcanized sheet or slab with inexpensive steel dies.	Practically any rubber material can be cut in almost any size; low cost; economical for small quantities.	Thickness of part is limited; limited to flat parts.

Source: Reprinted with permission from 1994 Materials Selector Issue, *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

G.2 Guidelines on Part Design for Plastics Processing Methods

						Reinforced plastic molding					
Design rules	Blow Molding	Casting	Compression Molding	Extrusion	Injection Molding	Wet Lay-up (Contact Molding)	Matched –die Molding	Filament winding	Rotational Molding	Thermo-Forming	Transfer Molding
Major shape characteristics	Hollow bodies	Simple configurations	Moldable in one plane	Constant cross-section profile	Few limitations	Moldable in one plane	Moldable in one plane	Structure with surfaces of revolution	Hollow bodies	Moldable in one plane	Simple configurations
Limiting size factor	M	M	ME	M	ME	MS	ME	WE	M	M	ME
Min inside radius, in	0.125	0.01–0.125	0.125	0.01–0.125	0.01–0.125	0.25	0.06	0.125	0.01–0.125	0.125	0.01–0.125
Undercuts	Yes	Yes^a	NR^b	Yes	Yes^a	Yes	NR	NR	Yes^c	Yes^a	NR
Min draft, degrees	0	0–1	>1	NA^b	<1	0	1	2–3	1		1
Min thickness, in	0.01	0.01–0.125	0.01–0.125	0.001	0.015	0.06	0.03	0.015	0.02	0.002	0.01–0.125
Max thickness, in	>0.25	None	0.5	6	1	0.5	1	3	0.5	3	1
Max thickness buildup, in	NA	2–1	2–1	NA	2–1	2–1	2–1^d	NR	NA	NA	2–1
Inserts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NR	Yes
Built-up cores	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Molded-in holes	Yes	Yes	Yes	Yes^e	Yes	Yes	Yes	Yes	Yes	No	Yes
Bosses	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Fins or ribs	Yes	Yes	Yes	Yes	Yes	Yes	No^f	No^g	Yes	Yes	Yes
Molded-in designs and nos	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes

Overall dimensional tolerance, in./in.	±0.01	±0.001	±0.001	±0.005	±0.001	±0.02	±0.005	±0.005	±0.01	±0.01	±0.001
Surface finish[h]	1–2	2	1–2	1–2	1	4–5	4–5	5	2–3	1–3	1–2
Threads	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes

M = material. ME = molding equipment. MS = mold size. WE = winding equipment.

[a] Special molds required.

[b] NR—not recommended; NA—not applicable.

[c] Only with flexible materials.

[d] Using premix: as desired.

[e] Only in direction of extrusion.

[f] Using premix: yes.

[g] Possible using special techniques.

[h] Rated 1 to 5:1 = very smooth, 5 = rough.

Source: Meier, J. F., "Fundamentals of Plastics and Elastomers", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., McGraw-Hill, New York, 1998.

G.3 *Approximate Part Size Ranges for Principal Processes*

APPENDIX G.3

Process	Smallest Known	Largest Commercial	Largest Known
Blow molding	⅜ in deep × 1¼in long	9 ½ ft long × 1 ft deep × 4 in thick, 28 in deep × 44 in long	1320-gallon tank
Casting	No limit	Limited only by physical ability to handle molds and moldments	Limited only by physical ability to handle molds and moldments
Coinjection molding	¼ × ¼ × ¼ in	2 × 5 × 5 ft	2 ½ × 4 × 10 ft
Cold molding	1½ × 1½ ft	10 × 10 × 1 ½ ft	14-ft boat hull
Compression molding	¼ × ¼ × 1⁄16 in	4 × 5 × 8 ft	1 ½ × 4 ½ × 14 ft
Extrusion	No limit	12 × 12 in	42 in deep
Filament winding	4 ft deep × 8 in long	13 ft deep × 60 ft long	10-ft high × 82 ½ ft deep
Injection molding	0.008 × 0.020 × 0.020 in	2 1/2 deep × 3 ft	4 ft × 4 ft 6 in × 7 ft
Lay-up and spray-up	¼ × 6 × 6 in	150-ft minesweeper	Continuous roadway
Machining	No limit	10 ft wide or 15 in deep	Limited by size of stock available
Pultrusion	1⁄16 in deep	12 × 12 in	15 × 100 in
Reaction injection molding	4 × 12 in	3 × 4 × 10 ft	10 × 10 ft
Resin transfer molding	1 in × 3 in × 2 ft	16 in × 4 ft × 8 ft	4 ft × 8 ft × 28 in
Rotational molding	½-in -diam sphere	6 ft deep × 18 ft long	12 ft deep × 30 ft long
Structural foam molding	¼ × ¼ × ¼ in	2 1/2 × 6 ½ × 6 ½ ft	2 ½ × 4 × 10 ft
Transfer molding	⅛ × ⅛ × 1⁄16 in	2 × 1 × ½ ft	2 ½ × 1 ft × 9 in
Thermoforming: thin gauge	¼ × 1 × 1 in	3 × 3 × 3 ft	3 × 3 × 3 ft
Thermoforming: heavy gauge	6 × 6 × 6 in	3 × 10 × 12 FT	2 × 6 × 20 ft
Twin-sheet thermoforming	6 × 6 × 6 in	6 in × 3 ft × 6 ft	6 in × 3 ft × 6 ft

Source: Rotheiser, J. I., "The Bigger Picture", *Plastics Engineering Magazine*, January, 1997.

G.4 Plastics Available for Certain Processes

APPENDIX G.4

Process	Materials
Blow molding	ABS, acrylic, cellulosics, nylon, polycarbonate, polyester (thermoplastic), polyethylene polypropylene, polystyrene, polysulfone, PVC, SAN
Casting	Acrylic (thermoset), alkyd, epoxy, nylon, phenolic, polyester (thermoset), polyurethane (thermoset), silicone
Cold molding	Epoxy, phenolic, polyester (thermoset), polyurethane (thermoset)
Compression molding (including BMC and SMC)	Alkyd, allyl, amino, epoxy, fluorocarbons, phenolic, polyester (thermoset), polyurethane (thermoset), silicone
Extrusion	ABS, acetal, acrylic, cellulosics, liquid crystal polymer, nylon, polycarbonate, polyester (thermoplastic), polyethylene, polyphenylene oxide polypropylene, polystyrene, polysulfone, polyurethane (thermoplastic), PVC, SAN
Filament winding	Epoxy, polyester (thermoset)
Gas-assisted injection molding	ABS, acetal, acrylic, cellulosics, nylon, polycarbonate, polyester (thermoplastic), polyethylene, polyphenylene oxide, polypropylene, polystyrene, PVC, SAN
Injection molding	ABS, acetal, acrylic, alkyd,* allyl,* amino,* cellulosics, epoxy,* fluorocarbons,* liquid crystal polymer, nylon, phenolic,* polycarbonate, polyester (thermoplastic), polyester (thermoset),* polyethylene, polyphenylene oxide, polypropylene, polystytrene, polysulfone, polyurethane (thermoplastic), PVC, SAN
Lay-up and spray-up	Epoxy, polyester (thermoset)
Pultrusion	Epoxy, polyester (thermoset), silicone
Reaction injection molding	Nylon, polyurethane (thermoset), epoxy, polyester
Resin transfer molding	Epoxy, polyester (thermoset), silicone
Rotational molding	Acetal, acrylic, cellulosics, fluorocarbons, nylon, polyester (thermoplastic), polyethylene, polypropylene, polystyrene, polyurethane (thermoplastic), PVC
Structural foam molding	ABS, acetal, nylon, polycarbonate, polyethylene, polyphenylene oxide, polypropylene, polystyrene, polysulfone, SAN
Thermoforming	ABS, acrylic, cellulosics, polycarbonate, polyethylene, polypropylene, polystyrene, polysulfone, PVC, SAN
Transfer molding	Alkyd, allyl, amino, fluorocarbons, phenolic, polyester (thermoset), polyurethane (thermoset), silicone

*Special equipment required.

Source: Rotheiser, J. I., "Design of Plastics Products", *Modern Plastics Handbook*, C. A. Harper, ed., McGraw-Hill, New York, 2000.

APPENDIX H

Recommended Materials for Specific Properties*

Property	Recommendation
Abrasion, resistance to (high)	Nylon
Cost:weight (low)	Urea, phenolics, polystyrene, polyethylene, polypropylene, PVC
Compressive strength	Polyphthalamide, phenolic (glass), epoxy, melamine, nylon, thermoplastic polyester (glass), polyimide
Cost:volume (low)	Polystyrene, polyethylene, urea, phenolics, polypropylene, PVC
Dielectric constant (high)	Phenolic, PVC, fluorocarbon, melamine, alkyd, nylon, polyphthalamide, epoxy
Dielectric strength (high)	PVC, fluorocarbon, polypropylene, polyphenylene ether, phenolic, TP polyester, nylon (glass), polyolefin, polyethylene
Dissipation factor (high)	PVC, fluorocarbon, phenolic, TP polyester, nylon, epoxy, diallyl phthalate, polyurethane
Distortion, resistance to under load (high)	Thermosetting laminates
Elastic modulus (high)	Melamine, urea, phenolics
Elastic modulus (low)	Polyethylene, polycarbonate, fluorocarbons

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[*] *Source:* Rotheiser, J. I., "Design of Plastic Products", *Modern Plastics Handbook*, C. A. Harper, ed., McGraw-Hill, New York, 2000.

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Property	Recommendation
Electrical resistivity (high)	Polystyrene, fluorocarbons, polypropylene
Elongation at break (high)	Polyethylene, polypropylene, silicone, ethylene vinyl acetate
Elongation at break (low)	Polyether sulfone, polycarbonate (glass), nylon (glass), polypropylene (glass), thermoplastic polyester, polyetherimide, vinyl ester, polyetheretherketone, epoxy, polyimide
Flexural modulus (stiffness)	Polyphenylene sulfide, epoxy, phenolic (glass), nylon (glass) polyimide, diallyl phthalate, polyphthalamide, TP polyester
Flexural strength (yield)	Polyurethane (glass), epoxy, nylon (carbon fiber) (glass), polyphenylene, sulfide, polyphthalamide, polyetherimide, polyetheretherketone, polycarbonate (carbon fiber)
Friction, coefficient of (low)	Fluorocarbons, nylon, acetal
Hardness (high)	Melamine, phenolic (glass) (cellulose), polyimide, epoxy
Impact strength (high)	Phenolics, epoxies, polycarbonate, ABS
Moisture resistance (high)	Polyethylene, polypropylene, fluorocarbon, polyphenylene sulfide, polyolefin, thermoplastic polyester, polyphenylene ether, polystyrene, polycarbonate (glass or carbon fiber)
Softness	Polyethylene, silicone, PVC, thermoplastic elastomer, polyurethane, ethylene vinyl acetate
Tensile strength, break (high)	Epoxy, nylon (glass or carbon fiber), polyurethane, thermoplastic polyester (glass), polyphthalamide, polyetheretherketone, polycarbonate (carbon filter), polyetherimide, polyether-sulfone
Tensile strength, yield (high)	Nylon (glass or carbon fiber), polyurethane, thermoplastic polyester (glass), polyetheretherketone, polyetherimide, polyphthalamide, polyphenylene sulfide (glass or carbon fiber)
Temperature, heat deflection	Phenolic, epoxies, polysulfone, thermoset polyesters, polyether sulfone, polyimide (glass)
Temperature (maximum use)	Fluorocarbons, phenolic (glass), polyphthalamide, polyimide thermoplastic polyester (glass), melamine, epoxy, nylon (glass or carbon fiber) polyetheretherketone, polysulfone, polyphenylene sulfide
Thermal conductivity (low)	Polypropylene, PVC, ABS, polyphenylene oxide, polybutylene, acrylic, polycarbonate, thermoplastic polyester, nylon

Property	Recommendation
Thermal expansion, coefficient of (low)	Polycarbonate (carbon fiber or glass), phenolic (glass), nylon (carbon fiber or glass), thermoplastic polyester (glass), polyphenylene sulfide (glass or carbon fiber), polyetherimide, polyetheretherketone, polyphthalamide, alkyd, melamine
Transparency, permanent (high)	Acrylic, polycarbonate
Weight (low)	Polypropylene, polyethylene, polybutylene, ethylene vinyl acetate, ethylene methyl acrylate
Whiteness retention (high)	Melamine, urea

APPENDIX I

Important Information Regarding Machining of Plastics

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I.1 Machining Guidelines for Common Plastics

Appendix I.1

	Sawing (Circular)	Sawing (Band)	Lathe (Turn)	Lathe (Cutoff)	Drilling	Milling	Reaming
Acetals:							
Speed, ft^2/min	4,000 to 6,000	600 to 2,000	450 to 600	600	300 to 600	1,000 to 3,000	350 to 450
Feed, in/rev	Fast, smooth	Fast, smooth	0.0045 to 0.010	0.003 to 0.004	0.004 to 0.015	0.004 to 0.016	0.0055 to 0.015
Tool	HSS*, carbide	HSS	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide
Clearance, deg	20 to 30		10 to 25	10 to 25	10 to 25	10 to 20	
Rake, deg	0	0 to 15 (positive)	0 to 15	0 to 15 (positive)	0 to 10 (positive)	0 to 5 (negative)	0 to 10 (positive)
Set	Slight	Slight					
Point angle, deg					90 to 118		
Cooling	Dry, air jet, vapor	Dry, air jet	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor
Acrylics:							
Speed, ft^2/min	8,000 to 12,000	8,000 to 12,000	300 to 600	450 to 500	200 to 400	300 to 600	250 to 400
Feed, in/rev	Fast, smooth	Fast, smooth	0.003 to 0.008	0.003 to 0.004	Slow, steady	0.003 to 0.010	0.006 to 0.012
Tool	HSS, carbide	HSS	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide
Clearance, deg	10 to 20		10 to 20	10 to 20	12 to 15	15	
Rake, deg	0 to 10 (positive)	0 to 10 (positive)	0 to 5	0 to 15 (negative)	0 to 5 (negative)	0 to 5 (negative)	0 to 10 (negative)
Set	Slight	Slight					
Point angle, deg					118		
Cooling	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, water solution	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor

Fluorocarbons:							
Speed, ft^2/min	8,000 to 12,000	5,000 to 7,000	400 to 700	425 to 475	200 to 500	1,000 to 3,000	300 to 600
Feed, in/rev	Fast, smooth	Fast, smooth	0.002 to 0.010	0.003 to 0.004	0.002 to 0.010	0.004 to 0.016	0.006 to 0.015
Tool	HSS, carbide	HSS	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide
Clearance, deg	20 to 30		15 to 30	10 to 25	20	7 to 15	10 to 20
Rake, deg	0 to 5 (positive)	0 to 10 (positive)	0 to 5	3 to 15 (positive)	0 to 10 (negative)	3 to 15 (positive)	0 to 10 (negative)
Set	Heavy	Heavy					
Point angle, deg					90 to 118		
Cooling	Dry, air jet, vapor	Dry, air jet,	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor
Nylons:							
Speed, ft^2/min	4,000 to 6,000	4,000 to 6,000	500 to 700	700	180 to 450	1,000 to 3,000	300 to 450
Feed, in/rev	Fast, smooth	Fast, smooth	0.002 to 0.016	0.002 to 0.016	0.004 to 0.015	0.004 to 0.016	0.005 to 0.015
Tool	HSS, carbide	HSS	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide
Clearance, deg	20 to 30		5 to 10	7 to 15	10 to 15	7 to 15	
Rake, deg	15 (positive)	0 to 15 (positive)	0 to 5	0 to 5 (positive)	0 to 5 (positive)	0 to 5 (negative)	0 to 10 (positive)
Set	Slight	Slight					
Point angle, deg					90 to 110 under $^1/_2$ in 118 over $^1/_2$ in		
Cooling	Dry, air jet, vapor	Dry, air jet,	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor

Appendix I.1 (*Continued*)

	Sawing (Circular)	Sawing (Band)	Lathe (Turn)	Lathe (Cutoff)	Drilling	Milling	Reaming
Polyolefins:							
Speed, ft/min	1,650 to 5,000	3,900 to 5,000	600 to 800	425 to 475	200 to 600	1,000 to 3,000	280 to 600
Feed, in/rev	Fast, smooth	Fast, smooth	0.0015 to 0.025	0.003 to 0.004	0.004 to 0.020	0.06 to 0.020	0.006 to 0.012
Tool	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide	HSS, carbide
Clearance, deg	15		15 to 25	15 to 25	10 to 20	10 to 20	10 to 20
Rake, deg	0 to 8 (positive)	0 to 10 (positive)	0 to 15	3 to 15 (positive)	0 to 5 (positve)	0 to 10 (positive)	0 to 10 (negative)
Set	Heavy	Heavy					
Point angle, deg							
Cooling	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor	Dry, air jet, vapor

[*] High-strength steel.

NOTE: This information is designed as a guideline and is not to be construed as absolute. Because of the variety of work and diversity of finishes required, it may be necessary to depart from the suggestions in the tabl. A good practice to follow is to run a test workpiece before starting a production run.

Source: Petrie, E. M., "Finishing, Assembly, and Decorating", *Modern Plastics Handbook*, C. A. Harper, ed., McGraw-Hill, New York, 2000.

I.2 Geometries for Cutting and Drilling Tools

Dril Geometry

Material	Rake Angle, Degrees	Point Angle, Degress	Clearance, Degrees	Rake, Degrees
Thermoplatics:				
Polyethylene	10–20	70–90	9–15	0
Rigid polyvinyl chloride	25	120	9–15	0
Acrylic (polymethyl) methacrylate)	25	120	12–20	0
Polystyrene	40–50	60–90	12–15	0 to −5
Polyamide resin	17	70–90	9–15	0
Polycarbonate	25	80–90	9–15	0
Acetal resin	10–20	60–90	10–15	0
Fluorocarbon TFE	10–20	70–90	9–15	0
Thermosetting:				
Paper or cotton base	25	90–120	10–15	0
Fibrous glass or other fillers	25	90–120	10–15	0

Cutting Tool Geometry

Work Material	Side Relief Angle, Degrees	End Relief Angle, Degrees	Back Rake Angle, Degrees
Polycarbonate	3	3	0–5
Acetal	4–6	4–6	0–5
Polyamide	5–20	15–25	−0.5–0
TFE	5–20	0.5–10	0–10
Polyethylene	5–20	0.5–10	0–10
Polypropylene	5–20	0.5–10	0–10
Acrylic	5–10	5–10	10–20
Styrene	0–5	0–5	0
Thermosets:			
Paper or cloth	13	30–60	−0.5–0
Glass	13	33	0

Source: Richardson, T. A., “Machining and Finishing”, *Modern Industrial Plastics*, Howard W. Sams & Co., New York, 1974.

I.3 Suggested Drill Sizes and Speeds for Various Plastic Materials[*]

Appendix I.3

Thermoplastics	Thermosets	Drill Speed
Small to 0.125	Small to 0.093	5000
0.126 to 0.177	0.094 to 0.140	3000
0.180 to 0.228	0.141 to 0.191	2500
0.232 to 0.312	0.192 to 0.250	1700
0.315 to 0.375	0.252 to 0.312	1300
0.377 to 0.500	0.315 to 0.375	1000
	0.377 to 0.500	700

[*] *Source:* Hull, J. L., “Design and Processing of Plastics Parts”, *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1998.

APPENDIX J

Sources of Specifications and Standards for Plastics and Composites*

As in other material categories, the reliable use of plastics and composites requires specification to support procurement of these materials and standards to establish engineering and technical requirements for processes, procedures, practices, and methods for testing and using these materials.

These specifications and standards may be general industry-wide, or they may be specific to one industry, such as the spaceborne industry, wherein plastics and composites must exhibit special stability in the harsh environments of temperature and vacuum. Specifications and standards for this industry, for instance, would be controlled by documents from the National Aeronautics and Space Administration (NASA).

Increasingly, the development and use of standards is becoming international. Since the total sum of these specifications and standards is voluminous, no attempt is made herein to itemize all of them. However, the names and addresses of organization that are sources of these documents, and information concerning them, are listed below.

Also, one comprehensive reference book that can be recommended to readers with interest in this area is given as Reference 1 at the end of this listing. Another excellent reference book dealing with the major issues of flammability standards of plastics and composites is listed as Reference 2.

Source: Traceski. F. T., Appendix E, *Handbook of Plastics, Elastomers, and Composites*, 4th ed., C. A. Harper, ed., McGraw-Hill, New York, 2002.

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

NAMES AND ADDRESSES OF ORGANIZATIONAL SOURCES OF SPECIFICATIONS AND STANDARDS FOR PLASTICS AND COMPOSITES:

Industry Standards

American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken,
PA 19248-2959

Federal Standards and Specifications

General Services Administration (GSA)
Seventh and D Streets, S.W.
Washington, DC 20407

Global Engineering Documents
American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

Document Engineering Company, Inc.
15210 Stagg St.
Van Nuys, CA 91405

Military Specifications and Standards

DODSSP–Customer Service
Standardization Document Order Desk
Building 4D

700 Robbins Ave.
Philadelphia, PA 19111-5090

Global Engineering Documents
American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

Spaceborne Plastics and Composites Specifications and Standards

For plastics:

Individual NASA Space Centers

For composites:

National Aviation and Space Administration (NASA)
ACEE Composites Project Office
Langley Research Center
Hampton, VA 23665-5225

Foreign or International Standards

American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

International Organization for Standardization (ISO)
1 Rue de Varembe
Case Postale 56
CH-1211 Geneva 20
Switzerland

International Standards and Law Information (ISLI)
P.O. Box 230
Accord, MA 02018

National and International Electrical Standards

National Electrical Manufacturers Association (NEMA)
1300 N. 17th St.
Suite 1847
Rossyln, VA 22209

International Electrotechnical Commission (IEC)
3 Rue de Varembe
Case Postal 131 Ch-1211 Geneva 20
Switzerland

American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

International Standards

ISO Central Secretariat
International Organization for Standardization (ISO)
1 Rue de Varembe
Case Postale 56
CH-1211 Geneva 20
Switzerland

Japanese Standards and Specifications

Japanese Standard Associations (JSA)
1-24, Akasaka 4, Minautoku
Tokyo 107-8440
Japan

German Standards

German Nationals Standards Organization
Deutsche Industrie Norman (DIN)
10772 Berlin
Germany

European Aerospace Specifications and Standards

AECMA
Bulledelle 94-b.5

B-1200 Brussels
Belgium

European Plastics Manufacturing Standards

Association of Plastics Manufacturers in Europe (APME)
Avenue E, van Nieuwenhuyse 4
Box 3
B-1160 Brussels
Belgium

Plastics Standards in United Kingdom

BSI Group Headquarters
389 Chiswick High Road
London W4 4AL, U.K.

BSI Inc.
12110 Sunset Hills Road
Reston, VA 20190, USA

European Plastics

Association of Plastics Manufacturers in Europe
Avenue E. van Nieuwenhuyse 4
Box 3
Belgium

Rubber and Plastic Standards in United Kingdom

RAPRA Technology, Ltd.
Shawburuy, Shrewsbury
Shropshire SY4 4NR, U.K.

Plastics Standards in France

French Association of Standardization (AFNOR)
11, Avenue Francis se Pressenre
93571 Saint-Denis La Plaine Cedex
Paris, France

Specifications and Standards for Aerospace Products

Aerospace Industries Association of America, Inc. (AIA)
1250 I Street N.W., Suite 1200
Washington, DC 2005-3924

National Standards for U.S. Standards Developing Bodies

American National Standards Institute (ANSI)
1819 L Street
Suite 600
Washington, DC 20036

Standards for Testing

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

Specifications and Standards for the Plastics Industry

Society of the Plastics Industry (SPI)
1801 K Street N.W., Suite 600
Washington, DC 20006

Specification and Standards for Composites Materials Characterization

Composite Materials Characterization, Inc.
Lockheed Martin Aeronautical Systems Company
Advance Structures and Materials Division
Marietta, GA 30063

Standards in Measurements

National Institute of Standards and Technology (NIST)
Standard Reference Materials Program
100 Bureau Drive, Stop 2322
Gaithersburg, MD 20899-2322

Specifications, Standard, and Industry Approvals for Plastics and Testing of Plastics

Underwriters Laboratories, Inc. (UL)
Corporate Headquarters 333 Pfingston Road
Northbrook, IL 60062-2096

Standardization of Composite Materials Test Methods

Composite Fabricators Association
1655 N. Fort Myer Drive, Suite 510
Arlington, VA 22209

References:

1. Traceski, F.T., *Specifications and Standards for Plastics and Composites*, ASM International, Materials Park, OH.
2. Hilado, C.J., *Flammability Handbook for Plastics*, 4th ed., Technomic Publishing Co., Inc., Lancaster, PA.

APPENDIX K

Important Information Regarding Assembly of Plastics and Adhesives

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Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

K.1 Assembly Methods for Plastics

Appendix K.1

	Common Assembly Methods							
Plastic	Adhesives	Dielectric Welding	Induction Bonding	Mechanical Fastening	Solvent Welding	Spin Welding	Thermal Welding	Ultrasonic Welding
Thermoplastics:								
ABS	X	…	X	X	X	X	X	X
Acetals	X	…	X	X	X	X	X	X
Acrylics	X	…	X	X	X	X	…	X
Cellulosics	X	…	…	…	X	X		
Chlorinated polyether	X	…	…	X				
Ethylene copolymers	…	X	…	…	…	…	X	
Fluoroplastics	X							
Ionomer	…	X	…	…	…	…	X	
Methylpentene	…	…	…	…	…	…	…	X
Nylons	X	…	X	X	X	…	…	X
Phenylene oxide–based materials	X	…	…	X	X	X	X	X
Polyesters	X	…	…	X	X	X	…	X
Polyamide-imide	X	…	…	X				
Polyaryl ether	X	…	…	X	…	…	…	X
Polyaryl sulfone	X	…	…	X	…	…	…	X
Polybutylene	…	…	…	…	…	…	…	X
Polycarbonate	X	…	X	X	X	X	X	X
Polycarbonate/ABS	X	…	…	X	X	X	X	X
Polyethylenes	X	X	X	X	…	X	X	X
Polyimide	X	…	…	X				
Polyphenylene sulfide	X	…	…	X				

Polypropylenes	X	X	X	X				
Polystyrenes	X	…	X	X	X	X	X	X
Polysulfone	X	…	…	X	X	…	…	X
Propylene copolymers	X	X	X	X	…	X	X	
PVC/acrylic alloy	X	…	X	X	…	…	…	X
PVC/ABS alloys	X	X	…	…	…	…	X	
Styrene acrylonitrile	X	…	X	X	X	X	X	X
Vinyls	X	X	X	X	X	…	X	
Thermosets:								
Alkyds	X							
Allyl diglycol carbonate	X							
Diallyl phthalate	X	…	…	X				
Epoxies	X	…	…	X				
Melamines	X							
Phenolics	X	…	…	X				
Polybutadienes	X							
Polyesters	X	…	…	X				
Silicones	X	…	…	X				
Ureas	X							
Urethanes	X	…	…	X				

Source: Engineer's Guide to Plastics, *Materials Engineering,* May 1972.

K.2 Description of Various Methods to Bond and Weld Plastics

Appendix K.2

Technique	Description	Advantages	Limitations	Processing Considerations
Solvent cementing and dopes	Solvent softens the surface of an amorphous thermoplastic; mating takes place when the solvent has completely evaporated. Bodied cement with small percentage of parent material can give more workable cement, fill in voids in bond area. Cannot be used for polyolefins and acetal homopolymers.	Strength, up to 100% of parent materials, easily and economically obtained with minimum equipment requirements.	Long evaporation times required; solvent may be hazardous; may cause crazing in some resins.	Equipment ranges from hypodermic meedle or just a wiping media to tanks for dip and soak. Clamping devices are necessary, and air dryer is usually required. Solvent-recovery apparatus may be necessary or required. Processing speeds are relatively slow because of drying times. Equipment costs are low to medium.
		Thermal Bonding		
Ultrasonics	High-frequency sound vibrations transmitted by a metal horn generate friction at the bond area of a thermoplastic part, melting plastics just enough to permit a bond. Materials most readily weldable are acetal, ABS, acrylic, nylon, PC, polyimide, PS, SAN, phenoxy.	Strong bonds for most thermoplastics; fast, often less than 1 s. Strong bonds obtainable in most thermal techniques if complete fusion is obtained	Size and shape limited. Limited applications to PVCs, polyolefins.	Converter to change 20 kHz electrical into 20 kHz mechanical energy is required along with stand and horn to transmit energy to part. Rotary tables and high-speed feeder can be incorporated.
Hot-plate and hot-tool welding	Mating surfaces are heated against a hot surface, allowed to soften sufficiently to produce a good bond, then clamped together while bond sets. Applicable to rigid thermoplastics.	Can be very fast, for example, 4 to 10 s in some cases; strong.	Stresses may occur in bond area.	Use simple soldering guns and hot irons, relatively simple hot plates attached to heating elements up to semiautomatic hot-plate equipment. Clamps needed in all cases.
Hot-gas welding	Welding rod of the same material being joined (largest application is vinyl) is softened by hot air or nitrogen as it is	Strong bonds, especially for large structural shapes.	Relatively slow; not an “appearance” weld.	Requires a hand gun, special welding tips, an air source, and welding rod. Regular hand-gun speeds run

	fed through a gun that is softening part surface simultaneously. Rod fills in joint area and cools to effect a bond.			6 in/min; high-speed hand-held tool boosts this to 48 to 60 in/min.
Spin welding	Parts to be bonded are spun at high speed, developing friction at the bond area; when spinning stops, parts cool in fixture under pressure to set bond. Applicable to most rigid thermoplastics.	Very fast (as low as 1 to 2 s); strong bonds.	Bond area must be circular.	Basic apparatus is a spinning device, but sophisticated feeding and handling devices are generally incorporated to take advantage of high-speed operation.
Dielectric	High-frequency voltage applied to film or sheet causes material to melt at bonding surfaces. Material cools rapidly to effect a bond. Most widely used with vinyls.	Fast seal with minimum heat applied.	Only for film and sheet.	Require rf generator, dies, and press. Operation can range from hand-fed to semiautomatic with speeds depending on thickness and type of product being handled. Units of 3 to 25 kW are most common.
Induction	A metal insert or screen is placed between the parts to be welded, and energized with an electromagnetic field. As the insert heats up, the parts around it melt, and when cooled form a bond. For most thermoplastics.	Provides rapid heating of solid sections to reduce chance of degradation.	Since metal is embedded in plastic, stress may be caused at bond.	High-frequency generator, heating coil, and inserts (generally 0.02 to 0.04 in thick). Hooked up to automated devices, speeds are high. Work coils, water cooling for electronics, automatic timers, multiple-position stations may also be required.
		Adhesives*		
Liquids solvent, water base, anaerobics	Solvent- and water-based liquid adhesives, available in a wide number of bases—for example, polyester, vinyl—in one- or two-part form fill bonding needs ranging from high-speed lamination to one-of-a-kind joining of dissimilar plastics parts. Solvents provide more bite, but cost much more than similar base water-type adhesive. Anaerobics are a group of adhesives that cure in the absence of air.	Easy to apply; adhesives available to fit most applications. anaerobics toxic.	Shelf and pot life often limited. Solvents may cause pollution problems; water-base not as strong;	Application techniques range from simply brushing on to spraying and roller coating-lamination for very high production. Adhesive application techniques, often similar to decoratingequipment, from hundreds to thousands of dollars with sophisticated laminating equipment costing in the tens of thousands of dollars. Anaerobics are generally applied a drop at a time from a special bottle or dispenser.

Appendix K.2 (*Continued*)

Technique	Description	Advantages	Limitations	Processing Considerations
Plates, mastics	High viscous single- or two-component materials which cure to a very hard or flexible joint depending on adhesive type.	Does not run when applied.	Shelf and pot life often limited.	Often applied via a trowel, knife, or gun-type dispenser; one-component systems can be applied directly from a tube. Various types of roller coaters are also used. Metering-type dispensing equipment in the $2500 range has been used to some extent.
Hot melts	100% solids adhesives that become flowable when heat is applied. Often used to bond continuous flat surfaces.	Fast application; clean operation.	Virtually no structural hot melts for plastics.	Hot melts are applied at high speeds via heating the adhesive, then extruding (actually squirting) it onto a substrate, roller coating, using a special dispenser or roll to apply dots or simply dipping.
Film	Available in several forms including hot melts, these are sheets of solid adhesive. Mostly used to bond film or sheet to a substrate.	Clean, efficient.	High cost.	Film adhesive is reactivated by a heat source; production costs are in the medium to high range depending on heat source used.
Pressure-sensitive	Tacky adhesives used in a variety of commercial applications. Often used with polyolefins.	Flexible.	Bonds not very strong.	Generally applied by spray with bonding effected by light pressure.
Mechanical fasteners (staples, screws, molded-in inserts, snap-fits, and variety of proprietary fasteners)	Typical mechanical fasteners are listed on the left. Devices are made of metal or plastic. Type selected will depend on how strong the end product must be, appearance factors. Often used to join dissimilar plastics or plastics to nonplastics.	Adaptable to many materials; low to medium costs; can be used for parts that must be disassembled.	Some have limited pull-out strength; molded-in inserts may result in stresses.	Nails and staples are applied by simply hammering or stapling. Other fasteners may be inserted by drill press, ultrasonics, air or electric gun, hand tool. Special molding—that is, molded-in-hole—may be required.

[*] Typical adhesives in each class are: Liquids: 1. Solvent—polyester, vinyl, phenolics acrylics, rubbers, epoxies, polyamide; 2. Water—acrylics, rubber-casein; 3. Anaerobics—cyanoacrylate; mastics—rubbers, epoxies; hot melts—polyamides, PE, PS, PVA; film—epoxies, polyamide, phenolics; pressure, sensitive—rubbers.

Source: Tauernicht, J. O., “Bonding and Joining, Weight the Alternatives”, *Plastics Technology,* August 1970.

K.3 *Adhesives Classified by Chemical Composition*

Appendix K.3

Classification	Thermoplastic	Thermosetting	Elastomeric	Alloys
Types within group	Cellulose acetate, cellulose acetate butyrate, cellulose nitrate, polyvinyl acetate, vinyl vinylidene, polyvinyl acetals, polyvinyl alcohol, polyamide, acrylic, phenoxy	Cyanoacrylate, polyester, urea formaldehyde, melamine formaldehyde, resorcinol and phenol-resorcinol formaldehyde, epoxy, polyimide, polybenzimidazole, acrylic, acrylate acid diester	Natural rubber, reclaimed rubber, butyl, polyisobutylene, nitrile, styrene-butadiene, polyurethane, polysulfide, silicone, neoprene	Epoxy-phenolic, epoxy-polysulfide, epoxy-nylon, nitrilephenolic, neoprene-phenolic, vinyl-phenolic
Most used form	Liquid, some dry film	Liquid, but all forms common	Liquid, some film	Liquid, paste, film
Common further classifications	By vehicle (most are solvent dispersions or water emulsions)	By cure requirements (heat and/or pressure most common but some are catalyst types)	By cure requirements (all are common); also by vehicle (most are solvent dispersions or water emulsions)	By cure requirements (usually heat and pressure except some epoxy types); by vehicle (most are solvent dispersions or 100% solids); and by type of adherends or end-service conditions
Bond characteristics	Good to 150–200°F; poor creep strength; fair peel strength	Good to 200–500°F; good creep strength; fair peel strength	Good to 150–400°F; never melt completely; low strength; high flexibility	Balanced combination of properties of other chemical groups depending on formulation; generally higher strength over wider temp range
Major type of use	Unstressed joints; designs with caps, overlaps, stiffeners	Stressed joints at slightly elevated temp	Unstressed joints on light-weight materials; joints in flexure	Where highest and strictest end-service conditions must be met; sometimes regardless of cost, as military uses
Materials most commonly bonded	Formulation range covers all materials, but emphasis on nonmetallics—esp. wood, leather, cork, paper, etc.	For structural uses of most materials	Few used "straight" for rubber, fabric, foil, paper, leather, plastics also as tapes. Most modified films; with synthetic resins	Metals, ceramics, glass, thermosetting plastics; nature of adherends often not as vital as design or end-service conditions (i.e., high strength, temp)

Source: Petrie, E. M., "Joining of Plastics, Elastomers, and Composites", *Handbook of Plastics, Elastomers and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

K.4 Thermosetting Adhesives

Appendix K.4

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
Cyanoacrylate	One-part liquid	Rapidly at RT in absence of air	Fast setting; good bond strength; low viscosity; high cost; poor heat and shock resistance; will not bond to acidic surfaces	Metals, plastics, glass	Very high
Polyester	Two-part liquid or paste	RT or higher	Resistant to chemicals, moisture, heat, weathering. Good electrical properties; wide range of strengths; some resins do not fully cure in presence of air; isocyanate-cured system bonds well to many plastic films	Metals, foils, plastics, plastic laminates, glass	Low-med
Urea formaldehyde	Usually supplied as two-part resin and hardening agent. Extenders and fillers used	Under pressure	Not as durable as others but suitable for fair range of service conditions. Generally low cost and ease of application and cure. Pot life limited to 1 to 24 h	Plywood	Low
Melamine formaldehyde	Powder to be mixed with hardening agent	Heat and pressure	Equivalent in durability and water resistance (including boiling water) to phenolics and resorcinols. Often combined with ureas to lower cost. Higher service temp than ureas	Plywood, other wood products	Medium

Resorcinol and phenol-resorcinol formaldehyde	Usually alcohol-water solutions to which formaldehyde must be added	RT or higher with moderate pressure	Suitable for exterior use; unaffected by boiling water, mold, fungus, grease, oil, most solvents. Bond strength equals or betters strength of wood; do not bond directly to metal	Wood, plastics, paper, textiles, fiberboard, plywood	Medium
Epoxy	Two-part liquid or paste; one-part liquid, paste, or solid; solutions	RT or higher	Most versatile adhesive available; excellent tensile-shear strength; poor peel strength; excellent resistance to moisture and solvents; low cure shrinkage; variety of curing agents/hardeners results in many variations	Metals, plastic, glass, rubber, wood, ceramics	Medium
Polyimide	Supported film, solvent solution	High temp	Excellent thermal and oxidation resistance; suitable for continuous use at 550°F and short-term use to 900°F; expensive	Metals, metal foil, honeycomb core	Very high
Polybenzimidazole	Supported film	Long, high-temp cure	Good strength at high temperatures; suitable for continuous use at 450°F and short-term use at 1000°F; volatiles released during cure; deteriorate at high temperatures on exposure to air; expensive	Metals, metal foil, honeycomb core	Very high
Acrylic	Two-part liquid or paste	RT	Excellent bond to many plastics, good weather resistance, fast cure, catalyst can be used	Metals, many plastics, wood	Medium

Appendix K.4 (*Continued*)

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
			as a substrate primer; poor peel and impact strength		
Acrylate acid diester	One-part liquid or paste	RT or higher in absence of air	Chemically blocked, anaerobic type; excellent wetting ability; useful temperature range −65 to 300°F; withstands rapid thermal cycling; high-tensile-strength grade requires cure at 250°F, cures in minutes at 280°F	Metals, plastics, glass, wood	Very high

Source: Petrie, E. M., "Joining of Plastics, Elastomers, and Composites", *Handbook of Plastics, Elastomers and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

K.5 *Thermoplastic Adhesives*

Appendix K.5

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
Cellulose acetate, cellulose acetate butyrate	Solvent solutions	Solvent evaporation	Water-clear, more heat resistant but less water resistant than cellulose nitrate; cellulose acetate butyrate has better heat and water resistance than cellulose acetate and is compatible with a wider range of plasticizers	Plastics, leather, paper, wood, glass, fabrics	Low
Cellulose nitrate	Solvent solutions	Evaporation of solvent	Tough, develops strength rapidly, water-resistant; bonds to many surfaces; discolors in sunlight; dried adhesive is flammable	Glass, metal, cloth, plastics	Low
Polyvinyl acetate	Solvent solutions and water emulsions, plasticized or unplasticized, often containing fillers and pigments. Also dried film which is light-stable, water-white, transparent	On evaporation of solvent or water; film by heat and pressure	Bond strength of several thousand lb/in.^{2} but not under continuous loading. The most versatile in terms of formulations and uses. Tasteless, odorless; good resistance to oil, grease, acid; fair water resistance	Emulsions particularly useful with porous materials like wood and paper. Solutions used with plastic films, mica, glass, metal, ceramics.	Low
Vinyl vinylidene	Solutions in solvents like methyl ethyl ketone	Evaporation of solvent	Tough, strong, transparent and colorless. Resistant to hydrocarbon solvents, greases, oils	Particularly useful with textiles; also porous materials, plastics	Medium

Appendix K.5 (*Continued*)

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
Polyvinyl acetals	Solvent solutions, film, and solids	Evaporation of solvent; film and solid by heat and pressure	Flexible bond; modified with phenolics for structural use; good resistance to chemicals and oils; includes polyvinyl formal and polyvinyl butaryl types	Metals, mica, glass, rubber, wood, paper	Medium
Polyvinyl alcohol	Water solutions, often extended with starch or clay	Evaporation of water	Odorless, tasteless and fungus-resistant (if desired). Excellent resistance to grease and oils; water soluble	Porous materials such as fiberboard, paper, cloth	Low
Polyamide	Solid hot-melt, film, solvent solutions	Heat and pressure	Good film flexibility; resistant to oil and water; used for heat-sealing compounds	Metals, paper, plastic films	Medium
Acrylic	Solvent solutions, emulsions and mixtures requiring added catalysts	Evaporation of solvent; RT or elevated temp (two-part)	Good low-temperature bonds; poor heat resistance; excellent resistance to ultraviolet; clear; colorless	Glass, metals, paper, textiles, metallic foils, plastics	Medium
Phenoxy	Solvent solutions, film, solid hot-melt	Heat and pressure	Retain high strength from 40 to 180°F; resist creep up to 180°F; suitable for structural use	Metals, wood, paper, plastic film	Medium

Source: Petrie, E. M., “Joining of Plastics, Elastomers, and Composites”, *Handbook of Plastics, Elastomers and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

K.6 *Elastomeric Adhesives*

Appendix K.6

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
Natural rubber	Solvent solutions, latexes and vulcanizing type	Solvent evaporation, vulcanizing type by heat or RT (two-part)	Excellent tack, good strength. Shear strength 30–180 lb/in.^{2}; peel strength 0.56 lb/in. width. Surface can be tack-free to touch and yet bond to similarly coated surface	Natural rubber, masonite, wood, felt, fabric, paper, metal	Medium
Reclaimed rubber	Solvent solutions, some water dispersions. Most are black. some gray and red	Evaporation of solvent	Low cost, widely used. Peel strength higher than natural rubber; failure occurs under relatively low constant loads	Rubber, sponge rubber, fabric, leather, wood, metal, painted metal, building materials	Low
Butyl	Solvent system, latex	Solvent evaporation, chemical cross linking with curing agents and heat	Low permeability to gases, good resistance to water and chemicals, poor resistance to oils, low strength	Rubber, metals	Medium
Polyisobutylene	Solvent solution	Evaporation of solvent	Sticky, low-strength bonds; copolymers can be cured to improve adhesion, environmental resistance, and elasticity; good aging; poor thermal resistance; attacked by solvents	Plastic film, rubber, metal foil, paper	Low

Appendix K.6 (*Continued*)

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
Nitrile	Latexes and solvent solutions compounded with resins, metallic oxides, fillers, etc.	Evaporation of solvent and/or heat and pressure	Most versatile rubber adhesive. Superior resistance to oil and hydrocarbon solvents. Inferior in tack range; but most dry tack-free, an advantage in precoated assemblies. Shear strength of 150–2,000 lb/in.^{2} higher than neoprene, if cured	Rubber (particularly nitrile) metal, vinyl plastics	Medium
Styrene butadiene	Solvent solutions and latexes. Because tack is low, rubber resin is compounded with tackifies and plasticizing oils	Evaporation of solvent	Usually better aging properties than natural or reclaimed. Low dead load strength; bond strength similar to reclaimed. Useful temp range from −40 to 160°	Fabrics, foils, plastics film laminates, rubber and sponge rubber, wood	Low
Polyurethane	Two-part liquid or paste	RT or higher	Excellent tensile-shear strength from −400 to 200° F poor resistance to moisture before and after cure; good good adhesion to plastics	Plastics, metals, rubber	Medium
Polysulfide	Two-part liquid or paste	RT or higher	Resistant to wide range of solvents, oils, and grease; good gas impermeability; resistant to weather, sunlight, ozone; retains flexibility over wide temperature range; not suitable for permanent load-bearing application	Metals, wood, plastics	High

Silicone	Solvent solution: heat or RT curing and pressure-sensitive; and RT vulcanizing solventless pastes	Solvent evaporation, RT or elevated temp	Of primary interest is pressure-sensitive type used for tape. High strengths for other forms are reported from −100 to 500^{0}F; limited service to 700^{0}F. Excellent dielectric properties	Metal; glass; paper plastics and rubber including silicone and butyl rubber and fluorocarbons	High–very high
Neoprene	Latexes and solvents solutions, often compounded with resins, metallic oxides, fillers, etc.	Evaporation of solvents	Superior to other rubber adhesives in most respect—quickness; strength; max temp (to 200^{0}F, sometimes 350^{0}F); aging; resistant to light, weathering, mild acids and oils	Metals, leather, fabric, plastics, rubber (particularly neoprene) wood, building material	Medium

Source: Petrie, E. M., "Joining of Plastics, Elastomers, and Composites", *Handbook of Plastics, Elastomers and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

K.7 Alloy Adhesives

Appendix K.7

Adhesive	Description	Curing Method	Special Characteristics	Usual Adherends	Price Range
Epoxy–phenolic	Two-part paste, supported film	Heat and pressure	Good properties at moderate cures; volatiles released during cure; retains 50% of bond strength at 500°F; limited shelf life; low peel strength and shock resistance	Metals, honeycomb core, plastic laminates, ceramics	Medium
Epoxy–polysulfide	Two-part liquid or paste	RT or higher	Useful temperature range −70 to 200°F, greater resistance to impact, higher elongation, and less brittleness than epoxies	Metals, plastic, wood, concrete	Medium
Epoxy–nylon	Solvent solutions, supported and unsupported film	Heat and pressure	Excellent tensile-shear strength at cryogenic temperature; useful temperature range −423 to 180°F; limited shelf life	Metals, honeycomb core, plastics	Medium
Nitrile–phenolic	Solvent solutions, unsupported and supported film	Heat and pressure	Excellent shear strength; good peel strength; superior to vinyl and neoprene–phenolics; good adhesion	Metals, plastics, glass, rubber	Medium

Neoprene–phenolic	Solvent solutions, supported and unsupported film	Heat and pressure	Good bonds to a variety of substrates; useful temp range -70 to 200°F, excellent fatigue and impact strength	Metals, glass, plastics	Medium
Vinyl-phenolic	Solvent solutions and emulsions, tape, and coreacting powder	Heat and pressure	Good shear and peel strength; good heat resistance; good resistance to weathering, humidity, oil, water, and solvents vinyl formal and vinyl butyral forms available, vinyl formal-phenolic is strongest	Metals, paper, honeycomb core	Low–medium

Source: Petrie, E. M., "Joining of Plastics, Elastomers, and Composites", *Handbook of Plastics, Elastomers and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

K.8 Common ASTM Adhesive Test Standards Related to Adhesives and Adhesion[*]

Aging	Resistance of Adhesives to Cyclic Aging Conditions, Test for (D1183) Bonding Permanency of Water- or Solvent-Soluble Liquid Adhesives for Labeling Glass Bottles, Test for (D 1581) Bonding Permanency of Water- or Solvent-Soluble Liquid Adhesives for Automatic Machine Sealing Top Flaps of Fiber Specimens, Test for (D1713) Permanence of Adhesive-Bonded Joints in Plywood under Mold Conditions, Test for (D 1877) Accelerated Aging of Adhesive Joints by the Oxygen-Pressure Method, Practice for (D 3632)
Amylaceous matter	Amylaceous Matter in Adhesives, Test for (D 1488)
Biodeterioration	Susceptibility of Dry Adhesive Film to Attack by Roaches, Test for (D 1382) Susceptibility of Dry Adhesive Film to Attack by Laboratory Rats, Test for (D 1383) Permanence of Adhesive-Bonded Joints in Plywood under Mold Conditions, Test for (D 1877) Effect of Bacterial Contamination of Adhesive Preparations and Adhesive Films, Test for (D 4299) Effect of Mold Contamination on Permanence of Adhesive Preparation and Adhesive Films, Test for (D 4300)
Blocking point	Blocking Point of Potentially Adhesive Layers, Test for (D1146)
Bonding permanency	(See Aging.)
Chemical reagents	Resistance of Adhesive Bonds to Chemical Reagents, Test for (D 896)
Cleavage	Cleavage Strength of Metal-to-Metal Adhesive Bonds, Test for (D 1062)
Cleavage/peel strength	Strength Properties of Adhesives in Cleavage Peel by Tension Loading (Engineering Plastics-to-Engineering Plastics), Test for (D 3807)
Corrosivity	Determining Corrosivity if Adhesive Materials, Practice for (D 3310)
Creep	Conducting Creep Tests of Metal-to-Metal Adhesives, Practice for (D 1780) Creep Properties of Adhesives in Shear by Compression Loading (Metal-to-Metal), Test for (D 2293) Creep Properties of Adhesives in Shear by Tension Loading, Test for (D 2294)
Cryogenic temperatures	Strength Properties of Adhesives in Shear by Tension Loading in the Temperature Range from −267.8 to −55 °C (−450 to −67 °F), Test for (D 2557)
Density	Density of Adhesives in Fluid Form, Test for (D 1875)
Durability (including weathering)	Effect of Moisture and Temperature on Adhesive Bonds, Test for (D 1151) Atmospheric Exposure of Adhesive-Bonded Joints and Structures, Practice for (D 1828) Determining Durability of Adhesive Joints Stressed in Peel, Practice for (D 2918) Determining Durability of Adhesive Joints Stressed in Shear by Tension Loading, Practice for (D 2919) (See also Wedge Test)

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[*] *Source:* E. M. Petrie, “Plastics and Elastomers as Adhsives,” *Handbook of Materials for Product Design,* 3rd ed., C. A. Harper (ed.), McGraw-Hill, New York, 2001.

Electrical properties	Adhesives Relative to Their Use as Electrical Insulation, Testing (D 1304)
Electrolytic corrosion	Determining Electrolytic Corrosion of Copper by Adhesives, Practice for (D 3482)
Fatigue	Fatigue Properties of Adhesives in Shear by Tension Loading (Metal/Metal), Test for (D 3166)
Filler content	Filler content of Phenol, Resorcinol, and Melamine Adhesives, Test for (D 3166)
Flexibility	(See Flexural strength)
Flexural strength	Flexural Strength of Adhesive Bonded Laminated Assemblies, Test for (D 1184)
	Flexibility Determination of Hot Melt Adhesives by Mandrel Bend Test Methods, Practice for (D 3111)
Flow properties	Flow Properties of Adhesives, Test for (D 2183)
Fracture strength in cleavage	Fracture Strength in Cleavage of Adhesives in Bonded Joints, Practice for (D 3433)
Gap-filling adhesive bonds	Strength of Gap Filling Adhesive Bonds in Shear by Compression Loading, Practice for (D 3931)
High-temperature effects	Strength Properties of Adhesives in Shear by Tension Loading at Elevated Temperatures (Metal-to-Metal), Test for (D 2295)
Hydrogen-ion concentration	Hydrogen Ion Concentration, est for (D 1583)
Impact strength	Impact Strength of Adhesive Bonds, Test for (D 950)
Light exposure	(See Radiation Exposure)
Low and cryogenic temperatures	Strength Properties of Adhesives in Shear by Tension Loading in the Temperature Range from −267.8 to −55°C (−450 to −67°F), Test for (D 2557)
Nonvolatile content	Nonvolatile Content of Aqueous Adhesives, Test for (D 1489)
	Nonvolatile Content of Urea-Formaldehyde Resin Solutions, Test for (D 1490)
	Nonvolatile Content of Phenol, Resorcinol, and Melamine Adhesives, Test for (D 1582)
Odor	Determination of the Odor of Adhesives, Test for (D 4339)
Peel strength (stripping strength)	Peel or Stripping Strength of Adhesive Bonds, Test for (D 903)
	Climbing Drum Peel Test for Adhesives, Method for (D 1781)
	Peel Resistance of Adhesives (T-Peel Test), Test for (D 1876)
	Evaluating Peel Strength of Shoe Sole Attaching Adhesives, Test for (D 2558)
	Determining Durability of Adhesive Joints Stressed in Peel, Practice for (D 2918)
	Floating Roller Peel Resistance, Test for (D 3167)
Penetration	Penetration of Adhesives, Test for (D 1916)
pH	(See Hydrogen-Ion Concentration)
Radiation exposure (including light)	Exposure of Adhesive Specimens to Artificial (Carbon-Arc Type) and Natural Light, Practice for (D 904)
	Exposure of Adhesive Specimens to High-Energy Radiation, Practice for (D 1879)
Rubber cement tests	Rubber Cements, Testing of (D 816)
Salt spray (fog) testing	Salt Spray (Fog) Testing, Method of (B 117)
	Modified Salt Spray (Fog) Testing, Practice for (G 85)
Shear Strength (Tensile Shear Strength)	Shear Strength and Shear Modulus of Structural Adhesives, Test for (E 229) Strength Properties of Adhesive Bonds in Shear by Compression Loading, Test for (D 905)
	Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading, Test for (D 906)

Shear Strength (*Continued*)	Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal), Test for (D 1002)
	Determining Strength Development of Adhesive Bonds, Practice for (D 1144)
	Strength Properties of Metal-to-Metal Adhesives by Compression Loading (Disk Shear), Test for (D 2181)
	Strength Properties of Adhesives in Shear by Tension Loading at Elevated Temperatures (Metal-to-Metal), Test for (D 2295)
	Strength Properties of Adhesives in Two-Ply Wood construction in Shear by Tension Loading, Test for (D 2339)
	Strength Properties of Adhesives in Shear by Tension Loading in the Temperature Range from −267.8 to −55°C (−450 to −67°F), Test for (D 2557)
	Determining Durability of Adhesive Joints Stressed in Shear by Tension Loading, Practice for (D 2919)
	Determining the Strength of Adhesively Bonded Right Plastic Lap-Shear Joints in Shear by Tension Loading, Practice for (D 3163)
	Determining the Strength of Adhesively Bonded Plastic Lap-Shear Sandwich Joints in Shear by Tension Loading, Practice for (D 3164)
	Strength Properties of Adhesives in Shear by Tension Loading of Laminated Assemblies, Test for (D 3165)
	Fatigue Properties of Adhesives in Shear by Tension Loading (Metal/Metal), Test for (D 3166)
	Strength Properties of Double Lap Shear Adhesive Joints by Tension Loading, Test for (3528)
	Strength of Gap-Filling Adhesive Bonds in Shear by Compression Loading, Practice for (D 3931)
	Measuring Strength and Shear Modulus of Nonrigid Adhesives by the Thick Adherend Tensile Lap Specimen, Practice for (D 3983)
	Measuring Shear Properties of Structural Adhesives by the Modified-Rail Test, Practice for (D 4027)
Specimen Preparation	Preparation of Bar and Rod Specimens for Adhesion Tests, Practice for (D 2094)
Spot-Adhesion Test	Qualitative Determination of Adhesion of Adhesives to Substrates by Spot Adhesion Test Method, Practice for (D 3808)
Spread (Coverage)	Applied Weight per Unit Area of Dried Adhesive Solids, Test for (D 898)
	Applied Weight per Unit Area of Liquid Adhesive, Test for (D 899)
Storage Life	Storage Life of Adhesives by Consistency and Bond Strength, Test for (D 1337)
Strength Development	Determining Strength Development of Adhesive Bonds, Practice for (D 1144)
Stress-Cracking Resistance	Evaluating the Stress Cracking of Plastics by Adhesives Using the Bent Beam Method, Practice for (D 3929)
Stripping Strength	(See Peel Strength)
Surface Preparation	Preparation of Surfaces of Plastics Prior to Adhesive Bonding, Practice for (D 2093)
	Preparation of Metal Surfaces for Adhesive Bonding, Practice for (D 2651)
	Analysis of Sulfochromate Etch Solution Used in Surface Preparation of Aluminum, Methods of (D 2674)
	Preparation of Aluminum Surfaces for Structural Adhesive Bonding (Phosphoric Acid Anodizing), Practice for (D 3933)
Tack	Pressure Sensitive Tack of Adhesives Using an Inverted Probe Machine, Test for (D 2979)
	Tack of Pressure-Sensitive Adhesives by Rolling Ball, Test for (D 3121)

Tensile Strength	Tensile Properties of Adhesive Bonds, Test for (D 897) Determining Strength Development of Adhesive Bonds, Practice for (D 1144) Cross-Lap Specimens for Tensile Properties of Adhesives, Testing of (D 1344) Tensile Strength of Adhesives by Means of Bar and Rod Specimens, Method for (D 2095)
Torque Strength	Determining the Torque Strength of Ultraviolet (UV) Light-Cured Glass/Metal Adhesive Joints, Practice for (D 3658)
Viscosity	Viscosity of Adhesives, Test for (D 1084) Apparent Viscosity of Adhesives Having Shear-Rate-Development Flow Properties, Test for (D 2556) Viscosity of Hot Melt Adhesives and Coating Materials, Test for (D 3236)
Volume Resistivity	Volume Resistivity of Conductive Adhesives, Test for (D 2739)
Water Absorptiveness (of Paper Labels)	Water Absorptiveness of Paper Labels, Test for (D 1584)
Weathering	(See Durability)
Wedge Test	Adhesive Bonded Surface Durability of Aluminum (Wedge Test) (D 3762)
Working Life	Working Life of Liquid or Paste Adhesive by Consistency and Bond Strength, Test for (D 1338)

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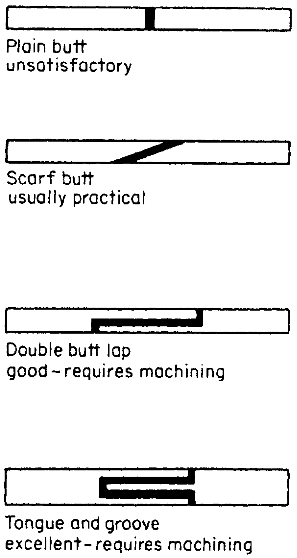
[*] The latest revisions of ASTM standards can be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

K.9 Common Adhesive Joint Designs*



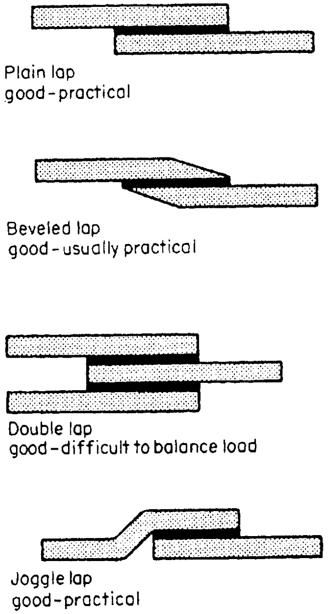
Plain butt
unsatisfactory

Scarf butt
usually practical

Double butt lap
good – requires machining

Tongue and groove
excellent – requires machining

Butt connections.



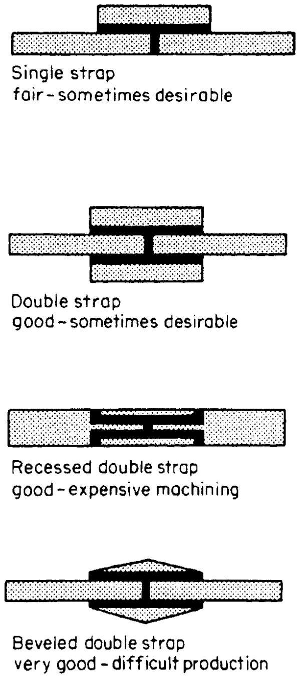
Plain lap
good – practical

Beveled lap
good – usually practical

Double lap
good – difficult to balance load

Joggle lap
good – practical

Lap connections.



Single strap
fair – sometimes desirable

Double strap
good – sometimes desirable

Recessed double strap
good – expensive machining

Beveled double strap
very good – difficult production

Strap connections.

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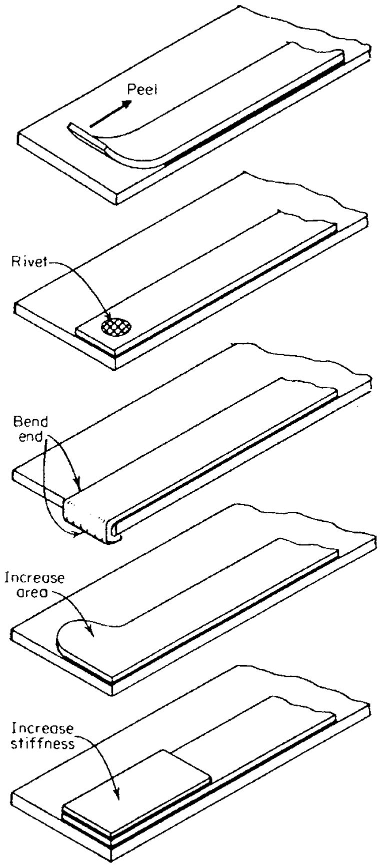
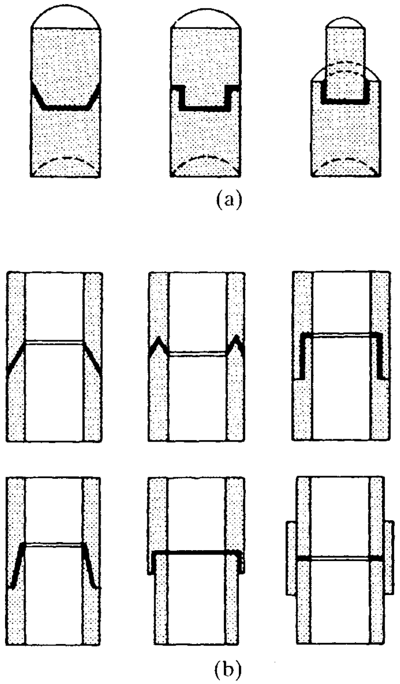
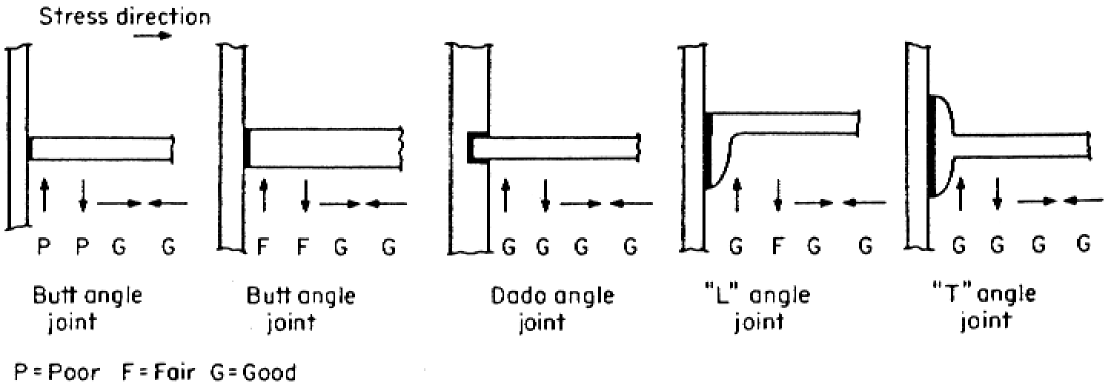
*Source: Petrie, E. M., "Joining of Plastics, Elastomers, and Composites", *Handbook of Plastics, Elastomers and Composites,* 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.



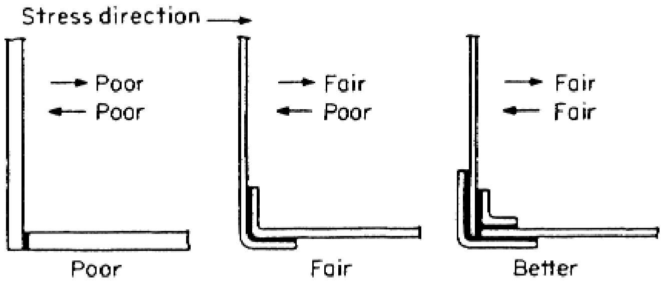
Minimizing peel in adhesive joints.



Recommended designs for rod and tube joints. (*a*) Three joint designs for adhesive bonding of round bars. (*b*) Six joint configurations useful in adhesive-bonding cylinders or tubes.



Types of angle joints and methods of reducing cleavage.



Reinforcement of bonded corners.

APPENDIX L

Important Information Regarding Liquid Resins

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

L.1 General Comparisons of Properties of Liquid Resins

APPENDIX L.1

Material	Cure Shrinkage	Adhesion	Thermal Shock	Electrical Properties	Mechanical Properties	Handling Properties	Cost
Epoxy:							
Room temperature cure	Low	Good	Fair*	Fair	Fair	Good	Moderate
High temperature	Low	Good	Fair*	Good	Good	Fair to good	Moderate
Flexible	Low	Excellent	Good	Fair	Fair	Good	Moderate
Polyesters:							
Rigid	High	Fair	Fair*	Fair to good	Good	Fair	Low to moderate
Flexible	Moderate	Fair	Fair	Fair	Fair	Fair	Low to moderate
Silicones:							
Rubbers	Very low	Poor	Excellent	Good	Poor	Good	High
Rigid	High	Poor	Poor	Excellent	Poor	Fair	High
Polyurethanes:							
Solid	Low	Excellent	Good	Fair	Good	Fair	Moderate
Foams	Variable	Good	Good	Fair	Good for density	Fair	Moderate
Butyl LM	Low	Good	Excellent	Good	Poor	Fair	Low to moderate
Butadienes	Moderate	Fair	Poor*	Excellent	Fair	Fair	Moderate

*Depends on filler.

Source: Buchoff, L. S., “Liquid and Low Pressure Resin Systems”, *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

L.2 Properties of Various Liquid Resins

Appendix L.2a

		Rigids (Silica-Filled)			Flexibilized Epoxies			Liquid Elastomers				Rigid Polyurethane
Property	ASTM	Styrene Polyester	Epoxy	Silicone	Epoxy-Polysulfide (50–50)	Epoxy-Polyamide (50–50)	Epoxy-Polyurethane (50–50, Diamine Cure)	Polysulfide	Silicone	Polyurethane-(Diamine Cure)	Plastisol	Prepolymer
					Electrical Properties							
Dielectric strength, V/mil*	D 149	425	425	350	350	430	640	340	400	350	200	
Dielectric constant:												
60 Hz	D 150	3.7	3.8	3.7	5.6	3.2		7.2	3	8.2	5.6	1.05
10^3 Hz	D 150	3.7	3.6	3.6	5.4	3.2	4.9	7.2	3	7.3	4.9	1.06
10^6 Hz	D 150	3.6	3.4	3.6	4.8	3.1		7.2	3		3.6	1.04
Dissipation factor:												
60 Hz	D 150	0.01	0.02	0.008	0.02	0.01		0.01	0.005	0.08	0.12	0.004
10^3 Hz	D 150	0.02	0.02	0.004	0.02	0.01	0.04	0.01	0.004	0.09	0.1	0.003
10^6 Hz	D 150	0.02	0.03	0.01	0.06	0.02		0.02	0.003		0.12	0.003
Surface resistivity, Ω/square:												
Dry	D 257	10^{15}	10^{15}	10^{15}	10^{12}	10^{14}		10^{11}	10^{13}		10^{10}	$> 10^{12}$
After 96 h at 95°F, 90% RH	D 257	10^{11}	10^{13}	10^{15}	10^{10}			10^{10}	10^{12}		10^{10}	$> 10^{12}$
Volume resistivity (dry), Ω-cm	D 257	$> 10^{15}$	$> 10^{15}$	10^{15}	10^{12}	10^{14}	10^{14}	10^{11}	10^{14}	10^{12}	10^{10}	$> 10^{14}$
					Mechanical Properties							
Tensile strength, lb/in^2	D 638, D 412	10,000	9,000	4,000	1,800	4,600	6,000	800	275	4,000	2,400	110
Elongation, %	D 142				30		10	450	200	450	300	
Compression strength, lb/in^2	D 695, D 575	25,000	16,000	13,000		7,000						85

Appendix L.2 (*Continued*)

		Rigids (silica-filled)			Flexibilized epoxies			Liquid elastomers				Rigid polyurethane
Property	ASTM	Styrene Polyester	Epoxy	Silicone	Epoxy-Polysulfide (50–50)	Epoxy-Polyamide (50–50)	Epoxy-Polyurethane (50–50, Diamine Cure)	Poly-sulfide	Silicone	Poly-urethane-(Diamine Cure)	Plas-tisol	Prepolymer
Flexural modulus of rupture, lb/in^2	D 790	10,000	12,000	8,000		8,300						
Izod impact strength (notched), ft-lb	D 256	0.3	0.4	0.3								
Shore hardness	D 676, D 1484				40D		80D	45A	35A	90A	80A	
Penetration at 77°F, mils	D 5											
Shrinkage on cooling or curing, % by vol		6	3.5	8	3	3	6	1	2	4.5		
Physical Properties												
Specific gravity	D 71, D 792	1.6	1.6	1.8	1.2	1.0	1.2	1.2	1.1	1.1	1.2	0.1†
Minimum cold flow, °F												
Softening or drip point, °F	D 36											
Heat-distortion temp, °F	D 648	230	165	300			100					
Maximum continuous service temp, °F		250	250	480	225	175	250	200	350	210	150	165
Coefficient of thermal expansion per °F $\times 10^{-6}$	D 696	26	22	44	44	44	110		128	110		19
Thermal conductivity, Btu/(ft^2)(h)(°F/ft)		0.193	0.29	0.23			0.77		0.13		0.09	0.02
Cost, $/lb		0.25	0.50	2.75	0.90	0.80	1.10	0.85	4.25	1.30	0.30	1.75

[*] Short-time test on 1/8-in specimen.

†6 lb/ft^3.

Source: Lundberg, C. V., "A Guide to Potting and Encapsulation Materials", *Materials Engineering*, May, 1980.

L.3 Characteristics Influencing Choice of Resins in Electrical Applications

Appendix L.3

Resin	Cure and Handling Characteristics	Final Part Properties
Epoxies	Low shrinkage, compatible with a wide variety of modifiers, very long storage stability, moderate viscosity, cure under adverse conditions	Excellent adhesion, high strength, available clear, resistant to solvents and strong bases, sacrifice of properties for high flexibility
Polyesters	Moderate to high shrinkage, cure cycle variable over wide range, very low viscosity possible, limited compatibility, low cost, long pot life, easily modified, limited shelf life, strong odor with styrene	Fair adhesion, good electrical properties, water-white, range of flexibilities
Polyurethanes	Free isocyanate is toxic, must be kept water-free, low cure shrinkage, solid curing agent for best properties	Wide range of hardness, excellent wear, tear, and chemical resistance, fair electricals, excellent adhesion, reverts in humidity
Silicones (flexible)	Some are badly cure-inhibited, some have uncertain cure times, low cure shrinkage, room temperature cure, long shelf life, adjustable cure times, expensive	Properties constant with temperature, excellent electrical properties, available from soft gels to strong elastomers, good release properties
Silicones (rigid)	High cure shrinkage, expensive	Brittle, high-temperature stability, electrical properties excellent, low tensile and impact strength
Polybutadienes	High viscosity, reacted with isocyanates, epoxies, or vinyl monomers, moderate cure shrinkage	Excellent electrical properties and low water absorption, lower strength than other materials

Appendix L.3 (*Continued*)

Resin	Cure and Handling Characteristics	Final Part Properties
Polysulfides	Disagreeable odor, no cure exotherm, high viscosity	Good flexibility and adhesion, excellent resistance to solvents and oxidation, poor physical properties
Depolymerized rubber	High viscosity, low cure shrinkage, low cost, variable cure times and temperature, one-part material available	Low strength, flexible, low vapor transmission, good electrical properties
Allylic resins	High viscosity for low-cure-shrinkage materials, high cost	Excellent electrical properties, resistant to water and chemicals

Source: Buchoff, L. S., "Liquid and Low Pressure Resin Systems", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

L.4 *Characteristics of Liquid Resins in Nonelectrical Applications*

Appendix L.4

Resin	Handling Characteristics	Final Part Properties	Typical Applications
Cast acrylics	Low to high viscosity, long cure times, bubbles a problem, special equipment necessary for large parts	Optical clarity, excellent weathering, resistance to chemicals and solvents	In glazing, furniture, embedments, impregnation
Cast nylon	Complex casting procedure, very large parts possible	Strong, abrasion-resistant, wear-resistant, resistance to chemicals and solvents, good lubricity	Gears, bushings, wear plates, stock shapes, bearings
Phenolics	Acid catalyst used, water given off in cure	High density unfilled, brittle, high temperature, brilliance	Billiard balls, beads
Vinyl plastisol	Inexpensive, range of viscosities, fast set, cure in place, one-part system, good shelf life	Same as molded vinyls, flame-resistant, range of hardness	Sealing gaskets, hollow toys, foamed carpet backing
Epoxies	Cures under adverse conditions, over a wide temperature range, compatible with many modifiers, higher filler loadings	High strength, good wear, chemical and abrasion resistance, excellent adhesion	Tooling, fixtures, road and bridge repairs, chemical-resistant coating, laminates, and adhesives
Polyesters	Inexpensive, low viscosity, good pot life, fast cures, high exotherm, high cure shrinkage, some cure inhibition possible, wets fibers easily	Moderate strength, range of flexibilities, water-white available, good chemical resistance, easily made fire retardant	Art objects, laminates for boats, chemical piping, tanks, aircraft, and building panels
Polyurethanes	Free isocyanate is toxic, must be kept water-free, low cure shrinkage, cast hot	Wide range of hardnesses, excellent wear, tear and, chemical resistance, very strong	Press pads, truck wheels, impellers, shoe heels and soles
Flexible soft silicone	High-strength materials, easily inhibited, low cure shrinkage, adjustable cure time, no exotherm	Good release properties, flexible and useful over wide temperature range, resistant to many chemicals, good tear resistance	Casting molds for plastics and metals, high-temperature seals

Appendix L.4 (*Continued*)

Resin	Handling Characteristics	Final Part Properties	Typical Applications
Allylic resins	Long pot life, low vapor pressure monomers, high cure temperature, low viscosity for monomers	Excellent clarity, abrasion resistant,- color stability, resistant to solvents and acids	Safety lenses, face shields, casting impregnation, as monomer in polyester
Depolymerized rubber	High viscosity, low cost, adjustable cure time	Low strength, low vapor transmission, resistant to reversion in high humidity	Roofing coating, sealant, in reservoir liners
Polysulfide	High viscosity, characteristic odor, low cure exotherm	Good flexibility and adhesion, excellent resistance to solvents and oxidation, poor physical properties	Sealants, leather impregnation
Epoxy vinyl esters	Low viscosity, high cure shrinkage, wets fibers easily, fast cures	Excellent corrosion resistance, high impact resistance, excellent electrical insulation properties	Absorption towers, process vessels, storage tanks, piping, hood scrubbers, ducts and exhaust stacks
Cyanate esters	Low viscosity at room temperature or heated, rapid fiber wetting, high temperature cure	High operating temperature, good water resistance, excellent adhesive properties and low dielectric constant	Structural fiber-reinforced products, high temperature film adhesive, pultrusion and filament winding

Source: Buchoff, L. S., "Liquid and Low Pressure Resin Systems", *Handbook of Plastics, Elastomers, and Composites*, 3rd ed., C. A. Harper, ed., McGraw-Hill, New York, 1996.

APPENDIX M

Important Information Regarding Fillers, Modifiers, Reinforcements

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Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

M.1 Types of Filler for Plastics[*]

APPENDIX M.1

Organic Materials

- A. Cellulosic products
  - 1. Wood products
    - a) Kraft paper
    - b) Chips
    - c) Coarse flour
    - d) Ground flour
      - 1. Softwood flour
      - 2. Hardwood flour
      - 3. Shell flour
  - 2. Comminuted cellulose products
    - a) Chopped paper
    - b) Diced resin board
    - c) Crepe paper
    - d) Pulp preforms
  - 3. Fibers
    - a) Alpha cellulose
    - b) Pulp preforms
    - c) Cotton flock
    - d) Textile byproducts
    - e) Jute
    - f) Sisal
    - g) Rayon
- B. Lignin-type products
  - 1. Ground bark
  - 2. Processed lignin
- C. Synthetic fibers
  - 1. Polyamides (nylon)
  - 2. Polyesters (Dacron)
  - 3. Polyacrylonitrile (Orlon)
- D. Carbon
  - 1. Carbon black
    - a) Channel black
    - b) Furnace black
  - 2. Ground petroleum coke
  - 3. Graphite filaments
  - 4. Graphite "whiskers"

Inorganic Materials

- A. Silica products
  - 1. Minerals
    - a) Sand
    - b) Quartz
    - c) Tripoli
    - d) Diatomaceous earth
  - 2. Synthetic materials
    - a) Wet process silica
    - b) Pyrogenic silica
    - c) Silica aerogel
- B. Silicates
  - 1. Minerals
    - a) Asbestos
  - 1. Chrysolite
  - 2. Amosite
  - 3. Anthophyllite
  - 4. Crocidolite
  - 5. Tremollite
  - 6. Actinolile
    - b) Kaolinite (China clay)
    - c) Mica
    - d) Talc
    - e) Wollastonite
  - 2. Synthetic Products
    - a) Calcium silicate
    - b) Aluminum silicate
- C. Glass
  - 1. Glass flakes
  - 2. Hollow glass spheres
  - 3. Solid glass spheres

Source: Seymour, R. B., "Additives for Plastics—Fillers and Reinforcements, *Plastics Engineering*, August 1976.

APPENDIX M.1 (*Continued*)

4. Milled fibers
5. Fibrous glass
    a) Filament
    b) Rovings
    c) Woven Roving
    d) Yarn
    e) Mat
    f) Fabric

D. Metals
1. Steel
2. Tungsten
3. Titanium
4. Beryllium filaments
5. Molybdenum filaments

E. Boron filaments

F. Metallic oxides
1. Ground material
    a) Zinc oxide
    b) Aluminum
    c) Magnesia
    d) Titania
2. “Whiskers”
    a) Aluminum oxide
    b) Beryllium oxide
    c) Magnesium oxide
    d) Thorium oxide
    e) Zirconium oxide

G. Calcium carbonate
1. Chalk
2. Limestone
3. Precipitated calcium carbonate

H. Polymeric fillers

I. Other fillers
1. “Whiskers” (non-oxide)
    a) Aluminum nitride
    b) Beryllium carbide
    c) Boron carbide
    d) Silicon carbide
    e) Silicon nitride
    f) Tungsten carbide
2. Barium ferrite
3. Barium sulfate

M.2 Filler/Reinforcement Applications*

Filler/reinforcement	Thermoplastics																			Thermosets				Comment
	Acetal	Acrylic	ABS	Cellulosics	Fluoroplastics	Nylon	Polycarbonate	Polyester, thermoplastic	Polyolefins	LDPE	HDPE	Polypropylene	PPO, modified	Polystyrene	Polysulfone	PPS	PVC	PVC, flexible	PVC, rigid	Epoxy	Phenolic	Polyester, unsaturated	Polyurethane (incl. RRIM)	
Alumina trihydrate			●							●							●			●	●	●	●	Extender; flame retardant; smoke suppressant
Barium sulfate																						●	●	Used as a filler and white pigment; increases specific gravity, frictional resistance, chemical resistance
Boron fibers																				●		●		High tensile strength and compressive load bearing capacity; expensive
Calcium carbonate			●			●			●					●			●			●	●	●	●	Most widely used extender/pigment or filler for plastics
Calcium sulfate						●					●						●					●		Extender; also enhances physical properties, increases impact, tensile, compressive strength

Carbon black			●						●					●			●							Filler; used as pigment, antistat agent, or to aid in cross-linking; conductive
Carbon/graphite fibers						●	●					●								●		●		Reinforcement; high modulus and strength; low density; low coefficient of expansion; low coefficient of friction; conductive
Ceramic fibers																				●		●		Reinforcement; very high temperature resistance; expensive
Feldspar and nepheline syenite		●		●								●					●			●		●		Specialty filler; easily wet and dispersed; enables transparency and translucency; weather and chemical resistance
Glass reinforcement (fiber, cloth, etc.)	●		●		●	●	●	●	●				●	●	●	●	●			●	●	●	●	Largest volume reinforcement; high strength, dimensional stability, heat resistance, chemical resistance

Source: Plastics Compounding, 1991/92 Redbook, Edgell Communications, Cleveland, Ohio.

	Thermoplastics																			Thermosets				
Filler/reinforcement	Acetal	Acrylic	ABS	Cellulosics	Fluoroplastics	Nylon	Polycarbonate	Polyester, thermoplastic	Polyolefins	LDPE	HDPE	Polypropylene	PPO, modified	Polystyrene	Polysulfone	PPS	PVC	PVC, flexible	PVC, rigid	Epoxy	Phenolic	Polyester, unsaturated	Polyurethane (incl. RRIM)	
Kaolin						●			●								●					●	●	Second largest volume extender/pigment, with largest use in wire and cable, SMC and BMC, vinyl flooring
Metal fillers, filaments			●			●	●					●		●			●			●	●	●		Used to impart conductivity (thermal and electrical) or magnetic properties or to reduce friction; expensive
Mica			●		●	●	●	●	●				●		●					●	●	●	●	Flake reinforcement; improves dielectric, thermal, mechanical properties; low in cost
Microspheres, hollow																				●		●	●	Reduces weight of plastic systems; improves stiffness, impact resistance
Microspheres, solid	●	●	●		●	●	●	●	●		●				●					●	●	●	●	Improves flow properties, stress distribution
Organic fillers				●													●			●	●	●	●	Extenders/fillers, like wood flour, nutshell, corncobs, rice, peanut hulls

Polymeric fibers						●														●	●	●	●	Reinforcement; lightweight
Silica		●							●					●			●					●	●	Fillers/extenders/reinforcements; functions in thickening liquid systems and making them thixotropic, in helping avoid plateout with PVC, in acting as flatting agents
Talc						●			●					●			●				●		●	Extenders/reinforcements/fillers; higher stiffness, tensile strength and resistance to creep
Wollastonite						●	●	●	●					●						●	●	●	●	High loadings possible; can improve strength, lower moisture absorption, elevate heat and dimensional stability, improve electricals

M.3 Additive/Modifier Applications*

		Thermoplastics																Thermosets			
Additive/modifier	**Function**	**Acetal**	**Acrylic**	**ABS**	**Cellulosics**	**Nylon**	**Polycarbonate**	**Polyester, thermoplastic**	**Polyethylene**	**LDPE**	**HDPE**	**Polypropylene**	**PPO, modified**	**Polystyrene**	**PVC**	**flexible**	**rigid**	**Epoxy**	**Phenolic**	**Polyester, unsaturated**	**Polyurethane**
Antiblocking agents	Prevent plastics films from sticking to each other or to themselves			●						●					●						
Antifogging agents	Prevent fogging that could obscure viewing through clear film or sheet									●					●	●					
Antioxidants	Prevent oxidative degradation	●	●	●	●	●	●		●	●	●	●		●	●	●	●	●		●	●
Antistatic agents	Prevent buildup of electrostatic charges on the plastics surfaces	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●		●	●
Biocides	Prevent growth of microorganisms on plastics surfaces that could cause odor, mildew, stains									●					●						●
Blowing agents	Create a gas that dissolves in the plastics to form a cellular or foamed structure																				
ABFA		●	●						●				●	●	●						
OBSH										●					●						
TSSC				●		●					●	●	●	●			●				
5-PT				●		●	●	●					●								
Others																				●	

Coupling agents	Provide improved bonding between resin and filler/reinforcements																				
Silanes			●	●		●	●		●					●	●			●	●	●	●
Titanates		●				●	●		●				●	●			●	●		●	●
Cross-linking agents	Cross-link various thermoplastics to improve physical properties									●	●										
Curing agents	Serve as catalyst or initiator in the curing of plastics																	●		●	
Defoamers (or air-release agents)	Facilitate removal of air entrapped in a mix																	●		●	●
Flame retardants	Yield products that would be difficult to ignite or to propagate flame																				
Alumina trihydrate				●						●					●			●	●	●	●
Antimony oxide				●		●		●	●					●		●		●		●	

*Source: *Plastics Compounding*, 1991/92 Redbook, Edgell Communications, Cleveland, Ohio.

Additive/modifier	Function	Acetal	Acrylic	ABS	Cellulosics	Nylon	Polycarbonate	Polyester, thermoplastic	Polyethylene	LDPE	HDPE	Polypropylene	PPO, modified	Polystyrene	PVC	flexible	rigid	Epoxy	Phenolic	Polyester, unsaturated	Polyurethane
Flame retardants																					
Borates									●						●					●	
Bromine compounds				●		●	●	●	●			●	●	●				●	●	●	●
Chlorine compounds				●		●			●							●		●		●	●
Molybdenums				●		●									●			●		●	●
Phosphorus compounds					●				●				●		●			●		●	●
Heat stabilizers	Prevent plastics from chemically breaking down under heat and further degrading	●	●	●	●	●			●					●	●			●		●	●
Impact modifiers	Improve the impact strength of plastics						●	●	●						●			●		●	●
Low-profile additives	Prevent shrinkage and warpage during polymerization of the resin																			●	
Lubricants	Improve processibility by lowering melt viscosity or preventing the polymer from sticking to the metal surfaces of the processing equipment		●	●	●	●	●		●					●	●	●	●	●	●	●	●
Plasticizers	Enhance flexibility, resiliency and melt flow		●		●	●			●					●	●			●	●	●	●

Slip agents	Provide surface lubrication to lower the coefficient of expansion and to reduce the possibility of the plastics film or sheet sticking to itself								●						●	●	●				
Thickeners, thixotropes	Increase viscosity of and/or impart thixotropy to fluid dispersions or solutions																			●	
UV stabilizers	Prevent plastics from deteriorating under exposure to UV light		●	●	●	●	●	●	●			●		●	●			●		●	●
Wetting agents	Wet out filler particles and provide for a more stable, homogeneous dispersion of the filler in the resin					●			●									●		●	●

M.4 Glass Fiber Reinforcement Forms[*]

APPENDIX M.4

Form of Fiber Glass Reinforcement	Definition and Description	Range of Grades Available	General types of Sizing Applied	General usage in RP/C (and Secondary Uses if Any)
Twisted yarns	Single-end fiberglass strands twisted on standard textile tube-drive machinery.	B to K fiber, S or Z twist, 0.25–10.0 twists/in, many fiber and yardage variations.	Starch.	Into single and plied yarns for weaving; many other industrial uses (and decorative uses).
Plied yarns	Twisted yarns plied with reverse twist on standard textile ply frames.	B to K fiber, up to 4/18 ply–- many fiber and yardage. variations.	Starch.	Weaving industrial fabrics and tapes in many different cloth styles; also heavy cordage.
Fabrics	Yarns woven into a multiplicity of cloth styles with various thicknesses and strength orientations.	D to K fibers, 2.5–40 oz/yd^2 in weight.	Starch size removed and compatible finish applied after weaving.	Wet lay-up for open molding, prepreg, high pressure lamination, and also some press molding.
Chopped strands	Filament bundles (strands) bonded by sizings, subsequently cured and cut or chopped into short lengths. Also the reverse, i.e., chopped and cured.	G to M fiber, 1/8–1/2 in or longer lengths, various yardages.	LSB and RTP.	Compounding, compression, transfer and injection press molding.
Roving	Gathered bundle of one or more continuous strands wound in parallel and in an untwisted manner into a cylindrical package.	G or T fiber used. Roving yields 1800 to 28 yd/lb and packages 15- to 450-lb weight (size of up to 24 × 24 in).	HSB, LSB, and RTP.	Used in all phases of RP/C. Some (HSB) are used in continuous form, e.g., filament winding, and others (LSB) are chopped, as in

				sheet molding compound for compression molding.
Woven roving	Coarse fabric, bidirectional reinforcement, mostly plain weave, but some twill. Uni- and multidirectional nonwoven rovings are also produced.	K to T fiber, fabric weights 10–48 oz/yd^2.	HSB.	Mostly wet lay-up, but some press molding.
Chopped strand mats	Strands from forming packages chopped and collected in a random pattern with additional binder applied and cured; some “needled” mat produced with no extra binder required.	G to K fiber, weights 0.75–6.0 oz/ft^2	HSB and LSB.	Both wet lay-up and press molding.
Mats, continuous strand (swirl)	Strands converted directly into mat form without cutting with additional binder applied and cured, or needled.	Nominally M to R fiber diameter, weights 0.75–4.5 oz/ft^2.	LSB.	Compression and press molding, resin transfer molding, and pultrusion.
Mat-woven roving combinations	Chopped strand mat and woven roving combined into a drapable reinforcement by addition of binder or by stitching.	30–62 oz/yd^2.	HSB.	Wet lay-up to save times in handling.
Three-dimensional reinforcements	Woven, knitted, stitched, or braided strands or yarns in bulky, continuous shapes.	—	HSB.	Molding, pultrusion.

APPENDIX M.4 (*Continued*)

Form of Fiber Glass Reinforcement	Definition and Description	Range of Grades Available	General types of Sizing Applied	General usage in RP/C (and Secondary Uses if Any)
Milled fibers	Fibers reduced by mechanical attrition to short lengths in powder or nodule form.	Screened from 1/32–1/4 in. Actual lengths range 0.001–1/4 in. Several grades	None, HSB, and RTP.	Casting, potting, injection molding, reinforced reaction injection molding (RRIM).
Related forms:				
Glass beads	Small solid or hollow sphere of glass.	Range 1–53 μm diameter, bulk densities; hollow = 0.15–0.38 g/cm^3, solid = 1.55 g/cm^3.	Usually treated with cross-linking additives	Used as a filler, flow aid, or weight reduction medium in casting, lamination, and press molding.
Glass flake	Thin glass platelets of controlled thickness and size.	0.0001 in an up thick.	None, or treated with doupling agent.	Used as a barrier in, or to enhance abrasion resistance of, linear resins; coatings used for corrosion-resistance applications. Also used in RRIM for increased dimensional stability.

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[*] *Source:* Milewski, J. V., *Handbook of Reinforcements for Plastics*, H. S. Katz (ed.), van Nostrand Reinhold, New york, 1987.

M.5 Electrical-Grade Glass Fabrics

APPENDIX M.5

	Count	Warp Yarn			Fill Yarn				Mass	Thickness	Breaking Strength
Fabric Style No.	Yarns/in Yarns/5 cm	Yarn Count TEX			Yarn Count TEX			Weave	oz/yd^2 g/m^2	in mm	lb/in N/(5 cm)
104	60 × 52	ECD	900	1/0	ECD	1800	1/0	Plain	0.58	0.0012	40 × 15
	118 × 102	ECS	5.5	1 × 0	EC5	2.75	1 × 0	Plain	19.7	0.030	350 × 131
108	60 × 47	ECD	900	1/2	ECD	900	1/2	Plain	1.43	0.0020	70 × 40
	118 × 93	EC5	5.5	1 × 2	EC5	5.5	1 × 2	Plain	48.5	0.051	613 × 350
112	40 × 39	ECD	450	1/2	ECD	450	1/2	Plain	2.10	0.0032	90 × 80
	79 × 77	EC5	11	1 × 2	EC5	11	1 × 2	Plain	71.2	0.081	788 × 701
116	60 × 58	ECD	450	1/2	ECD	450	1/2	Plain	3.16	0.0040	125 × 120
	118 × 114	EC5	11	1 × 2	EC5	11	1 × 2	Plain	107.0	0.102	1095 × 1051
2112	40 × 39	ECD	225	1/0	ECD	225	1/0	Plain	2.10	0.0034	82 × 80
	79 × 77	EC5	22	1 × 0	EC5	22	1 × 0	Plain	71.6	0.076	720 × 700
2116	60 × 58	ECD	225	1/0	ECD	225	1/0	Plain	3.16	0.0040	125 × 120
	118 × 114	EC5	22	1 × 0	EC5	22	1 × 0	Plain	107.0	0.102	1095 × 1050
7628	44 × 32	ECG	75	1/0	ECG	75	1/0	Plain	6.00	0.0068	250 × 200
	87 × 63	EC9	66	1 × 0	EC9	66	1 × 0	Plain	203.0	0.173	2189 × 1751
7642	44 × 20	ECG	75	1/0	ETG	37	1/0	Plain	6.87	0.0110	250 × 120
	87 × 39	EC9	66	1 × 0	ET9	134	1 × 0	Plain	232.0	0.279	2190 × 1050
1080	60 × 47	ECD	450	1/0	ECD	450	1/0	Plain	1.44	0.002	70 × 40
118 × 93	EC5	11		1 × 0	EC5	11	1 × 0	Plain	48.8	0.051	610 × 350

Source: Milewski, J. V., *Handbook of Reinforcement for Plastics*, H. S. Katz (ed.), van Nostrand Reinhold, New York, 1987.

M.6 Mechanical-Grade Glass Fabrics

APPENDIX M.6

	Count	Warp Yarn			Fill Yarn				Mass	Thickness	Breaking Strength
Fabric Style No.	Yarns/in Yarns/5 cm	Yarn Count TEX			Yarn Count TEX			Weave	oz/yd^2 g/m^2	in mm	lb/in N/(5 cm)
1581	57 × 54	ECG	150	1/2	ECG	150	1/2	8-H Satin	8.90	0.0090	350 × 340
	112 × 106	EC9	33	1 × 2	EC9	33	1 × 2	8-H Satin	302.0	0.228	3065 × 2977
1582	60 × 56	ECG	150	1/3	ECG	150	1/3	8-H Satin	13.90	0.0140	490 × 450
	118 × 110	EC9	33	1 × 3	EC9	33	1 × 3	8-H Satin	471.0	0.355	4291 × 3940
1583	54 × 48	ECG	150	2/2	ECG	150	2/2	8-H Satin	16.10	0.0160	650 × 590
	106 × 94	EC9	33	2 × 2	EC9	33	2 × 2	8-H Satin	545.0	0.406	5692 × 5166
1584	44 × 35	ECG	150	4/2	ECG	150	4/2	8-H Satin	26.00	0.0260	950 × 800
	87 × 69	EC9	33	4 × 2	EC9	33	4 × 2	8-H Satin	880.0	0.670	8318 × 7005
3706	12 × 6	ECG	37	1/0	ECG	37	1/2	Leno	3.70	0.0086	140 × 120
	24 × 12	EC9	134	1 × 0	EC9	134	1 × 2	Leno	125.0	0.218	125 × 1050
7781	57 × 54	ECDE	75	1/0	ECDE	75	1/0	8-H Satin	8.95	0.0090	350 × 340
	112 × 106	EC6	66	1 × 0	EC6	66	1 × 0	8-H Satin	304.0	0.228	3065 × 2977
7626	34 × 32	ECG	75	1/0	ECG	75	1/0	Plain	5.40	0.0066	225 × 200
	67 × 63	EC9	66	1 × 0	EC9	66	1 × 0	Plain	183.0	0.168	1970 × 1751
181	57 × 54	ECD	225	1/3	ECD	225	1/3	Satin	8.9	0.009	350 × 340
	22 × 21	EC5	22	1 × 3	EC5	22	1 × 3	Satin	302	0.229	3065 × 2971

Source: Milewski, J. V., *Handbook of Reinforcement for Plastics*, H. S. Katz (ed.), van Nostrand Reinhold, New York, 1987.

M.7 Marine-Grade Glass Fabrics

APPENDIX M.7

	Count	Wrap Yarn			Fill Yarn				Mass	Thickness	Breaking Strength
Fabric style No.	Yarns/in Yarns/5 cm	Yarn Count TEX			Yarn Count TEX			Weave	oz/yd^2 g/m^2	in mm	lb/in N/(5 cm)
1800	16 × 14	ECK	18	1/0	ECK	18	1/0	Plain	9.60	0.0130	450 × 350
	31 × 28	EC13	275	1 × 0	EC13	275	1 × 0	Plain	326.0	0.330	3940 × 3065
2532	16 × 14	ECH	25	1/0	ECH	25	1/0	Plain	7.25	0.0100	300 × 280
	31 × 28	EC10	200	1 × 0	EC10	200	1 × 0	Plain	246.0	0.254	2627 × 2452
7500	16 × 14	ECG	75	2/2	ECG	75	2/2	Plain	9.66	0.0140	450 × 410
	32 × 28	EC9	66	2 × 2	EC9	66	2 × 2	Plain	327.0	0.356	3940 × 3590
7533	18 × 18	ECG	75	1/2	ECG	75	1/2	Plain	5.80	0.0080	250 × 220
	35 × 35	EC9	66	1 × 2	EC9	66	1 × 2	Plain	197.0	0.203	2189 × 1926
7544	28 × 14	ECG	75	2/2	ECG	75	2/4	Basket	18.0	0.0220	750 × 750
	55 × 28	EC9	66	2 × 2	EC9	66	2 × 4	Basket	610.0	0.559	6567 × 6567
7587	40 × 21	ECG	75	2/2	ECG	75	2/2	Mock Leno	20.5	0.0300	750 × 450
	79 × 41	EC9	66	2 × 2	EC9	66	2 × 2	Mock Leno	695.0	0.761	6567 × 3940

Source: Milewski, J. V., *Handbook of Reinforcements for Plastics*, H. S. Katz (ed.), van Nostrand Reinhold, New York, 1987.

M.8 Scrim-Grade Glass Fabrics

APPENDIX M.8

Fabric Style No.	Count Yarns/in Yarns/5 cm	Wrap Yarn			Fill Yarn			Weave	Mass oz/yd^2 g/m^2	Breaking Thickness in mm	Strength lb/in N/(5 cm)
			Yarn Count TEX			Yarn Count TEX					
1610	32 × 28	ECG	150	1/0	ECG	150	1/0	Plain	2.41	0.0040	115 × 100
	63 × 55	EC9	33	1 × 0	EC9	33	1 × 0	Plain	84.1	0.102	1010 × 965
1650	20 × 10	ECG	150	1/0	ECG	75	1/0	Plain	1.60	0.0040	80 × 70
	39 × 20	EC9	33	1 × 0	EC9	66	1 × 0	Plain	54.3	0.102	700 × 615

Source: Milewski, J. V., *Handbook of Reinforcements for Plastics*, H. S. Katz (ed.), van Nostrand Reinhold, New York, 1987.

M.9 Properties of Glass Fibers

APPENDIX M.9

	Glass Type					
	A	C	D	E	R	S and S2
			Physical Properties			
Specific gravity	2.50	2.49	2.16	2.52–2.61	2.55	2.49
tensile strength, lb/in^2	350,000	400,000	350,00	500,000	640,000	665,000
Tensile elastic modulus	9,800,000	10,000,000	7,500,000	10,500,000	12,475,000	12,600,000
Elongation at 72°F, %	—	—	—	3–4	—	5.4
Poisson's ratio	—	—	—	0.22	—	—
			Thermal properties			
Softening point, °F	1300	1380	1420	1540–1555	1481	1778
Coefficient of thermal expansion—in/in/°F × 10^{-7}	90	40	17	28–33	74	13–17
Thermal conductivity (k) BTU in/hr/ft^2/°F at 72°F	—	—	—	7.2	6.9	—
Specific heat at 72°F BTU/lb/°F	—	—	—	0.197	—	—
			Optical properties			
Index of refraction	1.512	1.541	1.47	1.56	—	1.523
			Electrical properties			
Dielectric constant, 72°F, 10^6/Hz	6.90	6.24	3.56	6.1–6.7	6.2	5.34
Loss tangent, 72°F, 10^6 Hz	0.0085	0.0052	0.0005	0.001	0.0015	0.002

APPENDIX M.9 (*Continued*)

	Glass Type					
	A	C	D	E	R	S and S2
	Features					
	Soda-lime glass with limited water resistance	Chemical glass	Lowest dielectric constant	Electrical grade	High strength plus modulus	Highest physical properties
	Uses					
	Surface mat	Chopped roving surface mat yarns	Yarn	Roving fabrics yarn	Yarn	Roving yarn

Source: Sampson, R. N., "Laminates and Reinforcement plastic Materials and Processes", *Handbook of Plastic, Elastomers, and Composites*, 3rd ed., C. A. Harper, (ed.), McGraw-Hill, New York, 1996.

M.10 Fibers—Organic

APPENDIX M.10a

Material ↓	Form	Length (in.)	Width (m)	Cross Section	Specific[a] Gravity	Breaking Tenacity, (g/den) Dry-wet		Tensile Strength (10^3 psi)	Elongation, (%) Dry Wet	
Acetate base										
Acetate	Fil, staple	—	11–46	Cloverleaf	1.32	1.2–1.5	0.8–1.2	20–28	23–45	30–50
Triacetate (Arnel)	Filament	Contin	—	Cloverleaf	1.3	1.2–1.4	0.8–1	20–26	22–28	30–40
Acrylic (acrylonitrile) base										
Acrylic										
Orlon	Staple	1.5–4.5	14–27	Dogbone	1.14	2.2–2.6	1.8–2.1	32–39	20–28	26–36
Aramides										
Nomex	Fil, staple	1–2.5	—	Peanut	1.38	5.3	4.1	95.5	12.2	16
Kevlar	Filament	Contin	11.9–17.9	Round	1.44	22	22	410	3.6[b]	3.6[b]
Fluorocarbons										
TFE	Fil, tow, stap	—	—	Circular	2.1–2.3	0.9–2	0.9–2	25–47	13–140	—
FEP	Monofil	—	—	—	2.1	0.5	0.5	14	52	52
Expanded PTFE (Gore-Tex/Rastex)	Fil, tow, stap	—	—	Ribbon	0.8–2.2	3.0–4.0	3.0–4.0	85–115	5–20	5–20
Nylon										
Nylon 6/6										
Regular	Filament	Contin	11–150	Round	1.14	2.3–6	4–5.2	32–85	25–65	30–70
High tenacity	Filament	Contin	100–380	Round	1.14	5.9–9.8	5.1–8	86–134	15–28	18–35
Staple	Staple	1.5–4.5	14–43	Round	1.14	2.9–7.2	2.7–6.5	41–102	16–75	23–80
Nylon 6										
Regular	Filament	Contin	—	Round	1.14	4.6–5.8	4.3–5.3	73–84	24–34	28–38
High tenacity	Filament	Contin	—	Round	1.14	6.8–8.6	5.4–7.5	109–125	16–17.5	19–24
Staple	Staple	—	—	Round	1.14	3.8–5.5	—	70–80	37–40	42–46
Polyester (PET)										
Filament										
Regular	Filametn	Contin	12–280	Various	1.38	2.8–5.2	2.8–5.2	50–99	24–42	24–42
High tenacity	Filament	Contin	12–380	Various	1.38	6.8–9.5	6.8–9.5	10–168	9–27	9–27
Staple										
Regular	Staple	1.5–6	12–25	Various	1.38	2.4–5	2.4–5	39–90	45–55	45–55
High tenacity	Staple	1.5–6	12–25	Various	1.38	5.5–7	5.5–7	100–115	12–32	12–32

APPENDIX M.10a (*Continued*)

Material ↓	Form	Length (in.)	Width (m)	Cross Section	Specific[a] Gravity	Breaking Tenacity, (g/den) Dry-wet		Tensile Strength (10^3 psi)	Elongation, (%) Dry	Wet
Polyester, aromatic (LCP)	Filament	Contin	—	Round	1.4	22	—	412	3.3	—
Polyethylene										
Type I	Monofil	—	250–1300	Circular	0.92	1–3	1–3	11–35	20–80	20–80
Type II	Monofil	—	250–1300	Circular	0.95–0.96	5–7.3	5–7.3	50–90	10–40	10–40
Ultra-high molecular weight	Monofil	Contin	27–38	Circular	0.97	30–35	30–35	375–435	2.7–3.5	2.7–3.5
Polypropylene										
Monofil	Monofil	—	—	Circular	0.9–0.91	3.5–7	3.5–7	40–90	14–30	14–30
Multifil	Multifil	—	—	Circular	0.9–0.91	2.5–8	2.5–8	35–90	20–100	20–100
Staple	Staple, tow	—	—	Circular	0.9–0.91	3–6.5	3–6.5	30–75	20–120	20–120
Rayon (Viscose)										
Regular tenacity	Fil, staple	—	4.3–8.4	Irreg	1.46–1.54	0.7–3.2	0.7–1.8	28–47	15–30	20–40
Medium tenacity	Fil, staple	—	4.3–8.4	Irreg	1.46–1.54	2.4–3.2	1.2–1.9	28–47	15–20	17–30
High tenacity	Fill, staple	—	10–15	Irreg	1.46–1.54	3–5.7	1.9–4.6	56–88	9–26	14–34
Spandex (urethane) Lycra	Filament	Contin	50–500	Coalesced/ dogbone	1.21	0.6–1	—	9–13	400–700	—
Natural organics										
Cotton	Staple	1–1.5	16–21	Ribbon	1.55	1.5–6	1.5–6	—	6.9	7–10
Hemp	Staple	—	18–23	Triangle	1.48	5–7	5–7	—	1–3	1–3
Silk	Fil, staple	—	10–13	Triangle	1.25	3.5–4.5	3–4	—	20–25	25–30

[a] All physical properties at 70°F, 65% RH unless otherwise noted. [b] 2.4 for Kevlar 49.

Source: 1994 Materials Selector Issue, *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

APPENDIX M.10b

Material ↓	Stiffness[c] (g/den)	Strain Recovery[d]	Toughness (g-cm/den-c)	Moisture Regain (%)	Strong Acids	Weak Acids	Strong Alkalies	Weak Alkalies	Heat (°F)
Acetate base									
Acetate	3.5–5.5	48–65 (4%)	0.17–0.3	6	Decomposes	Decomposes	Saponifies to cellulose	Same	Sticks 350–375 Soft 400–445 Melts 500
Triacetate (Arnel)	5.2	88 (3%)	0.16	3.2	Decomposes	Decomposes	—	—	Melts 575
Acrylic (acrylonitrile) base									
Acrylic									
Orlon	10	73 (3%)	0.4–0.5	1.5	Exc.	Exc.	Poor	Fair-good	Sticks 455
Aramides									
Nomex	—	—	—	5	Str loss	Mod str loss	Str loss	Better than nylon 6/6	Good 500[g]
Kevlar									Degrades 700
Fluorocarbons									
TFE	525[e]	—	—	7[f]	Str loss	Mod str loss	Str loss	Mod str loss	Long-term 355
FEP	1.2–12	88	0.12–0.15	None	Inert	Inert	Inert	Inert	Good 400 Melts 500
Expanded PTFE (Gore-Tex/Rastex)	1.0	—	0.1–0.12	—	Inert	Inert	Inert	Inert	Good 400 Melts 500
Nylon									
Nylon 6/6									
Regular	—	—	—	None	Inert	Inert	Inert	Inert	Good 550 Melts 620
High tenacity	31–38	88	0.6–1.4	4.5	Dissolves in cold HCL, H_2SO_4 and HNO_3	Disintegrates in boiling HCL	Substantially inert	Substantially inert	Yellows slightly after 5 hr at 300.
Staple	15–70	89	0.8–1.3	4.5					
Nylon 6						Weakens on prolong. exp. to benzoic & oxalic			
Regular	15–18	82	0.6–1.4	4.5	Degraded by oxidizing agents & mineral acids				Melts at 482.
High tenacity	—	—	0.75	4.5			Substantially inert	Substantially inert	Yellows slightly after 5 hr at 300.
Staple	—	—	0.64–0.78	4.5					Melts at 482.
Polyester (PET)									
Filament									
Regular	—	—	0.85–1	4.5					
High tenacity	60–65 65–90	76[h] 88[i]	0.4–1.1 0.4–0.7	0.4 0.4	Good, Dissolves in H_2SO_4	Good	Disintegrates when boiled.	Fair-good	Sticks 440–445. Melts 480

APPENDIX M.10b (*Continued*)

Material ↓	Stiffness[c] (g/den)	Strain Recovery[d]	Toughness (g-cm/den-c)	Moisture Regain (%)	Strong Acids	Weak Acids	Strong Alkalies	Weak Alkalies	Heat (°F)
Staple									
Regular									
High tenacity	25–40	81	0.2–1	0.4					
Polyester, aromatic (LCP)	—	—	1.1	0.4					
Polyethylene	525	—	—	<0.1	Good @ <90%	Good	Str. loss	Good @ <30%	Good 400 Melts 625
Type I	2–12	90–95 (2%)	0.3	None	Excellent to all but oxidizing	Excellent	Excellent	Excellent	Melts 225, Melts 265–280
Type II	20–50	Slow	0.3	None					
Ultra-high molecular weight	—	—	—	<1	Excellent	Excellent	Excellent	Excellent	Melts 300
Polypropylene									
Monofil	20–60	98 (5%)	—	0.01–0.1	Excellent except chlorosulfonic, conc. HNO_3, oxidizing.	Excellent	Excellent	Excellent	Softens 285–330.
Multifil	15–40	94–98 (5%)	0.6–1.5	0.01–0.1					Melts 320–350.
Staple	3–40	69–100 (5%)	0.6–3.5	0.01–0.1					Melts 320–350.
Rayon (Viscose)									
Regular tenacity	6–16.6	82	0.04–0.32	11–13	Disintegrates in hot, dilute and cold, concentrated.	Same as in strong	Swelling; reduced strength.	Good	Loses strength 300
Medium tenacity	6–16.6	97	0.21	11–13					Decomposes 350–364
High tenacity	13–50	70–100	0.22–0.65	11–13					Does not melt.
Spandex (urethane) Lycra	—	97 (50%)	—	1.3	Depends on acid.	Good	Fair	Good	Melt 340–350
Natural Organics									
Cotton	60–70	95	0.15	6–8	Dissolves	Stable	Swells	Good	Good
Hemp	200	90 (<1%)	0.04	8	Dissolves	Stable	Swells	Stable	Stable
Silk	100	90 (<2%)	0.44	10	Dissolves	Fair	Dissolves	Fair	Good

[c] Ratio of breaking stress to breaking strain (g/den to rupture divided by strain in cm/cm). [d] Recovery after 2–3% strain except where specific percentage strain is given in parentheses. [e] 1000 for Kevlar 49. [f] 3.5 for Kevlar 49. [g] After 500 hr at 500°F, has 65% breaking strength. [h] 97 gm/den at 2%; 80 at 8%. [i] 100 gm/den at 2%; 90 at 8%.

Source: 1994 Materials Selector Issue, *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

M.11 Fibers—Inorganic

APPENDIX M.11a

		Asbestos		Boron	
Material →	Alumina Silica	Chrysotile	Crocidolite	Uncoated	SIC Coated[g] (Borsic)
Form	Staple	Crude	—	Fil	Fil
Length, in.	0.25–10	0.375–2	0.125–3	Cont.	Cont.
Width, μm	3–20	0.02	0.02	51–279	145
Cross Section	—	Tubular	Cylind	Circular	Circular
PROPERTIES[a]					
Specific Gravity	2.73	2.4–2.6	3.2–3.3	2.3–3.8	2.55
Breaking Tenacity (g/den) Dry	14–6.5	2.5–3.1	—	15–18	15–18
Wet	—	—	—	15	15
Tensile Strength (10^3 psi)	50–230	80–100	100–300	500–600	450–550
Breaking Elongation (%) Dry	1.4–2.7	—	None	0.8–0.9	0.8
Wet	—	—	None	0.8–0.9	0.8
Tensile Modulus (10^6 psi)	—	—	—	60	60
Strain Recovery[c] (%)	—	—	100	—	—
Stiffness[b] (g/den)	—	—	—	—	—
Toughness (g · cm/den · cm)	—	—	—	—	—
CORROSION AND HEAT					
Strong Acids	Sim. to boro sil glass	Poor	Good exc. HF	Excel	Excel
Weak Acids	—	Poor-good	Excel	Excel	Excel
Strong Alkalies	—	Excel	Excel	Excel	Excel
Weak Alkalies	—	Excel	Excel	Excel	Excel
Heat (°F)	2300 max.	800–1300	750–1100	[h]	[h]

Source: 1994 Materials Selector Issue, *Machine Design*, Penton Publishing, Cleveland, Ohio, 1993.

APPENDIX M.11b

	Carbon/Graphite		Glass			
Material →	High Modulus	High Strength	Type E	Type S	Silicon Carbide	Zirconia Silica
Form	Fil, strand	Fil, strand	Fil, strand	Fil, strand	Fil	Fil, strand
Length, in.	Cont, chop	Cont, chop	Cont	Cont	Cont	—
Width, µm	6.5–10	7–9.5	7	22	51–142	14
Cross Section	Bilobal	Circular	Circular	Circular	Circular	Circular
PROPERTIES[a]						
Specific Gravity	1.8–2	1.7–1.8	2.54–2.69	2.48–2.49	3–4	3.7
Breaking Tenacity (g/den) Dry	—	—	15.3	19.9	9	—
Wet	—	—	15.3	19.9	9	—
Tensile Strength (10^3 psi)	220–375	360–450	450–550	650–700	350–550	150
Breaking Elongation (%) Dry	0.4–0.75	1.1–1.4	4.8	5.3–5.7	0.65	1.1
Wet	—	—	4.8	5.3–5.7	0.65	—
Tensile Modulus (10^{6} psi)	45–75	30–40	10.5	12.4	62	14
Strain Recovery[c] (%)	—	—	100	100	—	—
Stiffness[b] (g/den)	—	—	320	380	—	—
Toughness (g · cm/den · cm)	—	—	0.37	0.53	—	—
CORROSION AND HEAT						
Strong Acids	Excel	Excel	Excel[d]	Excel	Excel	Fair[k]
Weak Acids	Excel	Excel	Excel	Excel	Excel	Good
Strong Alkalies	Excel	Excel	Good	Good	Excel	Excel
Weak Alkalies	Excel	Excel	Good	Good	Excel	Excel
Heat (°F)	750 air	600 air	600[e]	600[f]	[h]	Use 1830

[a] At 70°F, 65% RH unless otherwise noted. [b] Ratio of breaking stress to breaking strain (gm/den to rupture divided by strain in cm/cm). [c] Recovery after 2% strain. [d] Resists all except HF and hot H_3PO_4. [e] Retains 75% tensile strength at 650; soft 1350–1611. [f] Retains 80% tensile strength at 650; soft 1560–1778. [g] On tungsten substrate. [h] Function of matrix in composite. [k] Except HF, hot H_2SO_4.

APPENDIX N

Trade Name Directory[*]

The data in the Trade Name Directory are compiled from information supplied by the companies listed. Every effort has been made to be accurate, but authors and publishers can assume no liability in the event errors or omissions have been made in the compilation of this list.

A

A-Flex, Extruded tubing, Action Technology Co.

AA Analyzer, Automatic acetaldehyde measuring system, TopWave International, Inc.

Abcure, Benzoyl peroxide catalyst, ABCO Industries

Abfab, Nonwoven synthetic fabric, ABCO Industries

Abhesive, Release agent, Abatron, Inc.

Ablebond, Epoxy and polyimide compounds, Ablestik Laboratories

Ablefilm, Epoxy and polyimide compounds, Ablestik laboratories

Abletherm, Epoxy and polyimide compounds, Ablestik Laboratories

Ablex, Polyolefin extrusion blends, Action Technology Co.

Abocast, Casting compounds, encapsulants, adhesives (solventless), Abatron, Inc.

Abocoat, Coatings, Abatron, Inc.

Abocure, Crosslinking agents, catalysts, Abatron, Inc.

Absorptometer "E," Absorptivity measurement for carbon black, Brabender, C. W., Instruments, Inc.

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[*] Reprinted with permission from *Modern Plastics Encyclopedia* '98, William A. Kaplan (ed.), *Modern Plastics* is a Division of Chemical Week Associates, New York, NY, 1998.

Plastics Materials and Processes: A Concise Encyclopedia, by Charles A. Harper and Edward M. Petrie
ISBN 0-471-45603-9

Absylux, Acrylonitrile-butadiene-styrene, Westlake Plastics Co.

ABT Antiblock Talcs, Antiblock talcs for the plastic film industry, Specialty Minerals Inc.

A-C, Low molecular weight PE, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Accelerator NL, Accelerators for unsaturated polyesters, Akzo Nobel Chemicals Inc.

Accpro, Enhanced polypropylene, Amoco Polymers

AccriGloss, High-gloss/bright-colored custom extruded sheet, New Hampshire Plastics, Inc.

Acctuf, Polypropylene impact copolymer, Amoco Polymers

Accu-Chill, Reclaims chiller heat for other use, Van Steenburgh Liquid Chillers, Inc.

Accufly, Online stop/go feed, flycutter syste, ESI Extrusion Services

Accupunch, Online fabrication press system, ESI Extrusion Services

Accuthane, Thermoset urethane elastomers, Fiber Resin Corp., Subs. Of H. B. Fuller Co.

ACE, Stock vinyl and LDPE tubing, Anaheim Custom Extruders, Inc.

Acetron, Unfilled and filled acetals, DSM Engineering Plastic Products, Inc.

Achieve, Metallocene polypropylene, Exxon Chemical Co.

Aclar, CTFE film, AlliedSignal Inc., AlliedSignal Plastics

AClyn, Low molecular weight ionomers, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Acoustiflex, Polyurethane flexible foam systems, ICI Polyurethanes Group

Acrawatt, Electric heating elements, Acra Electric

Acrawax, Lubricants, Lonza Inc.

Acri-Tuf, Acrylic high-impact lenses and sheet, ICI Acrylics Inc.

Acrivue A, Abrasion-resistant coated acrylic, Pilkington Aerospace Inc.

Acroleaf, Hot stamping foil, Acromark Industries, Inc.

Acrycast, Cast acrylic sheet, Calsak Corp.

Acrylam, Acrylic-copper laminate, Sheldahl Inc.

Acrylite (Series), Acrylic sheet, acrylic resin, Cyro Industries

Acryrex, PMMA resin, Calsak Corp.

Acrysteel, Impact acrylic sheet, Aristech Acrylics LLC

Acrystone, Mineral-filled solid-surfacing acrylic sheet, Aristech Acrylics LLC

Acrythene, Ethylene methyl acrylate copolymers, Equistar Chemicals

Acsium, Alkylated chlorosulfonated polyethylene, DuPont Dow Elastomers

Actafoam, Blowing agent, activator, Uniroyal Chemical Co., Inc.

Acti-Min, Silane-treated mineral fillers, ITC Industrials

Actifresh, Bacteriocide, fungicide for plastics, Sanitized Inc.

Actilease, Active mold release and lubricants, Mann, George, & Co. Inc.

Actimers, Series of reactive FR monomers, Ameribrom Inc.

Activex, Chemical foaming/nucleating agents, B.I. Chemicals, Inc., Specialty Products Div.

Actone, Color enhancers, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Acu-Slit, Slitter modules, AZCO Corp.

ACumist, Micronized polyolefins, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Acura Blend, Feeding/blending system, Battenfeld Gloucester Engineering Co. Inc.

Adcote, Adhesives and coatings, Morton International Inc.

Addgards, Pedestrian barricade system, Remcon Plastics Inc.

ADDvantage-32, Digital drive, Avtron Mfg., Inc.

Adflex, Low-modulus resins, Montell North America

Adiprene, Polyurethane elastomer, Uniroyal Chemical Co., Inc.

Adjusto-Flex, Thermocouple, Noral, Inc.

Admex, Polymeric plasticizers, Creanova Inc.

Adstif, High-modulus polyolefins, Montell North America

Advance, EPDM/EVA-based dispersions, Harwick Chemical Manufacturing Corp.

Advanta, Specialty elastomer, DuPont Dow Elastomers

Advantage, Opaque polyolefin colorants, Milliken Chemical Co.

Advantage Series, Temperature controllers, Barber-Colman Co., Industrial Instruments Div.

Advantech, Small and complex parts molding, Techmire Ltd.

Advantex, Glass-fiber products, Owens Corning

Advapak, Multifunctional additive, Morton International Inc. Morton Plastics Additives

Advastab, PVC heat stabilizers, Morton International Inc., Morton Plastics Additives

Advawax, Internal and external lubricants, Morton International Inc., Morton Plastics Additives

Advera, Aluminosilicate stabilizers, PQ Corp.

The Advisor, One-hundred percent polymer web inspection system, Adaptive Optics Associates, Inc.

Aegis, Insulant, Xebec BV

Aero-Clean, Granulated acrylic mold cleaning media, Maxi-Blast, Inc.

Aeroflex, Polyethylene extrusions, Anchor Plastics Inc.

Aeroguard, Flame retardant, Cytec Industries Inc.

Aerosil, Fumed silica, Degussa Corp.

Aerosol, Surfactant, Cytec Industries Inc.

Aerotuf, Polypropylene extrusions, Anchor Plastics Inc.

Affinity, Polyolefin plastomers, Dow Plastics

Affirm, Clad metal laminates, Dow Plastics

Afflair, Pearlescents, coated mica platelets, EM Industries Inc.

AFlake, Mica flake, Zemex Mica Corp.

Aflon, ETFE and PFA fluoropolymer resins, AGA Chemicals, Inc.

AFS Series Coatings, Permanent antifog coatings, Exxene Corp.

Ag-Bin, Agricultural collapsible palletized bin, Perstorp Plastic Systems

AgClad, Silver-clad glass filaments and platelets, PQ Corp.

Aim, Advanced styrenics resins, Dow Plastics

Air-Scent, Fragrance, A/Air-Scent International

AirCap, Barrier bubble cushioning, Sealed Air Corp.

Airex, Linear foam, Baltek Corp.

Airflex, Ethylene-vinyl acetate, Air Products and Chemicals, Inc.

Airfly, Air-actuated flycutter, ESI Extrusion Services

Airlite, Crosslinked PVC foam, Baltek Corp.

Airthane, Polyurethane prepolymers, Air Products and Chemicals, Inc.

Airvol, Polyvinyl alcohol, Air Products and Chemicals, Inc.

AKcess, Controls, complete systems, American Kuhne Inc.

Akcrostab, Tin heat stabilizers for PVC, Akcros Chemicals America

Akroblend, Screws for melting/mixing, Akron Extruders, Inc.

Akrochlor, Chlorinated paraffins, Akrochem Corp.

Akroplast, Thermoplastic color concentrates, Akrochem Corp.

Akrosperse, Plasticizer color pastes, Akrochem Corp.

Akrowax, Paraffin and micro waxes, Akrochem Corp.

AL600/10, Polymer-coated balsa core, Baltek Corp.

AL-Tool/T-Lam, High-heat vacuum mold system, Seawolf Industries, Inc.

Alathon, Polyethylene (HDPE, HMW-HDPE), Equistar Chemicals

AlbaFlex, Fine mica flake, Zemex Mica Corp.

AlbaFlex Mica, Muscovite mica, Zemex Industrial Minerals, Inc.

AlbaShield, Water-ground muscovite mica, Zemex Mica Corp.

AlbaShield Mica, Muscovite mica, Zemex Industrial Minerals, Inc.

Albi Cote, Fire-retardant coatings, StanChem, Inc.

Alca Max, Cast plate, Alcoa Cast Plate

Alca Plus, Cast plate, Alcoa Cast Plate

Alcamizer 1, 2, 4, Heat stabilizer for PVC, Kyowa Chemical Industry Co. Ltd.

Alcel, Syntactic foams, AOC

Algoflon, Polytetrafluoroethylene (PTFE), Ausimont USA, Inc.

Alkanox, Organophosphites, Great Lakes Chemical Corp.

Allaco, Epoxy compounds, Bacon Industries, Inc.

Allbond, Epoxy adhesives, Bacon Industries, Inc.

Almatex, Acrylic resins, Anderson Development Co.

AlNel, Thermally conductive fillers, Advanced Refractory Technologies, Inc. (ART)

Alperox, Lauroyl peroxide, Elf Atochem North America, Inc.

Alpha, Flexible PVC, AlphaGary

Alpha-Cel, Purified powdered cellulose, International Filler Corp.

Alphaseal, Beverage cap liner compound, AlphaGary

Alsibronz, Mica, Engelhard Corp.

Altair, Crosslinked opaque and marbleized acrylic, Aristech Acrylics LLC

Altek, Polyester resins, AOC

Altymid, Polyimide parts, Greene, Tweed & Co.

Alu*Flake Glitter, Precision-cut decorative aluminum flakes, Glitterex Corp.

Alumec 89, Aluminum tooling material, Uddehoim

Alumold, Aluminum alloy for plastic molds, Thyssen Specialty Steels, Inc.

Alvinox, Antioxidants, 3V Inc.

AmalgaSeal, Self-fusing tapes, Scapa Tapes North America

Amalloy, Clear MBS copolymers, Amco Plastic Materials Inc.

Amaplast, High-performance dyes and colorants, Color-Chem International Corp.

AME, Marine resin, Ashland Chemical Co., Composite Polymers Div.

Amer-Plate, PVC sheet, Ameron Protective Linings

Amical, Calcium carbonate extender/filler, Franklin Industrial Minerals

Amicon, Surface mount adhesives, Emerson & Cuming Specialty Polymers, Div. of National Starch

Amicure, Epoxy curing agents, Air Products and Chemicals, Inc.

Amidan, Glass, carbon, or aramid fiber/nylon 11 pultruded shapes, Thermoplastic Pultrusions, Inc.

Aminox, Antioxidant, uniroyal chemical Co., Inc.

Amodel, Polyphthalamide, Amoco Polymers

Amorclean, Antibacterial glass flake, NGF Canada

Ampco Metals, Beryllium-free copper alloys, Performance Alloys and Services, Inc.

Amrel, Hydrophilic polyurethane foam, Rynel Ltd.

AMS, Asset management software, Fisher-Rosemount Systems, Inc.

Ancamide, Polyamide epoxy hardeners, Air Products and Chemicals, Inc.

Ancamine, Polyamine epoxy hardeners, Air Products and Chemicals, Inc.

Ancorene, High-impact polystyrene extrusions, Anchor Plastics Inc.

Ancorex, ABS extrusions, Anchor Plastics Inc.

Andi-Anderson, Single and multihead routers, Akhurst Machinery Ltd.

Andrez, Polystyrene-butadiene resins, Anderson Development Co.

Andur, Polyether and polyester prepolymers, Anderson Development Co.

Anox, Hindered bisethiophenolics, Great Lakes Chemical Corp.

Anquamide/Anquamine, Water-based epxoy curing agents, Air Products and Chemicals, Inc.

Anti-Static #79, Stops static and dust on hard plastic surfaces, Merix Chemical Co.

Antiblaze, Liquid and solid flame retardants, Albright & Wilson Americas

Antistatic, Antistats, 3V Inc.

Anvil Express, CAD/CAM software, Manufacturing & Consulting Services (MCS)

Anvyl, Vinyl extrusions, Anchor Plastics Inc.

Apacider A. Series, Antimicrobial powder, Sangi America, Inc.

Apec, High-heat polycarbonate resin, Bayer Corp., Polymers Div.

APT, All-poly rotationally molded tank, Hoover Materials Handling Group, Inc.

Aqua-Link, Water crosslinkable ethylene-vinyl-silane copolymer, AT Plastics Inc., AT Polymers Div.

Aqua-Novon, Waterproof/water soluble degradation system, Novon International, Inc.

Aqua Shield, Polyester resin, Advance Coatings Co.

AquaBlok, Water-blocking reinforcement, Owens Corning

Aquadag, Conductive/resistive coating, Acheson Colloids Co.

Aquadex, Water-dispersed polyurethane VOC compliant coating system, Dexter Adhesive & Coating Systems (IL); waterborne coatings, Dexter Automotive & Specialty Coatings

Aquadro, Hot or cold water soluble resins, Planet Polymer Technologies, Inc.

Aquaflo, Acrylic chip color concentrate, Indol Color, Div. of Magruder Color Co. Inc.

Aqualease, Water-based mold release agents, Mann, George, & Co. Inc.

Aqualift, Water-based external mold releases, Franklynn Industries

Aqualoy, Hydrolytically stable materials, ComAlloy International Co.

Aquanil, Desiccant concentrate, Willow Ridge Plastics, Inc.

Aquatac, Waterborne tackifiers, Arizona Chemical

Aquathene, Ethylene vinyl silane copolymers, Equistar Chemicals

AR-A1, AR-8, Antistatic chemical concentrate, Rogers Anti-Static Chemicals

Araldite, Epoxy resins and hardeners; epoxy structural adhesives, Ciba Specialty Chemicals, Performance Polymers

Arathane, Polyurethane adhesives, Ciba Specialty Chemicals, Performance Polymers

Aravite, Cyanoacrylate and acrylic adhesives, Ciba Specialty Chemicals, Performance Polymers

Arbocel, Powdered cellulose, Rettenmaier, J., USA LP

Arc Ease, Lubricant, release agent, American Resin

Arc Kleer, Adhesives, American Resin

ARcare, Pressure-sensitive medical tapes, Adhesives Research, Inc.

Arcel, Moldable foam, NOVA Chemicals Ltd.

ARclad, Pressure-sensitive tapes, Adhesives Research, Inc.

Ardel, Polyarylate, Amoco Polymers

Arimax, Structural RIM resin, Ashland Chemical Co., Composite Polymers Div.

Arlex, Converted polyester film, Xebec BV

Arlon, Polyketone thermoplastics, Greene, Tweed & Co.

Armac, Aliphatic amine acetates, Akzo Nobel Chemicals Inc.

Armid, Aliphatic amides, Akzo Nobel Chemicals Inc.

Armorbond, Vinyl coating bonded to steel tubing and pipe, Lakeland Plastics, Inc.

ArmoritePlus, Functional coating, CFC International, Inc.

Armorplate, Water-based catalytic paint for plating, Armitage, John L.

Armorthane, Polyurethane, Armitage, John L.

Armoslip, Slip aids and antiblock agents, Akzo Nobel Chemicals Inc.

Armostat, Antistatic agents, Akzo Nobel Chemicals Inc.

Arnite, Thermoplastic polyesters, DSM Engineering Plastics

Arnitel, Thermoplastic elastomers, DSM Engineering Plastics

Arocy, Cyanate esters, Ciba Spcialty Chemicals, Performance Polymers

Aroma Poly, Fragrance polymer concentrates, Aroma Tech

Aroma Puff, Foamed fragrance polymer pellets, Aroma Tech

Aromatran, Organic permeation testing, MOCON/Modern Controls, Inc.

Aropol, Unsaturated polyester resins, Ashland Chemical Co., Composite Polymers Div.

Aropol WEP, Water-extended polyester resin, Ashland Chemical Co., Composite Polymers Div.

Aroset, Acrylic resins, Ashland Chemical Co., Composite Polymers Div.

Arotech, Structural resin, Ashland Chemical Co., Composite Polymers Div.

Arotran, RTM body panel resin, Ashland Chemical Co., Composite Polymers Div.

Arquad, Quaternary ammonium compounds, Akzo Nobel Chemicals Inc.

ArtCAM, Engraving and routing software, Delcam International Inc.

Asaclean, High-performance purging agent, Sun Plastech Inc.

Ashlene, Thermoplastic engineering resins, Ashley Polymers

ASP, Water-washed kaolin, Engelhard Corp.

Aspun, Fiber grade resins, Dow Plastics

Astrawax, Amide wax, additive lubricant, AlliedSignal/Astor

Astryn, Mineral-filled polyolefin, Montell North America

Ateva, EVA copolymer resin, AT Plastics Inc., AT Polymers Div.

Athena, Injection molding manufacture, Aervoe-Pacific Co., Inc.

Atlac, Thermoset polyester, Reichhold

Atlasol, Nonaqueous dyes, Cromption & Knowles Colors Inc.

Atmer, Thermoplastic additives, Uniqema

Atomite, Calcium carbonate, ECC International

Atryl, Class A SMC, AOC

Attacote, Anhydrous carrier and filler, Engelhard Corp.

Attagel, Mineral thickener, Engelhard Corp.

Attain, ULDPE, Dow Plastics

Attasorb, Anhydrous carrier and filler, Engelhard Corp.

Aurum, Polyimide resin, Mitsui Chemicals America

Auto-Color, Benchtop sphere, BYK-Gardner USA

Auto-Disc, Precision synchronous blender, Plastrac Inc.

Auto-Grader, Online melt flow indexer, Brabender, C. W. Instruments, Inc.

Autofroth, Pressurized rigid froth polyurethane foam systems, BASF Corp., Urethanes Specialties

Autoguage, Automatic die, Production Components Cloeren Inc.

Autohopper, Pneumatic hopper loader, Webb Technologies Ltd.

Autonis, Imaging system, Sensor Products, Inc.

Autopour, Pressurized rigid polyurethane foam systems, BASF Corp., Urethanes Specialties

Autoprofile, Gauge control, Battenfeld Gloucester Engineering Co. Inc.

Autovisc, Viscosity measuring system, Cannon Instrument Co.

Autovision, Visual inspection systems, Autoroll Machine Corp.

Avalon, Pigmented PTFE, Greene, Tweed & Co.

Avantra, Styrenic polymer resins, BASF Corp., Polystyrene Business Group

Avirol, Emulsifier, surfactant, Henkel Corp.

Avloy, Decorative finish for plastic (automotive), Avery Dennision Corp.

Axelglo, RP finishing polish, Axel Plastics Research Laboratories, Inc.

Azmet, PBT and PET; glass fiber-reinforced composite, Azdel Inc./General Electric

B

Baeropan, PVC heat stabilizer one-pack, Baerlocher USA

Baerostab, PVC heat stabilizer, Baerlocher USA

Baltekbond, Core laminating adhesive, Baltek Corp.

Baltekmat, Laminate bulker, Baltek Corp.

Bamberko, Purging compound, Bamberger, Claude P., Molding Compounds Corp.

Bamberko Purge, Purging compound, Bamberger, Claude P., Molding Compounds Corp.

Bapolan, Polystyrene, SAN, and ABS, Bamberger Polymers, Inc.

Bapolene, LDPE, LLDPE, HDPE, and PP Bamberger Polymers, Inc.

Bapolon, Nylon 6 and 66, Bamberger Polymers, Inc.

Barb-Sert, Press/heat/ultra-brass insert, Groov-Pin Corp.

Barex, Nitrile-based barrier resin, BP Chemicals, Inc.

Barr ET Screw, High-performance screw,Glycon Corp.

Bartex, White barium sulfate extender pigment, Hitox Corp.

Baublys, CNC and laser engraving equipment, JRM International

Bayblend, Polycarbonate/ABS blends, Bayer Corp., Polymers Div.

Baydur, Rigid structural urethane foam system, Bayer Corp., Polymers Div.

Baydur STR, Polyurethane composite solid or foam systems, Bayer Corp., Polymers Div.

Bayertitan, Titanium dioxide pigment, Bayer Corp., Industrial Chemicals

Bayferrox, Iron oxide pigments, Bayer Corp., Industrial Chemicals

Bayfit, Polyurethane molded foam systems, Bayer Corp., Polymers Div.

Bayflex, Polyurethane elastomeric RIM systems, Bayer Corp., Polymers Div.

Baysilone, Silicone fluids, Bayer Corp., Industrial Chemicals

Baytec, Polyurethane cast elastomer systems and prepolymers, Bayer Corp., Polymers Div.

Baytherm, Rigid urethane foam chemicals, Bayer Corp., Polymers Div.

Beetle, Urea molding compound, AC Molding Compounds; crosslinking agents; urea resin, Cytec Industries Inc.

BekiShield, metal fibers and rovings, Bekaert Corp., Fibre Technologies

Belcobalsa, Rigid core materials, Baltek Corp.

Benathix, Thixotropic thickeners, Rheox, Inc.

Bench Pultruder, Lab-scale pultruder for test purposes, Vermont Instrument Co.

Benefos, Stabilizers, Mayzo Inc.

Benetex, Brighteners, Mayzo Inc.

Benol, White mineral oil, Witco Corp., Performance Chemicals Group

Benox, Benzoyl peroxides, Norac Co.

Bentone, Thixotropic thickeners, Rheox, Inc.

Benwood Talc, High-purity talc, Zemex Industrial Minerals, Inc.

Benzoflex, Plasticizers, Velsicol Chemical Corp.

Betabrace, Reinforcing composites, Dow Plastics

Betadamp, Acoustical damping system, Dow Plastics

Betafoam, NVH, Dow Plastics

Betaguard, Sealers, Dow Plastics

Betamate, Structural adhesives, Dow Plastics

Betaseal, Glass bonding systems, Dow Plastics

Bettermade, Velcro/suction cup pockets, Sportsmen's Plastics Inc.

BHA-TEX, PTFE membrane, BHA Group, Inc.

BHEB, Antioxidant, Aceto Chemical Co.

Bi-Ply, Combination mat/woven roving, Owens Corning

Bicor, Biaxially oriented polypropylene, Mobil Chemical Co., Films Div.

Biju, Biju Ultra, Bismuth-based pearl pigments and pastes, Engelhard Corp.

Bimax, Biaxial reinforced broad goods, A & P Technology Inc.

Bio Pruf, Antimicrobial, Morton International Inc.

Bio-Sil, Silicone tubing, Sil-Med Corp.

Bird Net, Netting, Tipper Tie-Net

BitterGuard, Anti-ingestant, aversant, Burlington Biomedical & Scientific Corp.

Black Pearls, Pelletized furnace carbon black, Cabot Corp., Special Blacks Div.

Black Shield, Pigmented dispersions in plasticizers, polyesters, epoxies, and alkyds, CDI Dispersions

Black 200, Multiuse black color concentrate, CSI International, Inc.

Blak-Stretchy, Cold molding compound, Perma-Flex Mold Co.

Blak-Tufy, Cold molding compound, Perma-Flex Mold Co.

Blanc Fixe, Synthetic barium sulfate, Sachtleben Corp.

Blandol, White mineral oil, Witco Corp., Performance Chemicals Group

Blas-Tic, Cylindrical polycarbonate deflashing media, Maxi-Blast, Inc.

BLE, Antioxidant, Uniroyal Chemical Co., Inc.

Blendex, Resins for modifying polymers, GE Co., GE Specialty Chemicals

BLIS-400, Fully integrated manufacturing system, B & L Information Systems, Inc.

Bio-Foam, Chemical blowing agents, exothermic, Rit-Chem Co. Inc.

BLS, UV absorbers; stabilizers, Mayzo Inc.

Blu-Sil, Silicone cold moldig compound, Perma-Flex Mold Co.

Blue Star, Antimony oxide, Great Lakes Chemical Corp.

BNX, Antioxidants, Mayzo Inc.

Boltamask, Masking film, Empire Plastics Inc.

Boltamount, Printing plate mounting base, Empire Plastics Inc.

Boltaron, Rigid thermoplastic sheet, Empire Plastics Inc.

Bolton Dicer, Dicers, Dicer Corp.

Bomb-Lube, Mold lubricant, Price-Driscoll Corp.

Bond It, Adhesive, Cotronics Corp.

Bondica #101, Mica, Engelhard Corp.

Bondmaster, Structural adhesives, National Starch and Chemical Co.

Borofuse Process, Protective wear coating, Materials Development Corp.

Borogard ZB, Antimicrobial/fungicide, U.S. Borax Inc.

Boss, Adhesives and sealants, Meter Mix Div., Accumetric Inc.

Brad-Point, Drill guide assembly for composites, International Carbide Corp.

Brand-O, Jean-patch vinyl, General Foam Corp.

Bridgeveyor, Overhead conveyor, Pacline Conveyor Systems

Brite-X, Mica reinforcement/filler, Pacer Corp.

Britol, White mineral oil, Witco Corp., Performance Chemicals Group

Brock Silos, Bulk storage siolos, Brock Manufacturing

Brush-On 50, Liquid rubber, Smooth-On, Inc.

Brushmaster, Solvent-borne contact adhesives, National Starch and Chemical Co.

Brytec, High-yield shrink film, Uniplast Industries Inc.

Buca, Water-washied kaolin, Engelhard Corp.

Budene, Polybutadiene, Goodyear Tire & Rubber Co., Chemical Div.

Bulab 600, Polyurethane foam catalyst, Buckman Laboratories, Inc.

Bulab 693, Delayed reaction foam catalyst, Buckman Laboratories, Inc.

Bulkdrum, Blow-molded bottle inside cage, Hoover Materials Handling Group, Inc.

BulkSonics, Ultrasonic level sensors, Monitor Mfg.

Buna CB, Polybutadiene impact modifier, Bayer Corp., Fibers, Additives & Rubber Div.

Bur-A-Loy, Nitrile/PVC elastomeric blends, Mach-1 Compounding

BurlOx, Antioxidants, Burlington Biomedical & Scientific Corp.

Burn Ex, Flame retardant, PQ Corp.

Burst Tester, Pressure resistance, TopWave International, Inc.

Busan 11-M1, Flame-retardant microbiocide, Buckman Laboratories, Inc.

Busperse 47, Viscosity depressant, Buckman Laboratories, Inc.

Butacite, Polyvinyl butyral sheeting, DuPont

Butanox, Ketone peroxide (organic peroxide), Akzo Nobel Chemicals Inc.

Butter-Board, Urethane tooling board, Goldenwest Mfg., Inc.

Butvar, Polyvinyl butyral resins, Solutia Inc.

C

C-Loc, Engineered vinyl sheet piling, Crane Plastics

C-Wax 100, Paraffin wax, Cardinal Companies

C-Wax 140, Ester lubricant, Cardinal Companies

Cab-O-Sil, Amorphous fumed silica, Cabot Corp.

Cab-O-Sperse, Aqueous silica dispersion, Cabot Corp.

Cablon-Flex, Viscoelastomer with high-elongation and memory recovery, Cabot Development

Cachalot, mold release agent, Michel, M., & Co., Inc.

Cadco, Plastic rod, sheet, tubing, film, Cadillac Plastic, Busn. Unit of M.A. Hanna Co.

Cadet, Organic peroxides, Akzo Nobel Chemicals Inc.

Cadet, Ionizing air blowers, SIMCO

Cadmolith, Lithopone-type cadmium pigments, Millennium Specialty Chemicals, Colors and Silica

Cadon, Styrene maleic anhydride resin, Bayer Corp., Polymers Div.

Cadox, Organic peroxides, Akzo Nobel Chemicals Inc.

Calcmaster, Mold quoting software, injection Molding Industries

Calibre, Polycarbonate resins, Dow Plastics

Calthane, Two-component urethane elastomers, Cal Polymers, Inc.

Calwhite, Calcium carbonate, Georgia Marble Co.

Calwhite II, Reinforcing calcium carbonate fillers, Georgia Marble Co.

Camel-Cal/Camel-Cal ST, Calcium carbonate, ECC International

Camel-Carb, Calcium carbonate, ECC International

Camel-Fil, Calcium carbonate, ECC International

Camel Fine, Calcium carbonate, ECC International

Camel Fine ST, Calcium carbonate, ECC International

Camel Tex, Calcium carbonate, ECC International

Camel-Wite/Camel-Wite ST, Calcium carbonate, ECC International

CAMMS-B, Computer automated molding machine setup, Plastics & Computer Inc.

Candy-Cane, Christmas tree netting for retail lots, Tipper Tie-Net

CannOxide, Liquid carbon dioxide blown molded foams, Cannon USA Inc.

Canvex, Woven-reinforced material, Raven Industries Inc., Engineered Films Div.

CAO, Antioxidants, PMC Specialties Group

Capcure (Series), Epoxy curing agents; cure accelerators, Henkel Corp.

Capran, Nylon films, AlliedSignal Inc., AlliedSignal Plastics

Capran Emblem, Biaxially oriented nylon film, AlliedSignal Inc., AlliedSignal Plastics

Capran Unidraw, Uniaxially oriented nylon film, AlliedSignal Inc., AlliedSignal Plastics

Capron, Nylon resins and compounds, AlliedSignal Inc., AlliedSignal Plastics

Carb-O-Fil, Filler and additive, Shamokin Filler Co. Inc.

Carbotex, Injection molding grade polycarbonate resin and alloys, Civiera & silver International Inc.

Carbothane, Polycarbonate-based polyurethane, Thermedics Inc.

Carbotherm, Thermal conductive additive for potting applicatins, Carborundum Corp., Boron Nitrid

CarDio, Liquid carbon dioxide blown slabstock foams, Cannon USA Inc.

Caremold, Eutectic plaster tooling material, Composites Horizons, Inc.

Carilon, Polyketone, Shell Chemicals

Carstab, Antioxidants; UV absorbers, Morton International Inc., Morton Performance Chemicals

Castomer, Urethane elastomer, IPI International, Inc.

Casttool, Rapid injection molds for prototypes, Metalcast Engineering

Cata-Chek, Urethane foam catalysts, Ferro Corp., Polymer Additives Div.

Catalloy Process Polymers, Thermoplastic olefins, Montell North America

Catalpo, Water-washed kaolin, Engelhard Corp.

Caterpuller, Heavy-duty track type haul-off, Entwistle

Cavco Glas, Coupling agent for glass fiber reinforced products, McGean-Rohco, Inc.

Caytur, Curing agent, catalyst, uniroyal Chemical

Celanese, Nylon 6/6, Ticona

Celanex, Thermoplastic polyester, Ticona

Celcon, Acetal copolymer resin, Ticona

Cell-Aire, Foamed polyethylene; laminates, Sealed Air Corp.

Cell Flake, Pigment flakes, Eckart America LP

Cellu-Cushion, High-density polyethylene foam, Sealed Air Corp.

Celluliner, Resilient expanded polystyrene foam, Gilman Brothers Co.

Cellulite, Expanded polystyrene foam insulation, Gilman Brothers Co.

Celogen (Series), Blowing agents, Uniroyal Chemical

Celstran, Long fiber-reinforced thermoplastics, Ticona

Centrex, Acrylonitrile-styrene-acrylic blends, Bayer Corp., Polymers Div.

Ceram P, Organic filled UHMW polyethylene, Poly Hi Solidur

Ceres, Organic dyestuff, Bayer Corp., Performance Products

Ceridust, Micronized waxes, Clariant Corp., BU Additives

Certene, Private label certified prime, Muehlstin

CF Fibers, Cellulose fibers, Custom Fibers International

ChambIR, Electric infrared chamber heater, Research Inc.

Champion, Clays/kaolin, Harwick Standard Distribution Corp.

Change-It, Quick mold and die changing systems, Airfloat/HSI Systems, Inc.

Chargemaster, Charging for chill roll pinning, SIMCO

Charmax, Charforming smoke suppressants; charforming flame retardants, Marshall, R. J., Co., Polymer Additives Group

Chem-Vac, Pneumatic conveyor for pellets, Christianson Systems, Inc.

Chemfilm, PTFE film, Chemfab Corp.

Chemglas, Glass fiber reinforcements, PTFE coated-woven, Chemfab Corp.

Chemigum, Nitrile rubber powder, Goodyear Tire & Rubber Co., Chemical Div.

Chemlok, Elastomer bonding adhesives, Lord Corp., Chemical Products Div.

Chemstab, Heat stabilizers for PVC, Blachford, Chemical Specialties Div.

Chemstat, Polymer additives, Chemax, Inc.

Chimassorb, Hindered amine light stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Chlorendic Anhydride, Anhydride reactive flame retardant, Velsicol Chemical Corp.

Chlorez, Resin chloroparaffins, Dover Chemical Corp., Subs. ICC Industries, Inc.

Cho-Bond, Conductive adhesives, Chomerics, Div. of Parker Hannifin Corp.

Cho-Seal, Conductive EMI shielding material, Chomerics, Div. of Parker Hannifin Corp.

Cho-Shield, EMI shielding paint, Chomerics, Div. of Parker Hannifin Corp.

Cho-Sil, Conductive EMI shielding material, Chomerics, Div. of Parker Hannifin Corp.

ChopVantage, Thermoplastic reinforcements, PPG Industries, Inc., Fiber Glass

Chrom/Slik, Chrome/Teflon composite coating, Chromium Industries, Inc.

Chroma-Spheres, Micro pellet precolors for rotational molders, Chroma Corp.

Chromaflo, Low-viscosity dispersions, Plasticolors

Chromals, Aluminum pigments, Eckart America LP

Chromalux, Aluminum pigment, leafing, Eckart America LP

Chromanite, Chrome steel grinding beads, Draiswerke Inc.

Chromicolor, Thermochromic concentrates, Matsui International

Chromtex, Metallized transfer film, Kutz-Hastings, Inc.

ChronoFlex AL, Thermoplastic, biodurable polyurethane elastomers, CT Biomaterials, Div. of CardioTech

ChronoFlex AR, Segmented, aromatic biodurable polyurethane elastomers, CT Biomaterials, Div. of CardioTech

ChronoThane P, Thermoplastic, polyether polyurethane, CT Biomaterials, Div. of CardioTech

CIM-Link Shotscope, Process monitoring system, Branden Technologies, Inc.

CIM System, Computer integrated manufacturing, Hunkar Laboratories, Inc.

Cimagrafi, Engraving software, Cimatron Technologies

Cimatronit, CAD/CAM software, Cimatron Technologies

Cimpact (Series), Talc, Luzenac America

Cinox/Therminox, Alcohol, solvent, prepolymer, chemicals, Maag Pump Systems Textron

Citroflex, Citric acid-based plasticizer, Morflex, Inc.

Clarene, Process aid, blow molding, Colortech Inc.

Claritech 5300 Series, Silicone rubber compound, Silicone Products & Technology Inc.

Class-Meter I, II, IV, Economic process management system, Hunkar Laboratories, Inc.

Classic Series, HVLP spray guns, ITW DeVilbiss

Claytone PS, PS-3, Organophilic clays for pregel unsaturated polyesters, Southern Clay Products

Clean Flow, Magnetic housing, Industrial Magnetics

Clean Wiz, Mold cleaners, Axel Plastics Research Laboratories, Inc.

Clear-Ad, Clear flex vinyl with adhesive, Catalina Plastics & Coating Corp.

Clear-40, Clear schedule 40 PVC pipe, NewAge Industries Inc., Plastics Technology Group

Clearflo, Clear PVC tubing, NewAge Industries Inc., Plastics Technology Group

Clearlink, Chain extender for polyurethanes, coating, UOP Adsorbents Div.

ClearTint, Transparent polyolefin colorants, Milliken Chemical Co.

Cleartuf, PET resin, Shell Chemicals

Cliderite, Potting compound, Thermo Cote, Inc.

Cling Foam, Elastomeric blown PVC foam, Gaska-Tape Inc.

Cloud, High-density cushioning foams, General Foam

Clysar, Shrink film, DuPont

Coad, Metallic stearates, Norac Co.

Cobaloy, Conductive, Armitage, John L.

Cobocell, Cellulose acetate butyrate tubing, Cobon Plastics Corp.

Coboflow, Tetrafluoroethylene tubing, Cobon Plastics Corp.

Cobonol, Polyethylene tubing, Cobon Plastics Corp.

Cobothane, Ethylene-vinyl acetate tubing, Cobon Plastics Corp.

Cobovin, Reinforced PVC tubing, Cobon Plastics Corp.

Cobra, Static neutralizing blowoff gun, SIMCO

Cocure, Organo-metallic catalysts, CasChem, Inc.

Codemark, Brass and steel hot stamping type, Schwerdtle Inc.

COFAB, Biaxial and unidirectional glass and aramid fabrics, CollinsCraft Composites Group, Inc.

Cohrlastic, Silicone rubber sheet and sponge foam, CHR Div. of Furon Co.

Coiltef, Coiled fluoroplastic tubing, NewAge Industries Inc., Plastics Technology Group

Colmonoy, Hard-surfacing alloys, Wall Colmonoy

Color Crystals, Color concentrate, Teknor Color Co.

Color-Eye, Spectrophotometer, GretagMacbeth

Color-Guide, Portable sphere, BYK-Gardner USA

Color Spheres, Maximum-loaded concentrate spheres, Teknor Color Co.

Color-View, Benchtop spectrophotometer, BYK-Gardner USA

Colorblend, Digital disc blender, Colortronic, Inc.

Colorcomp, Custom-colored heat resins, LNP Engineering Plastics Inc.

Colorit, Pigment stamping foil, Kurz-Hastings, Inc.

Colormatch, Pigment dispersions, Plasticolors

Colormax, Masterbatch color, Ruscoe, W. J., Co.

ColorSoft, PC windows software, ColorTec

Colortherm, Zinc ferrite pigment, Bayer Corp., Industrial Chemicals

ColorTools QC, Color quality control software, Datacolor International

Comboloob, Hydrocarbon wax blends, additive lubricants, AlliedSignal

Combomat, Woven roving mat, PPG Industries, Inc., Fiber Glass

Comfort Foam, Residental spray polyurethane foam, Foam Enterprises

Comfortex, Breathable polyurethane compound, Raffi & Swanson, Inc.

Comfortwall, Construction adhesive, Foamseal, Inc.

Commander, Controllers, ABB Instrumentation

Compact, Two-stage, low-speed, screenless granulator, FBE Corp.

Compax Supreme, Mold steel, Uddeholm

Compel, Long fiber-reinforced thermoplastics, Ticona

Composite Shield, Release agent, Zyvax, Inc.

Compulloy, Glass-reinforced shapes, Polygon Co.

Computrac, Moisture analyzer, Arizona Instrument

Comshield, EMI/RFI antistatic materials, ComAlloy International Co.

Comtuf, Impact-resistant materials, ComAlloy International Co.

Con-T, Convoluted PTFE tubing, Furon Co.

Conaform, Double cone vacuum dryers, Patterson Process Equipment Div.

Conapoxy, Epoxy casting, potting, tooling, and adhesive compouns, Conap, Inc.

Conathane, Polyurethane casting, potting, tooling, and adhesive compounds, Conap, Inc.

Conduct-O-Fil, Conductive additives, Potters Industries Inc.

ConductCoat, Epoxy conductive coating, Sauereisen

Conductex 975 Ultra, Conductive grade carbon black, Columbian Chemicals Co.

Conductex SC Ultra, Conductive grade carbon black, Columbian Chemicals Co.

ConducTop, Epoxy conductive surfacer, Sauereisen

Conductron, EMI/RFI coating for plastics, Richards, W. C., Co.

Confor, Ergonomic foam, E-A-R Specialty Composites

Conformat, Continuous strand reinforcing mat, Nicofibers Co.

Connex, Net-shape thread braids, A & P Technology

ConoGlaze, Protective coating, Sauereisen

Constat, Antistatic polyethylene, Crystal-X Plastics

Contef, Convoluted flexible fluoroplastic tubing, NewAge Industries Inc., Plastics Technology Group

Contourkore, Balsa core material, Baltek Corp.

Contrabend, Reverse deflection chill roll for sheet, New Castle Industries, Inc.

Contracool, Air-cooled extruder, Battenfeld Gloucester Engineering Co. Inc.

Contrim, Conductive copolymer, Crystal-X Plastics

ControllR, SCR power control systems, Research Inc.

Conveyostat, In-line neutralizing for conveying, SIMCO

Convo Flex, Convoluted FEP tubing, Furon Co.

Cool-Tip, Plastic drill, International Carbide Corp.

Copaco, Rag electrical insulating paper (100%), Cottrell Paper Co.

CopyCAD, Design and engineering (reverse engineering), Delcam International Inc.

Core-Bond, Polyester-based syntactic adhesives, ATC Chemical Corp.

Core-Cell, Closed-cell rigid foams, ATC Chemical Corp.

CoreLyn, Polyester molding compound, Bulk Molding Compounds Inc.

Coremat, Laminate bulker, Baltek Corp.

Corex, Extrusion gear pimp for thermoplastics and elastomers, Maag Pump Systems Textron Inc.

CoREZYN, Vinyl ester resins, Interplastic Corp., CoREZYN Div.

Corrtef, Corrugated flexible fluoroplastic tubing, NewAge Industries Inc., Plastics Technology Group

Corterra, Polytrimethylene terephthalate, Shell Chemicals

Corvel, Powder coatings, Morton international Inc.

Corzan, Chlorinated PVC industrial systems, BFGoodrich Specialty Chemicals

Coscat, Amine and specialty catalysts for polyurethanes, CasChem, Inc.

Cosmic Black, Fine bone black pigment, Ebonex Corp.

Cotin, Organotin catalysts, CasChem, Inc.

Courtgard, UV-absorbing polyester film, Courtaulds Performance Films

CPM, Continuous particulate monitor, BHA Group, Inc.

Crastin PBT, Thermoplastic polyester (PBT) resin, DuPont Engineering Polymers

CRATEC, Dry-use chopped strands, Owens Corning

CRATEC Plus, Pelletized chopped glass fibers, Owens Corning

Crelon, Precision-cut synthetic flock on film, Creative Coatings Corp.

Crelsuede, Random-cut synthetic flock on film, Creative Coatings Corp.

Crimpex, Crimpless-stitched sleevings, A & P Technology

Crodamide, Slip, antiblocking, and mold release additives, Croda

Crodamol GMS-NE, Antistat and lubricant, Croda

Cromophtal, High-grade organic pigments, Ciba Specialty Chemicals Corp., Pigments Div.

Cronar, PET photographic film base, DuPont Polyester Films

Cross-Country, Christmas tree netting for growers/wholesaleers, Tipper Tie-Net

Cross-Town, Christmas tree netting for retail lots, Tipper Tie-Net

Cryoflex, Format ester plasticizer, Sartomer Co. Inc.

Crystalene, PE sheet, Crystal-X Plastics

Crystalfil, Ultrafine powdered glass, Potters Industries Inc.

CrystalVue, CrystalVue II, Abrasion-resistant coated acrylic, Pilkington Aerospace Inc.

Crystar, Specialty resin, DuPont Polyester Resins & Intermediates

Crystat, Antistatic polyolefin, Crystal-X Plastics

CT-Flex, Corrugated fluoroplastic FEP tubing, Furon Co.

CTH-Glas Trac, Indirect weathering testing, Atlas Weathering Services Group

Cultivator, Production/process management systems, Nicollet Process Engineering Inc.

Cumar, Coumarone-indene resins, Neville Chemical Co.

Cunilate, Fungicidal material, Morton International Inc. Morton Plastics Additives

Curene, Crosslinking agents, Anderson Development

Curithane, Liquid catalysts, Dow Plastics

CustomerLink, Self-managed project web sites, GZA Information Systems Div.

Cut Rite, Manufacturing software, Holzma-U.S., Div. of Stiles Machinery

Cyagard, Antioxidants, antistatics, UV light stabilizers, UV absorbers, Cytec Industries Inc.

Cyanox, Antioxidant, Cytec Industries Inc.

Cyasorb, Light absorber; light stabilizer, Cytec Industries Inc.

Cyastat, Antistatic agent, Cytec Industries Inc.

CyberCell, Expanded PVC, Cybertech Polymers

CyberLast, PVC alloy compounds, Cybertech Polymers

CyberShield, Wire and cable compounds, Cybertech Polymers

CyberTuff, PVC footwear compounds, Cybertech Polymers

Cybond, SMC adhesive, Cytec Fiberite Inc.

Cyclease, Mold release system, Lilly Industries, Inc.

Cycolac, ABS resin, GE Plastics

Cycom, Advanced composite Cytec Fiberite Inc.

Cyglas, Mineral-filled, glass-fiber-reinforced molding compound, Cytec Fiberite Molding Compounds

Cyla-Sphere, Lightweight filler beads, Cylatec, Inc.

Cylacell, Inorganic foaming agent, Cylatec, Inc.

Cylacell-PA, Processing aids, Cylatec, Inc.

Cylapurge, Inorganic purging compound, Cylatec, Inc.

Cylatherm, Inorganic intumescent, Cylatec, Inc.

Cylon, Prepregs, thermoplastic and thermoset, Cytec Fiberite Inc.

Cymel, Melamine molding compound, AC Molding Compounds; crosslinking agents; melamine resin, Cytec Industries Inc.

Cynpol, Polyolefin resins, Vinmar International Ltd.

CYP, Polymers (acrylic, polyvinyl acetate), Merrand International Corp.

Cyrex, Acrylic polycarbonate alloys, Cyro Industries

Cyrolite, Acrylic-based multipolymer compounds, Cyro Industries

Cyrolon ZX, Polycarbonate sheet, Cyro Industries

Cythane, Crosslinking agents, Cytec Industries Inc.

D

D-Tex, Intermeshing twin screw extruder, Davis-Standard Corp., A Crompton & Knowles Co.

Dabco, Amine and tin catalysts, crosslinkers and silicone surfactants, Air Products and Chemicals, Inc.

DAC, Injection molding control, Hunkar Laboratories

Dalamar, Monoazo yellows, Clariant Corp., BU Additives

Daltoped, Elastomeric polyurethane systems, ICI Polyurethanes Group

Dandux, Material handling systems, Daniels, C. R.

Dantocol, Glycol hydantoins, Lonza Inc.

Dantoin, Hydantoin derivatives, Lonza Inc.

Dapex, Diallyl phthalate molding compound, Rogers Corp.

Dapro, Silicone-free and silicone-modified additive, Elementis Specialties Colorants & Additives Business

Daran, Polyvinylidene chloride emulsion coatings, Hampshire Chemical Corp., Subs, of Dow Chemical

Daratak, Polyvinyl acetate homopolymer emulsions, Hampshire Chemical Corp., Subs. of Dow Chemical

Darex, Styrene-butadiene latexes, Hampshire Chemical Corp., Subs. of Dow Chemical

Dartek, Cast film and sheet, nylon; blown film, DuPont

Darvan, Dispersing agents, Vanderbilt, R. T., Co.

DAT, Data acquisition terminal (injection), Hunkar Laboratories

Data Trend, Computer-based control system, WABASH MPI

Datamatch, Color formulation software, Datacolor International

DataTemp, Industrial monitoring software, Raytek

Daxad, Pigment dispersants, Hampshire Chemical Corp., Subs. of Dow Chemical

Day Mold, High-performance mold system, Seawolf Industries, Inc.

DCP, Degradable and compostable plastics, EPI Environmental Products Inc.

DCP-Superflow, High-flow recirculation grinding/dispersing, Draiswerke Inc.

Decanox, Decanoyl peroxide, Elf Atochem North America, Inc.

Dechlorane Plus, Fire-retardant additive, Occidental Chemical Corp.

Deco-Bond, Adhesives, Epoxies, Etc.

Deco-Clean, Nontoxic solvent cleaners, Epoxies, Etc.

Deco Image, Heat transfer labels, Xebec BV

Decolite, Lightweight plywood replacement, Baltek

Deduster, Kinetic gravity dust removal systems, Pelletron Corp.

DegraNovon, Nonstarch degradable additive system, Novon International, Inc.

D.E.H., Epoxy catalyst resins, Dow Plastics

Dehydat, Antistatic agents, Henkel Corp.

Dehydguard, Surfactant, Henkel Corp.

DekorFlake, Nondispersing reflective flakes, Mica-Tek Div. of Miller and Co.

Delcrome, Iron-based metal alloy coatings, Stellite Coatings

Deloro, Nickel-based metal alloy coatings, Stellite Coatings

Delrin, Acetal resin, DuPont Engineering Polymers

Delrin P, Acetal resin, DuPont Engineering Polymers

Delrin ST, Tough acetal homopolymer, DuPont Engineering Polymers

Delta V, Process automation system, Fisher-Rosemount Systems, Inc.

DEltaChop, Fine fiber reinforcements, PPG Industries, Inc., Fiber Glass

DeltaRim Series, Reaction injection molding machine, Gusmer-Admiral, Inc.

D.E.N., Epoxy novolac resins, Dow Plastics

Denflex, Formulated PVC, polyurethanes, epoxies, Dennis Chemical Co.

Densetec, HDPE sheet, Polymer Industries

Deplastol, Viscosity depressant Henkel Corp.

D.E.R., Epoxy resins, Dow Plastics

Derakane, Epoxy vinyl ester resins, Dow Plastics

Desmodur, Polyisocyantes for coatings, Bayer Corp., Performance Products

Desmophen, Polyester resins for coatings, Bayer Corp., Performance Products

DewPro, Trace/mid-range moisture, Endress + Hauser

Dexflex, Thermoplastic olefin elastomers, Solvay Engineered Polymers

Dezat, Dehumidifying hopper dryer, Nissui Corp.

Di-Cup, Dicumyl peroxide, Hercules Inc.

Dia-Chip, Pigments for rock imitation, Eckart America

Diamondkote, Water-based external mold releases, Franklynn Industries

Dianol, Alkoxylated bisphenol A, Akzo Nobel Chemicals Inc.

Diasource, Diatomaceous earth (noncalcined), Intercorp, Inc.

Die Plank, Metal forming and vac-forming, Tool Chemical Co., Inc.

Dielectrite, Polyester molding compounds, Industrial Dielectrics Inc.

Diene, Polybutadiene, Firestone Synthetic Rubber & Latex Co.

Diff-Therm, Vacuum diffusion pump heaters, Dalton Electric Heating Co., Inc.

Diffracto-Lite, Vacuum metallized prismatic films, Coburn Corp.

Difine, Direct injection molding foam compound, AT Plastics Inc., AT Polymers Div.

Digisonic, IBC control, Battenfeld Gloucester Engineering Co, Inc.

Dimodan, Concentrated monoglyceride, Danisco Ingredients USA, Inc.

Dion, Unsaturated polyester, Reichhold

Diprofil, Mold polishing machinery, Engis Corp.

Direct Flow, Manifold systems, balanced hot runner manifolds, Incoe Corp.

Disco* Flake Glitter, Precision-cut decorative pearlescent flakes, Glitterex Corp.

Disorbene, Disorbene M, Clarifiers, polypropylene, Roquette America Inc.

Disperbond, Water-based polyurethanes for adhesives, Merquinsa

Disperplast, Dispersion Additives for fillers, pigments, PVC plastisols, Byk-Chemie U.S.A.

Disperse-Ayd, Multifunctional pigment dispersing agents, Elementis Specialties Colorants & Additives Business

Display-Station, Graphic computer monitor, ASC Systems

Disponel, Antifogging agent, surfactant, Henkel Corp.

Diversi-Board, Corrugated sheet, Diversi-Plast Products

Dixie Clay, Filler for polyesters, Vanderbilt, R.T., Co.

DMF, Medical device films, Dow Plastics

DML, Industrial circular saw blades, Primark Tool Group

Dr. C-MOLD, Desktop molding simulation, C-MOLD

Dolphon, Epoxy resin and compounds, polyester resins, Dolph, John C., Co.

Double Angle Cut, Counter-slanted blade design, Polymer Systems, Inc.

Double/Bubble, Two-part packaged adhesives, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Doverphos, Organophosphites, Dover Chemical Corp., Subs. ICC Industries, Inc.

Dowfrost, Heat transfer fluids, Dow Chemical Co., Polyglycols

Dowlex, LLDPE, Dow Plastics

Dowtherm, Heat transfer fluids, Dow Chemical Co. Polyglycols

Drapex, Epoxy and polymeric plasticizers, Witco Corp., Polymer Chemicals Group

Draver, Feeders, Gump Div., Buffalo Technologies

Dri-Lite, Expanded polystyrene, Poly Foam, Inc.

Dri-Loc, Pre-applied adhesive, Loctite Corp., North American Group

Drikalite, Calcium carbonate, ECC International

Drool Disc, Barrel insulation blanket, Unitherm

Dry-Ground Mica, Mica, Franklin Industrial Minerals

DSB, Barrier feedscrew, Davis-Standard Corp., A Crompton & Knowles Co.

DSBM-T, Spiral barrier feedscrew, Davis-Standard Corp., A Crompton & Knowles Co.

DT/Rigo, Thermoforming machinery, Detroit Tool

Dualite, Composite polymeric microspheres, Pierce & Stevens Corp., Sovereign Specialty Chemicals

Dublfilm, Double-coated tapes, Scapa Tapes North America

Duct, Design and simulation, Delcam International Inc.

Ductall, Vacuum hose and ducting, Plastiflex

Duex, Color concentrates, Dunlop Plastics Canada

Dun-Brite, Metallic-colored polyester film, Dunmore

Dun-Chrome, Metallized polyester film, Dunmore

Dun-Kote, Coatings on polyester film, Dunmore

Dun-Lar, Coatings on PVF film, Dunmore

Dun-Oro, Gold-colored polyester film, Dunmore

Dun-Thane, Polyurethane transfer films, Dunmore

Dun-Tran, Metallic transfer films, Dunmore

Duo-Sense, Deep and shallow well sensing, Harrel

Duofoam, Double-coated foams, Scapa Tapes North America

Duomeen, Aliphatic diamines, Akzo Nobel Chemicals Inc.

DuoMod, Impact modifiers, Zeon Chemicals, Inc.

Dura, Hot runner system, Mold-Masters

Dura Centi-Shot, Hot runner system, Mold-Masters

Dura Deci-Shot, Hot runner system, Mold-Masters

Dura Femto-Shot, Hot runner system, Mold-Masters

Dura Hecto-Shot, Hot runner system, Mold-Masters

Dura Mega-Shot, Hot runner system, Mold-Masters

Dura Pico-Shot, Hot runner system, Mold-Masters

Durabond, High-temperature adhesive, Cotronics

Duracap, Vinyl capstock compounds, Geon Co.

DuraCore, Reusable plastic cores, DC Extrusions, Inc.

Duradene, Styrene-butadiene copolymers, Firestone Synthetic Rubber & Latex Co.

Duradex, Solvent-borne coatings, Dexter Automotive & Specialty Coatings

Duraflight, Feed screw, New Castle Industries, Inc.

DuraGlas Mats, Fiberglass mats surfacing, Johns Manville

Dural, Rigid PVC, AlphaGary Corp.

Duralco, High-temperature epoxies, Cotronics

Duralene, LDPE-based sealant webs, Duralam Inc.

Duralife, Pultrusion, dies, Martin Pultrusion Group, Inc.

Durallin, LLDPE-based sealant webs, Duralam Inc.

Duraloc, Reclosable zippered pouches, Duralam Inc.

Duramene, MDPE-based sealant webs, Duralam Inc.

Duramite, Calcium carbonate, ECC International

Durane, Polyurethane compounds, Raffi & Swanson

Durapul, Pulrusion machines, Martin Pultrusion Group

Duraseal, High-temperature coating, Cotronics

Duraspin, Roller tool material, DSM Engineering Plastic Products, Inc.

Duratech 3300 Series, Silicone rubber compound, Silicone Products & Technology Inc.

Duration, Polyimide, DSM Engineering Plastic Products, Inc.

Durayl, Acrylic molding compound, Southern Plastics Co.

Durethan, Nylon 6, Bayer Corp., Polymers Div.

Durez, Powder and flake phenolic resin, Occidental Chemical Corp.

Duro-Flex, Waterborne and solventless laminating adhesives, National Starch and Chemical Co.

Duro-Lam, Hot-melt laminating adhesives, National Starch and Chemical Co.

Duro-Lok, Duro-Lok Plus, Wood-bonding adhesives, exterior exposure, National Starch and Chemical Co.

Duro-O-Set, Polyvinyl acetate and ethlyene, National Starch and Chemical Co.

Duro-PT, Fasteners for thermosets, Camcar Textron

Duro Scrim, String-reinforced LLDPE, Raven Industries Inc., Engineered Films Div.

Duro-Tak, Hot-melt and solution PSAs, National Starch and Chemical Co.

Duroflow, Blower, Gardner Denver Machinery Inc.

Durotex, Antimicrobial, Morton International Inc., Morton Plastics Additives

Dust Detect 2000, Broken bag detector, Bin-Master, Div. Garner Industries

Dust-Pak, Dust collectors, Airflow Systems, Inc.

Dustcontrol, Dust collecting equipment, Transmatic Environmental Systems

DMF, Dow Window Film, Dow Plastics

Dykor, Powder coatings, Whitford Corp.

Dylark, Styrene-maleic anhydride copolymers, NOVA Chemicals

Dylene, Polystyrene, NOVA Chemicals

Dylite, Expandable polystyrene, NOVA Chemicals

Dylyn, Tailorable thin films, Advanced Refractory Technologies, Inc. (ART)

Dymsol, Surfactants, lubricants, Henkel Corp.

Dyna-Blue, Wear-resistant surface treatment, Dynamic Metal Treating, Inc.

Dyna-Brite, Polished coating process, Dynamic Metal Treating, Inc.

Dyna-Purge, Purging compounds, Shuman Plastics

Dynaflex, Thermoplastic rubber compound, GLS Corp., Thermoplastic Elastomers Div.

Dynamar, Polyolefin processing additives, Dyneon

DynaMet, Just-in-time automated metallizer, Leybold Technologies

Dynasolve, Removal of cured silicones, epoxies, Dynaloy Inc.

Dynasylan, Organofunctional silanes, Sivento Inc.

Dynatrol, Testing instrumentation, Automation Products, Inc.

Dyneon THV, Fluorothermoplastics, Dyneon

Dyphene, Phenolic resins, PMC Specialties Group

E

E-Flow Desiccant, Draws moisture off resins (processing aid), Novon International, Inc.

E-Flow Extrusion Aid, Processing aid, Novon International Inc.

Ease Release, Mold release agents, Mann, George, & Co. Inc.

Easigel, Organo clay, Akzo Nobel Chemicals Inc.

Eastapak, PET, Eastman Chemical Co.

Eastar, Copolyester thermoplastics; PETG, Eastman Chemical Co.

Eastobrite, Optical brightener, Eastman Chemical Co.

Eastotac, Hydrocarbon tackifying resins, Eastman Chemical Co.

Easy Flow, Easy-processing LLDPE film resins, Union Carbide Corp.

EasyFroth, Gaseous blowing agent premix unit, Cannon USA Inc.

E-B Mesh, Chopped fiber for concrete, Ensign-Backford Industries Inc., Film Fibers Div.

Ebony, Channel black concentrate, PolyVISIONS, Inc.

Ecca Tex (Series), Hydrous clays, ECC International

Eccobond, One-and two-component coatings, Emerson & Cuming Specialty Polymer, Div. of National Starch

Eccocoat, One-and two-component adhesives, Emerson & Cuming Specialty Polymers, Div. of National Starch

ECCOH, Flame retardant halogen-free compounds, Mach-1 Compounding

Ecdel, Copolyester elastomers, Eastman Chemical Co.

Eclipse, High-performance VOC compaliant coating system, Dexter Adhesive & Coating Systems (IL)

ECO, Additive feeders, Motan Inc.

Ecolotex, Water-based paint, Armitage, John L.

Econo Blak, Black color concentrate, Rondy & Co.

Econo-Cube, Bulk mold releases, IMS Co.

Econogel, Organo clay, Akzo Nobel Chemicals Inc.

Ecosource 9534, Black HDPE PCR resin, Ecoplast

Ecosource 9607, Natural HDPE PCR resin, Ecoplast

Ecosplice, Repulpable tape, Scapa Tapes North America

ECRGLAS, Corrosion-resistant glass fibers, Owens Corning

Edenol, Viscosity depressant, plasticizer, Henkel

Edge-Glo, Transparent fluorescent colorants, M.A. Hanna Color

Eject-o-couple, Ejector pin thermocouple, Nanmac Corp.

Ekanate, Urethane prepolymer crosslinking agents, Merquinsa

Elastalon, Urethane-filled cast nylon rods, sheets, and tubes, Cast Nylons Ltd.

Elastichem, PVC elastomers, Colorite Plastics Co.

Elastifilm, Cast coextruded PE stretch film, Huntsman Packaging Corp., Sales

Elastoblend, Injection moldable toughened compounds, TP Composites, Inc.

Elastocarb, Smoke suppressant, Morton International

Elastocast, Castable polyurethane elastomer systems, BASF Corp., Urethanes Specialties

Elastoflex, Flexible polyurethane systems, BASF Corp., Urethanes Specialties

Elastoflex R, Semi-flexible polyurethane systems, BASF Corp., Urethanes Specialties

Elastoflex TF, Thermoformable polyurethane foams, BASF Corp., Urethanes Specialties

Elastoflex W, Flexible polyurethane foam systems, BASF Corp., Urethanes Specialties

Elastofoam I, Flexible integral skin polyurethane systems, BASF Corp., Urethanes Specialties

Elastofoam WB, Water-blow flexible integral skin PU systems, BASF Corp., Urethanes Specialties

Elastolit M, Microcellular RIM and polyurethane foam systems, BASF Corp., Urethanes Specialties

Elastolit SR, Structural RIM polyurethanes, BASF Corp., Urethanes Specialties

Elastollan, Thermoplastic polyurethane elastomers, BASF Corp., Urethanes Specialties

Elastomag, Magnesium oxide, Morton International Inc., Morton Performance Chemicals

Elastopan S, Shoe sole polyurethane materials, BASF Corp., Urethanes Specialties

Elastopor, Rigid polyurethane foam systems, BASF Corp., Urethanes Specialties

Elate, p-Phenylene diisocyanate, Akzo Nobel Chemicals Inc.

Electra-Kool, Filtered blowers, Wayne Products Inc.

Electra-Saver, Compressor, Gardner Denver Machinery Inc.

Electrablend, Electrically active injection moldable compounds, TP Composites, Inc.

Electrafil, Conductive thermoplastics, DSM Engineering Plastics

Electrodag, Conductive shielding, Acheson Colloids Co.

Electrogrip, Plated diamond and CBN tools/wheels, Engis Corp.

Electrolize, Micro-hardening/release technology, Electrolizing Inc.

Electrosol, Antistatic agents, Alframine Corp.

Elexar, Styrenic elastomers, wire and cable, Teknor Apex International

Elfan, PVC emulsifier, Akzo Nobel Chemicals Inc.

Elfoam, PU and PIR rigid foam insulation board, Elliott Co. of Indianapolis, Inc.

Elftex, Fluffy furnace carbon black, Cabot Corp., Special Blacks Div.

Eliminator, Airless cushion tube, Anaheim Custom Extruders, Inc.

Elite, Enhanced polyethylene resins, Dow Plastics

Elmax, Stainless mold steel, Uddeholm

Eltesol, Catalysts, Albright & Wilson Americas

Elvaloy, Ethylene/ester/CO terpolymers, DuPont

Elvamide, Nylon multipolymer resins, DuPont

Elvanol, Polyvinyl alcohol, DuPont

Elvax, EVA resins, DuPont

Emamelt, Electromagnetic hot melts, Emabond Systems, Ashland Chemical Co.

Emarex, Nylon 66/PPE blend, MRC Polymers Inc.

Emaweld, Electromagnetic welding materials, Emabond Systems, Ashland Chemical Co.

Emblem Seat, Heat-activated emblem backing, Industrial Coatings Group, Inc.

Emcor, Ultra-short fibers, Engelhard Corp.

Emi-Blend, Compound for EMI shielding, Howard Industries, Inc.

Emi-X, EMI attenuated thermoplastic composites, LNP Engineering Plastics Inc.

Emiclear, Conductive plastic, Toshiba Chemical America Inc.

EmiStat, Electrically conductive compounds, Foster Corp.

Emmaqua, Reflecting solar concentrator, Atlas Weathering Services Group

Emsodur, Nylon-6, nylon-12 deflashing media, EMS-American Grilon Inc.

Enamelescent, Nacreous pigments, Ferro Corp., Color Div.

Endover, Tumbler for closed drums, Morse Mfg. Co.

Endura, Shrinking process for labeled containers, B & H Labeling Systems

Enduro-Grade, Granulated polyester mold cleaning media, Maxi-Blast, Inc.

Enduron, Phenolic sheet molding compound, Cytec Fiberite Molding Compounds

Endurophthal, Phthalocyanine blues, Clariant Corp., BU Additives

Energy $aver, Adjustable frequency drives, GE Fuji Drives USA, Inc.

Enflon, Filled PTFE basic shapes, Enflo Corp.

Engage, Polyolefin elastomer, DuPont Dow Elastomers

Enshield, EMI shielding processes, Enthone-OMI Inc., Subs. Asaro Inc.

Enshield Plus, EMI shielding processes, Enthone-OMI Inc., Subs. Asarco Inc.

Ensicar, Extruded polycarbonate, Ensinger, Inc.

Ensidur, Extruded acrylonitrile-butadiene-styrene, Ensinger, Inc.

Ensifide, Extruded polyphenylene sulfide, Ensinger, Inc.

Ensifone, Extruded polysulfone, Ensinger, Inc.

Ensikem, Extruded polyvinylidene fluoride, Ensinger, Inc.

Ensilon, Extruded nylon, Ensinger, Inc.

Ensipro, Extruded polypropylene rod, Ensinger, Inc.

Ensital, Extruded acetal, Ensinger, Inc.

Ensital HPV, Extruded homopolymer acetal with polytetra fluorethylene, Ensinger, Inc.

Ensitep, Extruded polyethylene terephthalate, Ensinger, Inc.

EnviroPlastic, Water soluble/dispersible/compostable polymer resin, Planet Polymer Technologies, Inc.

Enviroprill, Nondusting flame retardants, Great Lakes Chemical Corp.

Envirostrand, Nondusting flame retardants, Great Lakes Chemical Corp.

Envri-Flo, Antimony oxide compound concentrate, Howard Industries, Inc.

Epamine, Epoxy hardener, Epic Resins

Epi-Cure, Curing agents, Shell Chemicals

Epi-Rez, Waterborne resins, Shell Chemicals

Epic III, Supervisory controls, Davis-Standard Corp., A Crompton & Knowles Co.

EPIcell, Exothermic chemical foaming agent, EPI Environmental Products Inc.

EPIcor, Endothermic chemical foaming agent, EPI Environmental Products Inc.

Epilink, Epoxy curing agents, Akzo Nobel Chemicals Inc.

EPIpurge, Purging compound, EPI Environmental Products Inc.

Epo-Tek, Epoxies, Epoxy Technology, Inc.

Epocap, Two-part epoxy compounds, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Epocolor, Daylight fluorescent pigments, United Mineral & Chemical Corp.

Epocure, Epoxy curing agents, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Epodil, Hydrocarbon and reactive diluents, Air Products and Chemicals, Inc.

Epolene, Low-molecular-weight waxes, Eastman Chemical Co.

Epolight, nfrared absorbing dyes, Epolin, Inc.

Epolite, Thermoset epoxy resin systems, Fiber Resin Corp., Subs. of H. B. Fuller Co.

Epon, Epoxy resins, Shell Chemicals

Eposet, Two-part epoxy compounds, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Epotuf, Epoxy resins and hardeners, Reichhold

Epoweld, Two-part epoxy compounds, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Epox-Eez, Premeasured, easy-to-use epoxy kit, Cotronics Corp.

Equatemp, Internally heated bushings, Melt Design Inc.

Eramide, Erucamide mold release agent, Ferro Corp., Polymer Additives Div.

Ertalyte, Thermoplastic polyester, DSM Engineering Plastic Products, Inc.

Ervol, White mineral oil, Witco Corp., Performance Chemicals Group

Esbrid, Ceramic/glass reinforced nylon, Thermofil, Inc.

Escalloy, Environment-resistant materials, ComAlloy International Co.

Escorene, Polyethylene, polypropylene, Exxon Chemical Co.

Esperal, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Espercarb, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Esperfoam, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Esperox,, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Estabex, Epoxidized soybean oil, Akzo Nobel Chemicals Inc.

Estaloc, Glass fiber-reinforced urethane elastomer, BFGoodrich Specialty Chemicals

Estane, Polyurethane resins and compounds, BFGoodrich Specialty Chemicals

Estofil, Polymer soluble dyes, Clariant Corp., BU Additives

Estyrene, Flame-retarded, UV stable HIPS, Thermofil, Inc.

ET Screw, Single screw extrusion, blow molding, and injection molding, Barr, Robert, Inc.

Ethacure, Liquid aromatic diamine epoxy, and urethane curatives, Albemarle

Ethafoam, Polyethylene foam, Dow Plastics

Ethanox, Hindered phenolic antioxidants, Albemarle

Ethavin, Fire and abrasion resistant olefin alloy, Vi-Chem Corp.

Ethofat, Ethoxylated fatty acids, Akzo Nobel Chemicals Inc.

Ethomeen, Ethoxylated amines, Akzo Nobel Chemicals Inc.

Ethoquad, Ethoxylated quaternary ammonium salts, Akzo Nobel Chemicals Inc.

Euclid Quantum, CAD/CAM/CAE/PDM software, Matra Datavision

Eupolen, Pigment dispersions, BASF Corp., Coatings & Colorants Div.

Europrene SOL, Styrene-butadiene rubber, EniChem ElastomersAmericas, Inc.

Europrene SOL T, Styrenic block copolymer, EniChem Elastomers Americas, Inc.

Euthylen, Pigment dispersions, BASF Corp., Coatings & Colorants Div.

Evancure, Curing agent, Evans Chemetics, Hampshire Chemical Corp.

Evangard, Antioxidants, Evans Chemetics, Hampshire Chemical Corp.

Evanstab, Thiodipropionate antioxidants, Hampshire Chemical Corp., Subs. of Dow Chemical

Evatane, EVA copolymers, Elf Atochem North America, Inc.

Everflex, Polyvinyl acetate copolymer emulsions, Hampshire Chemical Corp., Subs. of Dow Chemical

Everflex Bondaprene, Sealant, Surebond, Inc.

Everlube, Solid lubricant, E/M Corp.

Evershield, EMI/RFI coatings, E/M Corp.

Eversorb, Benzophenones; benzotriazoles; hindered amies, Everlight Chemical Industrial Corp.

Eversorb 12, Benzophenone, Everlight USA, Inc.

Eversorb 71, 73, 74, and 75, Benzotriazole, Everlight USA, Inc.

Eversorb 90, HALS, monomeric, Everlight USA, Inc.

Eversorb 91, HALS, oligomeric, Everlight USA, Inc.

Evoprene, Styrenic block copolymer, AlphaGary Corp.

EW-Pol, Surfactant, Henkel

Exac, Fluoropolymer machining stock, Norton Performance Plastics Corp.

Exact, Metallocene plastomer, Exxon Chemical Co.

Excalibur, Reinforced stainless steel coating, Whitford

Exceed, Metallocene linear two-density PE, Exxon Chemical Co.

Exceflow, “Shark skin” reducer, LioChem Inc.

Excelon, Rods, tubes, profiles, pipe, Thermoplastic Processes, Inc.

Exocerol, Chemical foaming/nucleating agents, B.I. Chemicals, Inc., Specialty Products Div.

Exolite, Acrylic double-skinned sheet, Cyro Industries

Expac, Extrusion control system with gear pump and drive unit, Maag Pump Systems Textron

Expandex, Blowing agents, Uniroyal Chemical

Extend, Exothemic/endothermic CBA blend, Hughes Industrial Corp.

Extendospheres, Ceramic hollow microspheres, PQ Corp.

Extendospheres-Bubble Kup, Surface-modified hollow microspheres, PQ Corp.

Extrex, Extrusion and compounding gear pump with broad application range, Maag Pump Systems Textron

Extrol, Extrusion control system, Battenfeld Gloucester Engineering Co. Inc.

Extrud-o-couple, Extruder nozzle thermocouple, Nanmac Corp.

Extrud-PC, Simulation software fox extrusion, Scientific Process & Research Inc.

Exxpol, Metallocene catalyst technology, Univation Technologies

Exxtral, Thermoplastic olefin elastomer, Exxon Chemical Co.

E-Z Arm, Mechanical fume/dust arm extractor, Airflow Systems, Inc.

EZ Fill, Extrusion foam filling, Foamseal, Inc.

E/Z Prime 893 WRX-2, Water-resistant primer, film/foil, Elm Grove Industries, Inc.

E/Z Prime 895, Primer/adhesive, ext. film & foil, Elm Grove Industries, Inc.

E/Z Prime 950, Primer/adhesive, polyolefin films, Elm Grove Industries, Inc.

E/Z Purge, Purging compound, Elm Grove Industries, Inc.

EzGage Systems, Plug-and-play measurement, Adaptive Technologies, Inc.

F

F-2000 Series, Brominated epoxies, Ameribrom Inc.

faBest, Finite element injection molding flow analysis, Plastics & Computer Inc.

Fabmat, Chopped and woven glass reinforcement, Fiber Glass Industries Inc.

faGaim, Finite element flow analysis for gas-assisted injection molding, Plastics & Computer Inc.

faHold, Finite element packing/holding phase analysis, Plastics & Computer Inc.

Fanchom, Organic pigments, Bayer Corp., Performance Products

Faradex, Conductive thermoplastics, DSM Engineering Plastics

Fascat, Stabilizers, Elf Atochem North America, Inc.

faShape, Finite element final shape prediction for injection molded parts, Plastics & Computer Inc.

Fast Clean, Purging compound, Calsak Corp.

faTherm, Mold thermal analysis, Plastics & Computer Inc.

FDM Quantum, Fast rapid prototyping system, Stratasys, Inc.

FDM2000, FDM8000, Rapid prototyping system, Stratasys, Inc.

Fe Thane, Two-part castable urethane, Foam Enterprises

Felmarx, Liquid reservoirs, acetate, Action Technology Co.

Femco, Saws and splitters, Ferry Industries Inc.

Ferrex, High-gloss mineral-filled polypropylene, Ferro Corp., Filled & Reinforced Plastics Div.

Ferro-Tic, Titanium carbide metal matrix composites, Alloy Technology International, Inc.

Ferrocon, Conductive thermoplastic, Ferro Corp., Filled & Reinforced Plastics Div.

Ferroflex, TPO elastomer, Ferro Corp., Filled & Reinforced Plastics Div.

Ferroflo, Lubricated thermoplastic, Ferro Corp., Filled & Reinforced Plastics Div.

Ferropak, Filled packaging thermoplastic, Ferro Corp., Filled & Reinforced Plastics Div.

Fiber-Cut Drill, Drill for cutting Kevlar, International Carbide Corp.

Fiberfil, Thermoplastic compounds, DSM Engineering Plastics

Fiberglas, Glass fibers, Owens Corning

Fiberglass Shield, High-gloss release agent, Zyvax

Fiberlite, Light-weight high-strength composite roller, Rockford Roller Corp.

Fiberloc, Glass fiber-reinforced vinyl compounds, Geon Co.

Fibermaster, Extruder for fibers, Davis-Standard Corp., A Crompton & Knowles Co.

Fiberod, Long fiber-reinforced thermoplastics, Ticona

FibreCrete, Thick-film, fiber-filled protective coating, Sauereisen

FibreLine, Thick-film, fiber-filled protective coating, Sauereisen

Fibresinol, Phenolic/glass fiber molding compound, Raschig Corp.

Filamid, Colorants for polyamide fibers and plastics, Ciba Specialty Chemicals Corp., Pigments Div.

Filawound, Glass filament windings, Spaulding Composites Co.

Filester, Melt-soluble colorant for polyester, Ciba Specialty Chemicals Corp., Pigments Div.

Fillex, wollastonite and mica (surface-modified), Intercorp, Inc.

Filmex, Cast film extruder, Windmoeller & Hoelscher Corp.

FilmLink, Additives for film, ECC International

Filon, Fiberglass reinforced sheet for RV industry, Kemlite

Firebrake 415, Flame-retardant, smoke-suppressant zinc borate, U.S. Borax Inc.

Firebrake 500, Flame-retardant, smoke-suppressant zinc borate compounds, U.S. Borax Inc.

Firebrake ZB, Flame-retardant, smoke-suppressant zinc borate compounds, U.S. Borax Inc.

Firebrake ZB-Fine, Flame-retardant, smoke-suppressant zinc borate compounds, U.S. Borax Inc.

Fireflake, Bright aluminum pigments, U.S. Aluminum

Fireguard, Low-smoke PVC, Teknor Apex International

Firemaster, Flame retardants, Great Lakes Chemical Corp.

Fireshield, Antimony trioxide, Laurel Industries, Inc.

Fish-Tail, rill guide assembly for composites, nternational Carbide Corp.

Fixture Plank, Checking and holding fixtures, Tool Chemical Co., Inc.

Flair, Patterned plastic sheets, AtoHaas Americas Inc.

Flake Mica, Plastics reinforcement, Franklin Industrial Minerals

Flamebloc, Flamebloc 381, Flame retardant, Buckman Laboratories, Inc.

FlameGuard, Hydrated aluminas, flame-retardant, smoke-suppressant additive, Alcoa Industrial Chemicals

Flamtard, Flame retardant; smoke suppressant, Alcan Chemicals, Div. Alcan Aluminum

Flamtard, Fire-retardant polyolefin sheet, Twinpak Inc.

Flat-Ayd, Predispersed flatting bases dispersions of silicas and polyolefins, Elementis Specialties Colorants & additives Business

Fleka, Granulated glass flake, NGF Canada Ltd.

Flex-Auger Plus, Material conveying system, Brock Manufacturing

Flex-Guard, Tubular web sleeving, Nalle Plastics, Inc.

Flex-Spreader, Plastics web spreader roller, Bingham

Flex 2000, Flexible SMC, Budd Co., Plastics Div.

Flexbase, Laminated polyester or polyimide with copper, Sheldahl Inc.

Flexbond, Acrylics, Air Products and Chemicals, Inc.

Flexchem, PVC elastomers, Colorite Plastics Co.

Flexclear, Flexible vinyl sheets, O'Sullivan Corp.

Flexible Finishing Systems, Automatic dryblast machinery, Guyson Corp.

FlexiBrass, Ultra-thin decorative sheets, Rowmark

Flexipol, Urethane foam systems, Flexible Products

Flexobond, Urethane compounds, Bacon Industries

Flexomer, Flexible polyolefin copolymers, Union Carbide Corp.

Flexprene, Styrenic TPEs, Teknor Apex International

Flexseal, Impregnation resin for sealing electronic components, Loctite Corp., North American Group

Flexstrand, Glass roving, Fiber Glass Industries, Inc.

Flexthane, Urethane/acrylic dispersions, Air Products and Chemicals, Inc.

Flexzone, Antiozonant, Uniroyal Chemical Co., Inc.

FliteScan, On-line electronic wear detection, Glycon

Flonac, Pearlescent pigments, Kemira Pigments Inc.

Flow-Cell, Microencapsulated blowing agent, Hughes Industrial Corp.

Flow Detect 1000, Flow/no flow sensor, Bin-Master Div. Garner Industries.

Flowchop, Chop system using flow technology, Venus-Gusmer, Inc.

Fluoroplast F4, Fluoroplastics (PTFE), Fluortek Inc., Distribution & Reclaim Div.

Fluoroplast 4MB, Fluoroplastics (FEP), Fluortek Inc., Distribution & Reclaim Div.

Fluorosint, PTFE-fluorocarbon base composition, DSM Engineering Plastic Products, Inc.

Foam-Kon, Foam concentrates, LNP Engineering Plastics Inc.

Foam-X, Polystyrene foam-centered board, Alusuisse Composites, Inc.

Foama-Spheres, Micro pellet with blowing agent, Chroma Corp.

Foamaster, Surfactant, Henkel Corp.

Foamspan, Thermoplastic foams, ComAlloy International Co.

Foilmarker, Handheld roller stamping unit, United Silicone Inc., an Illinois Tool Works Co.

Fomblin, Lubricant (PFPE), Ausimont USA, Inc.

Fomrez, Polyester polyols, Witco Corp., Performance Chemicals Group

Forex EPC, Polycarbonate sheet (foamed), Alusuisse Composites, Inc.

Forge Loop, Spiral wound corrugated hose, Action Technology Co.

Format, Bonded glass mat, Fiber Glass Industries, Inc.

Formion, Ionomer compounds, Schulman, A., Inc.

Formlite, Rib system, Baltek Corp.

Formolene, Polyethylene; polypropylene, Formosa Plastics Corp., USA

Formolcon, Suspension and dispersion resins, Formosa Plastics Corp., USA

Fortesil, Glass roving, Fiber Glass Industries, Inc.

Fortiflex, High-density polyethylene, Solvay Polymers

Fortilene, Polypropylene, Solvay Polymers

Fortron, Polyphenylene sulfide, Ticona

Fostalon, Medical-grade flexible nylon compounds, Foster Corp.

Fostathane, Medical-grade urethane compounds, Foster Corp.

Fournier, Wood-grain stamping foil, Kurz-Hastings

FR Cros, ammonium polyphosphates, Great Lakes Chemical Corp.

FR-20 Series, Magnesium hydroxide, Ameribrom Inc.

Franklin Fiber Filler, Acicular calcium sulfate, United States Gypsum Co.

FRE, ATH/mineral blend, Huber, J.M., Corp., Engineered Minerals Div.

Free, Flame-retardant polypropylene, Federal Plastics

Freez-Dri Colorant, Highly loaded pigment dispersions, M.A. Hanna Color

Frekote, Mold release agents, Dexter Polymer Systems

Frimp, Flame-retardant polystyrene, Federal Plastics

Froth-Pak, Two-component polyurethane foam, Insta-Foam Products Inc.

FS Systems, Process stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

FT Series, Titanium dioxide, Ishihara Corp. (U.S.A)

Fulton 404, TFE-lubricated acetal, LNP Engineering Plastics Inc.

Fungitrol, Fungicide, Creanova Inc.

Fusabond, Maleic anhydride modified polyolefins, DuPont

Fuson, Decorative heat transfer decals, Meyercord

Fusor, Epoxy structural adhesives, Lord Corp., Chemical Products Div.

Fyrebloc, Flame-retardant concentrates, Great Lakes Chemical Corp.

Fyrex, Fire retardant, Akzo Nobel Chemicals Inc.

Fyrol, Fire retardant, Akzo Nobel Chemicals Inc.

G

Gama-Plas, Calcium carbonate for glass fiber-reinforced polyester systems, Georgia Marble Co.

Gama-Sperse, Calcium carbonate, Georgia Marble Co.

Gama-Sperse CS-11, Finely ground calcium stearate-coated product, Georgia Marble Co.

Gamaco, Calcium carbonate, Georgia Marble Co.

Gamaco II, Reinforcing calcium carbonate fillers, Georgia Marble Co.

Gapex, Engineered polypropylene resins, Ferro Corp., Filled & Reinforced Plastics Div.

Gar-Dur Plastic, UHMV polymer, Garland Mfg. Co.

Garaflex E, Crosslinked thermoplastic vinyl elastomer, AlphaGary Corp.

Garaflex O, Thermoplastic olefin for zero halogen wire and cable, AlphaGary Corp.

Garaflex V, Thermoplastic vulcanizate, AlphaGary Corp.

Garal, Granite stone colors, Calsak Corp.

Garalease, Mold release agent, Lilly Industries Inc.

Gardglas, Acrylic sheet, Southern Plastics Co.

Gas-Cat, Flameless catalytic gas heaters, American Catalytic Technologies

Gasketform, Belling by use of vacuum process, United Plastics Machienry Inc.

Gawis-OD, Thickness and dimensional measurement of bottles, TopWave International, Inc.

Gawis-Std, Thickness measurement of plastic bottles and containers, TopWave International, Inc.

Geartruder, Extruder and integral gear pump, Harrel

Gecet, High-temperature EPS copolymer Huntsman Corp., Headquarters

Gelimat, Compounding system, Draiswerke Inc.

Geloy, Weatherable ASA terpolymer, GE Plastics

Gelva, Polyvinyl acetate resins, Solutia Inc.

Gemini, Conical twin extruder, Davis-Standard Corp., A Crompton & Knowles Co.

Genamid, Epoxy curing agents, Henkel Corp.

Genisys, 3D printer, Stratasys, Inc.

Gental, Alcohol solutions of nylon, General Plastics, Div. of PMC Inc.

Genton, Aqueous dispersions of nylon, General Plastics, Div. of PMC Inc.

Geode, Complex inorganic pigments, Ferro Corp., Color Div.

Geolast, Oil-resistant thermoplastic elastomer, Advanced Elastomer Systems LP

get a grip, Modular robotic end-of-arm tooling, SAS Automation

Gexol, High-performance wire and cable insulation compounds, Union Carbide Corp.

Givsorb UV-1, UV absorbers (formamidine) for urethane applications, Givaudan-Route Corp.

Glas Shot, Glass bead media, Cataphote

Glasbord, Glass fiber-reinforced plastic sheet, Kemlite

Glasdramatic, Glass fiber-reinforced rods and tubes, Polygon Co.

Glasguard, Flame- and corrosion-resistant sheet, Glastic Corp.

Glasrod, Glass-reinforced rod, Glastic Corp.

Glass-Cut, Fiberglass drill, International Carbide Corp.

Glimmer, Pigment, irridescent flakes, Eckart America

Glinstar, Shape molding machines, Foam Equipment & Consulting Co.

Glo-Clear, Flexible vinyl sheets, O'Sullivan Corp.

Gloria, White mineral oil, Witco Corp., Performance Chemicals Group

Glufil, Nutshell flour, Agrashell, Inc.

Glycolube, Lubricants/compatibilizers, Lonza Inc.

Glycostat, Antistat, Lonza Inc.

Golden Wax, Liquid mold release wax, Specialty Products Co.

Good-Rite, Antioxidants, stabilizers, BFGoodrich Specialty Chemicals

Gra-Tufy, Cold molding compound, Perma-Flex Mold

GranitEx, Simulated granite polystyrene, American Sheet Extrusion Corp.

Granu-Grinder, Small batch granulator, Brabender, C. W., Instruments, Inc.

GraphiColor, Cast polyvinylidene fluoride, Avery Dennison Corp.

Graphitan, Graphite pigment, Ciba Specialty Chemicals Corp., Pigments Div.

Graphite, Carbon, Shamokin Filler Co. Inc.

Graphtol, Organic pigments, Clariant Corp., BU Additives

Gravi-Cal, Automatic gravimetric calibration system for blenders, Plastic Inc.

Gravi-Merge, Blender, A. O. Smith Engineered Storage Products Co.

Graviblend, Continuous gravimetric blender, Colortronic, Inc.

Gravimerik, Gravimetric feeders, Merrick Industries

Gravo-Tac, ADA compliant sign material, New Hermes Inc.

Gravoply, Laminated engraving stock, New Hermes Inc.

Great Stuff, One-component urethane foam, Flexible Products Co.

Greene Line, Vinyl with recycled content for the looseleaf industry, O'Sullivan Corp.

Grilamid, Nylon-12 and transparent nylons, EMS-American Grilon Inc.

Grilbond, Adhesion promoters, EMS-American Grilon Inc.

Grilon, Nylon-6, 66, and copolymers, EMS-Amerian Grilon Inc.

Griltex, Nylon and polyester adhesives, EMS-American Grilon Inc.

Grindsted Acetem, Acetylated monoglycerides, Danisco Ingredients USA, Inc.

Grindsted Mono-Di, Monodistearates, monodioleates, Danisco Ingredients USA, Inc.

Grindsted PS, Specialty monoglycerides, Danisco Ingredients USA, Inc.

Grivory, Amorphous copolymers, EMS-American Grilon Inc.

GSC Gate Sequence Control, Linear position valve gate controller, Incoe Corp.

GSP (Series), Calcium carbonate, ECC International

GUR, UHMW-PE, Ticona

H

Hakuenka, Precipitated surface-treated calcium carbonates, Royal, H. M., Inc.

Hal-Lub, Lubricants (metallic stearates), Halstab Div., Hammond Group, Inc.

Halar, ECTFE (ethylene-chlorotrifluoroethylene), Ausimont USA, Inc.

Halbase, Heat stabilizers (lead sulfates), Halstab Div., Hammond Group, Inc.

Halcarb, Heat stabilizers (lead carbonates), Halstab Div., Hammond Group, Inc.

Hallco, Modifiers, additives and plasticizers, Hall, C. P., Co.

Hallcomid, Fatty acid amides, Hall, C. P., Co.

Hallcote, Release agents, Hall, C. P., Co.

Haloflex, Vinylidene chloride, vinyl chloride, acrylic terpolymer emulsions, Zeneca Resins

Halphos, Heat and light stabilizers (lead phosphites), Halstab Div., Hammond Group, Inc.

Haltex, White flame retardant pigment, Hitox Corp.

Halthal, Heat stabilizers (lead phthalates), Halstab Div., Hammond Group, Inc.

Hamp-ene, Chelating agents, Hampshire Chemical Corp., Subs. of Dow Chemical Co.

Hamp-ex, Chelating agents, Hampshire Chemical Corp., Subs. of Dow Chemical Co.

Hamp-ol, Chelating agents, Hampshire Chemical Corp., Subs. of Dow Chemical Co.

Hamposyl, Surfactants, Hampshire Chemical Corp., Subs. of Dow Chemical Co.

Hanacelan, PE/PS, Miwon America, Inc.

Hanaden, Engineering plastics, Miwon America, Inc.

Hanalac, ABS, Miwon America, Inc.

Hanapor, Polystyrene, expandable beads, Miwon America, Inc.

Hanarene, Polystyrene, Miwon America, Inc.

Hanasan, SAN, Miwon America, Inc.

Handy-Spec, Portable spectrophotometer, BYK-Gardner USA

HAR Mica, High-aspect-ratio muscovite mica, Franklin Industrial Minerals

Hatcol, Plasticizers, external lubricants, Hatco Corp.

Haul-All Box Trucks, Molded plastic waste trucks, Bayhead Products Corp.

Haul-All Tilt Trucks, Waste hauling trucks, Bayhead Products Corp.

Hauthane, Waterborne urethane compounds, Hauthaway, C. L., & Sons Corp.

Heat-Prober, Handheld temperature meters, Wahl Instruments Inc.

Heat-Spy, Infrared digital thermometers, Wahl Instruments Inc.

Heatflo, Mold temperature controller, Chromalox

Heavy Silver, Pool filter connection hose, Action Technology Co.

Heliogen, Phthalocyanine pigments, BASF Corp., Coatings & Colorants Div.

Heloxy, Epoxy modifier, Shell Chemicals

Heplon, Polylactide polymer resin, Chronopol, Inc.

Hercolite, Hydrogenated hydrocarbon resins, Hercules Inc.

HercuFlex Strand, Polymer-impregnated glass fiber strand, PPG Industries, Inc., Fiber Glass

Hetero-cavity, Custom injection molding, Security Plastics, Inc.

Hetron, Polyester resins, Ashland Chemical Co., Composite Polymers Div.

Heuco Flush, Organic pigment flushes, Heucotech

Heuco Pigments, Organic pigments, Heucotech

Heucodur, Complex inorganic pigments, Heucotech

HeucoRox, Iron oxides, Heucotech

Hi-Flex SMC, Flexible SMC, Budd Co., Plastics Div.

Hi-Pflex, Modified ground limestone, Specialty Minerals Inc.

Hi-Point, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Hi-Q, Powder coatings, Ferro Corp., Powder Coatings

Hi-Sil, Amorphous silica powders and pellets, PPG Industries, Inc., Chemicals Group

Hi-Stat, Electrostatic vinyl, Catalina Plastics & Coating

Hi-TempIR, High-temperature infrared heaters, Research Inc.

Hi-Vac, Heavy duty suction hose, Plastiflex

Hi-Zex Million, UHMW-PE, Mitsui Petrochemical Industries Ltd.

Hifax, Thermoplastic olefins, Montell North America

Hiflon, PTFE resins and compounds, Resource Trading Co.

Higlass, Glass-reinforced polyolefin, Montell North America

Hilene, Polyolefin resins, Vinmar International Ltd.

Hiloy, High-strength materials, ComAlloy International Co.

HiMod Mica, High-purity mica, Franklin Industrial Minerals

Hipertuf, PEN resin, Shell Chemicals

Hipscon, Conductive HIPS sheet, BFGoodrich Co., Static Control Polymers

HiSorb, Sorption material for chemicals/petroleum, HiTech Polymers

Hitone, Pigments, Datacolor Corp.

Hivynol, PUR waste to polyol, Hafner Industries, Inc.

Hoechst Wax, Montan and polyolefin waxes, Clariant Corp., BU Additives

Holcobatch, Encapsulated pigment dispersion, Holland Colors Americas, Inc.

Hole-O-Magic, Drill guide assembly for composites, International Carbide Corp.

Hombitan, Fiber/film white pigment concentrates, Sachtleben Corp.

Homeseal N.A.I.S., HVAC sealing, Foamseal, Inc.

Honey Plus, Mold preps, Specialty Products

Honey Wax, Mold release wax, Specialty Products

Hose Links, Interconnecting sections, pool vacuum hose, Action Technology Co.

Hostaflam, Wax-based lubricants, Clariant Corp., BU Additives

Hostaflon, PTFE, Custom Compounding, A Div. of Dyneon LLC

Hostalen GUR, Polyethylene, UHMWPE, Ticona, Hostalen GUR Business Unit

Hostalub, Wax-based lubricants, Clariant Corp., BU Additives

Hostalux, Optical brightener, Clariant Corp., BU Additives

Hostamont, Lubricants; mold release agents; nucleating agents, Clariant Corp., BU Additives

Hostanox, Antioxidants, Clariant Corp., BU Additives

Hostaperm, High-performance organic pigments, Clariant Corp., BU Additives

Hostaprime, Adhesion promoters; coupling agents, Clariant Corp., BU Additives

Hostasol, Fluorescent dyes, Clariant Corp., BU Additives

Hostastat, Antistatics, Clariant Corp., BU Additives

Hostavin, UV stabilizers, HALS, Clariant Corp., BU Additives

Hot Edge, Hot runner gating method, Mold-Masters

HP Multipolymer, Acrylic-based multipolymer sheet, Cyro Industries

HT Lakes, FD&C certified lake pigments, Colorcon

HTAF Series Coatings, Permanent hard antifog coatings, Exxene Corp.

HTAS Series Coatings, Permanent antistat hard coatings, Exxene Corp.

HTPC Series Coating, Photochromic hard coating, Exxene Corp.

HTR, Mold release coatings, General Magnaplate

Huberbrite, Barium sulfate, Huber, J. M., Corp., Engineered Minerals Div.

Hubercarb, Calcium carbonate, Huber, J. M., Corp., Engineered Minerals Div.

Hy-Pact Polymer, Ultra-high-molecular-weight polyethylene, King Plastic Corp.

Hybon, Glass fiber reinforcements, PPG Industries, Inc., Fiber Glass

Hybond, Elastomeric contact adhesive, Pierce & Stevens Corp., Sovereign Specialty Chemicals

Hycar, Reactive liquid polymers, BFGoodrich Specialty Chemicals

Hydcast, Cast nylon rod, slab, and tube, Hyde, A. L., Co.

Hydcor Series, Corrosion-resistant thermoplastic rods, Hyde, A. L., Co.

Hydel Series, Electrically active thermoplastic rod and slab, Hyde, A. L., Co.

HyDense, Dense stearates, Baerlocher USA LLC

Hydex Series, High-performing materials in rod and slab, Hyde, A. L., Co.

Hydlar Series, Thermoplastic and elastomer aramid resins, blends, Hyde, A. L., Co.

Hydra-Jaws, Quick mold change systems, American Aerostar Corp./Tech-RX

Hydra-Latch, Quick mold change systems, American Aerostar Corp./Tech-RX

Hydral, Hydrated aluminas, flame-retardant, smoke suppressant additive, Alcoa Industrial Chemicals

Hydramax, Endothermic flame retardants, Marshall, R. J., Co., Polymer Additives Group

Hydrax, Endothermic flame retardants, Marshall, R. J., Co., Polymer Additives Group

Hydrex, Polyester marine resin (modified vinyl ester), Reichhold

Hydrex 100, Vinyl ester (100%), Reichhold

Hydrobrite, White mineral oil, Witco Corp., Performance Chemicals Group

Hydrocerol, Endothermic foaming/nucleating agents, B.I. Chemicals, Inc., Specialty Products Div.

Hydrocerol Liquid CBA, Endothermic liquid foaming/nucleating agents, B.I. Chemicals, Inc., Specialty Products Div.

Hydrofin, Decorative post-mold coating, Waterlac Coatings, Inc.

Hydrofoam, Water-resistant urethane, Plastomer

Hydropel, Vinyl ester resins, AOC

Hydroplas, Waterborne interior coatings, Red Spot Paint & Varnish Co.

Hydrosil, Water-based organofunctional silanes, Sivento Inc.

Hydrosulfite, Catalyst promoters, Henkel Corp.

HydroThane, Thermoplastic, elastomeric hydrogel, CT Biomaterials, Div. of Cardio-Tech Int.

Hyfil, ATH/mineral blend, Huber, J. M., Corp., Engineered Minerals Div.

Hyflon, Perfluoroalkoxy, Ausimont USA, Inc.

Hyflon MFA, Tetrafluoroethylene and perfluoromethyl vinyl ether, Ausimont USA, Inc.

Hygard, Laminated polycarbonate sheet, DSM Sheffield

Hylar, Polyvinylidene fluoride, Ausimont USA, Inc.

Hylozene, High-release, low-slip polyethylene films, Industrial Coatings Group, Inc.

Hymod, Surface-modified alumina trihydrate, Huber, J. M., Corp., Engineered Minerals Div.

Hyonic, Biodegradable emulsifier; viscosity depressant, Henkel Corp.

Hypalon, Chlorosulfonated polyethylene (HDPE), DuPont Dow Elastomers

Hyperm, High-performance hot-melt adhesives, National Starch and Chemical Co.

Hypermer, Hyperdispersants, Uniqema

Hypol, Hydrophilic polyurethane prepolymers, Hampshire Chemical Corp., Subs. of Dow Chemical

Hyprez, Diamond powders, compounds and slurries, Engis Corp.

Hyrizon, Polyester-polyurethane hybrid foam system, Aristech Acrylics LLC

Hysafe, Stabilizers, Huber, J. M., Corp., Chemicals Div.

Hysol, Adhesives and structural materials, Dexter

Hystrene, Premium-grade fatty acids, Witco Corp., Oleochemicals & Derivatives Div.

Hytrel, Copolyester elastomer, DuPont Engineering Polymers

Hyzod, Polycarbonate sheet, DSM Sheffield

I

I-Helix, Spiral wound corrugated hose, Action Technology Co.

I.C.E. Block, EPS foam stay-in-place concrete forms, Cincinnati Foam Products Inc.

Iceberg, Anhydrous aluminum silicate, Burgess Pigment Co.

Icecap K, Anhydrous aluminum silicate, Burgess Pigment Co.

Icewagon, Liquid chillers, GC Industries Inc.

Identifiers, Badges, badge holders, badge inserts, Rowmark

Illumiyarn, Pigment, needle flakes, Eckart America LP

IM Level-Rite Mount, Leveling, vibration isolation antiwalking mount, Unisorb Installation Technologies

Imicure, Imidazole-based catalysts, Air Products and Chemicals, Inc.

Impax Supreme, Prehardened mold steel, Uddeholm

Impet, Thermoplastic polyester, Ticona

Implex, Impact acrylic sheet, AtoHaas Americas Inc.

Impress, In-mold coating for plastic, Ferro Corp., Powder Coatings

Imprimis, Client/server manufacturing software, Tangible Vision Inc.

Impruv, Ultraviolet curing adhesive, Loctite Corp., North American Group

Imsil, Micronized microcrystalline silica, Unimin Specialty Minerals Inc.

Incofiber, Nickel-coated fibers, INCO Specialty Powder Products

Incoshield, Long-fiber nickel concentrates, INCO Specialty Powder Products

Indofast, Organic pigment, Bayer Corp., Performance Products

Indopol, Polybutene, Amoco Chemicals

Industrene, Technical-industrial fatty acids, Witco Corp., Oleochemicals & Derivatives Div.

Inertec, Polypropylene sheet, Polymer Industries

InFilm (Series), Kaolin clay antiblocking agents, ECC International

Infinity, Continues rotor stator mill, KADY, International

InfoLink, Web-based information management systems, GZA Information Systems Div.

Infraseal, Spray elastomer, Foamseal, Inc.

Inhibitor, Inhibitors for unsaturated polyesters, Akzo Nobel Chemicals Inc.

Injecta-Color, Liquid colorants, Morton International

Inspire, Polypropylene resins, Dow Plastics

Insta-Pro Foam System, One-component polyurethane foam, Insta-Foam Products Inc.

Insta-Seal, One-component polyurethane foam, Insta-Foam Products Inc.

Insta-Stik, Urethane roof board adhesive, Flexible Products Co.; one-component polyurethane roof adhesive, Insta-Foam Products Inc.

Instant-Lok, Hot-melt adhesives, National Starch and Chemical Co.

Instathane, Formulated polyurethane elastomers, Dennis Chemical Co.

Instaweld, Hot-melt adhesives, National Starch and Chemical Co.

Instex, Micropulverized concentrate, Teknor Color Co.

Instill, Semifinished material, Dow Plastics

Integral, Adhesive films and web, Dow Plastics

Intelimer, Polymer, Landec Corp.

Intercide, Antimicrobials for polymers, Akcros Chemicals America

Interflo 62, Interflo 66, Hydrocarbon wax, The International Group, Inc.

Interstab, Process additives, Akcros Chemicals America

Intraplast, Nonaqueous dyes, Crompton & Knowles Colors Inc.

Ion Bond, Coatings, Multi-Arc Inc.

Ion Last, Proprietary ion nitride coating process, Dicer Corp.

Ion Wear, Wear-enhancing coatings, Dicer Corp.

Iosol, Nonaqueous dyes, Crompton & Knowles Colors Inc.

IP/DP Box, Instrument panel/door panel box, Atlas Weathering Services Group

Ircogel, Liquid thixotropic thickeners, Lubrizol Corp.

Irgacolor, Inorganic pigments, Ciba Specialty Chemicals Corp., Pigments Div.

Irgafos, Process stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irgalite, Organic pigments, Ciba Specialty Chemicals Corp., Pigments Div.

Irganox, Antioxidants, Ciba Specialty Chemicals Corp., Additives Div.

Irganox B-Blends, Process stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irganox HP Products, Melt-processing stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irganox LC-Blends, Low-color process stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irganox LM-Blends, Process stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irgasperse, Liquid colorants, Ciba Specialty Chemicals Corp., Pigments Div.

Irgastab, Heat stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irgastab T-265, PVC heat stabilizers, Ciba Specialty Chemicals Corp., Additives Div.

Irgazin, High-grade organic pigments, Ciba Specialty Chemicals Corp., Pigments Div.

Iriodin, Pearlescents, coated mica platelets, EM Industries Inc.

Irracure, Radiation crosslinkable polymers, NOVA-BOREALS Compounds LLC

Isobind, Isocyanate binders, Dow Plastics; Dow Chemical Co.

Isodamp, Vibration damping and isolation materials, E-A-R Specialty Composites

Isofoam, Urethane foam chemicals, IPI International

Isofroth, Urethane foam chemicals, IPI International

Isoloss, Energy absorbing materials, E-A-R Specialty Composites

Isonate, Pure and modified MDI, Dow Chemical Co.

Isonol, Polyether polyols, Dow Chemical Co., Polyurethanes

Isoplast, Engineering thermoplastic polyurethane resins, Dow Plastics

The Itemizer, Computer software, R & R Drummond

Itenite, Vulcanized fiber, Iten Industries

Iupilon, Polycarbonate, Mitsubishi Gas Chemical America, Inc.

Iupital, Polyacetal (copolymer), Mitsubishi Gas Chemical America, Inc.

J

Jeffamine, Reactive polyether amines, Huntsman Corp., Headquarters

Jeffcat, Catalysts, Huntsman Corp., Headquarters

Jenite, White rigid vinyl, Kings Specialty

Jet Kote, High-velocity oxy-fuel thermal-spray system, Stellite Coatings

JET/SPS, Plastic lumber molding systems, Mid-Atlantic Plastic Systems, Inc.

Jetfil (Series), Talc, Luzenac America

JGA, Conventional gun, ITW DeVilbiss

JMB, Cadmium pigments, United Mineral & Chemical Corp.

K

K-Resin, Styrene-butadiene, Phillips Chemical Co.

Kadel, Polyketone, Amoco Polymers

Kadox, Zinc oxide, Zinc Corp. of America

KADY Mill, Rotor-stator dispersion mill, KADY International

KadyZolver, Blade mixer, KADY International

Kaladex, Polyethylene naphthalate (PEN) film, DuPont Polyester Films

Kalene, Elastomeric compounds, Elementis Performance Polymers, Div. Harcros Chemicals

Kalex, Two-part polyurethane elastomers, Elementis Performance Polymers, Div. Harcros Chemicals

Kalidar, PEN container, fiber resins, DuPont Polyester Resins & Intermediates

Kalrez, Perfluoroelastomer parts, DuPont

Kane Ace, Impact modifiers/processing aids, Kaneka Texas

Kanevinyl, PVC resin/CPVC resin, Kaneka Texas

Kantstik, Release compounds, Specialty Products Co.

Kapton, Polyimide film, DuPont

Kasichek, Zero speed switch, ASI Instruments

Kasicond, Conductance level switch, ASI Instruments

Kasiflo, Ultrasonic flow sensor, ASI Instruments

Kasilink, Computerized inventory control system, ASI Instruments

Kasisub, Static head transmitter, ASI Instruments

Kasitrol, Capacitance level switch, ASI Instruments

Kaydol, White mineral oil, Witco Corp., Performance Chemicals Group

KC Series, Alumina trihydrate, Georgia Marble Co.

KEK, Size reduction equipment, Kemutec

Kelmar, Processed UHMWPE blends, Kelly, R. F.

Kelon A, Nylon 6/6, Lati USA Inc.

Kelon B, Nylon 6, Lati USA Inc.

Kelron, Plastic panels, Otron Tech Inc.

Keltan, EPDM, DSM Copolymer, Inc.

Kemamide, Antiblock agents, Witco Corp., Polymer Chemicals Group

Kemester, Fatty and nonfatty esters, Witco Corp., Oleochemicals & Derivatives Div.

Kemgard, Smoke suppressants; flame retardants, Sherwin-Williams Chemicals

Kemolit, Wollastonite and mica (natural), Intercorp, Inc.

Kemtec, Blowing agent, PMC Specialties Group

Ken-Cel AC-1, Azodicarbonamide blowing agent, Kenrich Petrochemicals, Inc.

Ken-Kem, Cumyl phenol derivatives and flame retardants, Kenrich Petrochemicals, Inc.

Ken-React CAPOW, Coupling agent powder, Kenrich Petrochemicals, Inc.

Ken-React CAPS, Coupling agent pellet system, Kenrich Petrochemicals, Inc.

Ken-React KR TTS, Monoalkoxy titanate coupling agent for fillers, Kenrich Petrochemicals, Inc.

Ken-React LICA, Neoalkoxy titanate liquid coupling agents, Kenrich Petrochemicals, Inc.

Ken-React NZ, Neoalkoxy zirconate liquid coupling agents, Kenrich Petrochemicals, Inc.

Ken-Stat, Antistatic agents, Kenrich Petrochemicals, Inc.

Kencolor, Silicone/pigments dispersion, Kenrich Petrochemicals, Inc.

Kenite, White flux-calcined diatomite, antiblock additive, Celite Corp., c/o World Minerals Inc.

Kenmix, Pigment paste dispersions, Kenrich Petrochemicals, Inc.

Kenplast, Plasticizers, Kenrich Petrochemicals, Inc.

Kepital, Acetal copolymer, Calsak Corp.

Kerafast, Cobalt, complex inorganic pigment, Johnson Matthey, Pigments & Dispersions

Keratherm, Cadmium, pigments, Johnson Matthey, Pigments & Dispersions

Ketjenblack, Conductive carbon black, Akzo Nobel Chemicals Inc.

Ketjenflex, Sulfonamides, Akzo Nobel Chemicals Inc.

Ketjensil, Matting agent, silica, Akzo Nobel Chemicals Inc.

Kevlar, Aramid fiber, DuPont

Kibisan, SAN resin, Calsak Corp.

King ColorCore, Environmentally stabilized polymer engraving sheet, King Plastic Corp.

King CuttingBoard, Commercial grade HDPE-textured board, King Plastic Corp.

King CuttingBoard XL, Cellular commercial grade food cutting board, King Plastic Corp.

King PlastiBal, Multipurpose HDPE architectural board, bathroom partitions, King Plastic Corp.

King StarBoard, Marine grade PE sheet extruded, King Plastic Corp.

King StarBoard XL, Cellular marine grade polymer, King Plastic Corp.

King StarLite XL, Cellular marine grade upholstery board; PE sheet, King Plastic Corp.

Kinmar, Oriented polyester film, Kings Specialty

KISUMA 5, Magnesium hydroxide for PVC, Kyowa Chemical Industry Co. Ltd.

Kleer-Stik, Oriented polyester film, adhesive-coated, Kings Specialty

Kloro, Plasticizers, Ferro Corp., Keil Chemical Div.

Knight Brand, Insulation blowing hose, Plastiflex

Knytex, Glass fiber reinforcements, fabric, Owens Corning

KOR-LOK, Holds/pulls slides/cores for slide actuated molding, PFA Inc.

Korad, Acrylic multipolymer, Polymer Extruded Products Inc.

Korad Acrylic, Weatherable surfacing for ABS, HIPS, and PVC, Polymer Extruded Products Inc.

Korad Acrylic Film, Weatherable, decorative film, Polymer Extruded Products Inc.

Korad Klear, Clear acrylic multipolymer, Polymer Extruded Products Inc.

Korton, Fluoropolymer films, Norton Performance Plastics Corp.

Kotamite, Calcium carbonate, ECC International

Kraton, Thermoplastic elastomer, Shell Chemicals

Krolor, Inorganic pigments, superior heat stability, Dominion Colour Corp.

Kronitex, Triaryl phosphate ester, FMC Corp., Process Additives Div.

Kycerol, Chemical blowing agents, endothermic, Rit-Chem Co. Inc.

Kynar ADS, Polyvinylidene fluoride, Elf Atochem North America, Inc.

Kynar Flex (Series), Polyvinylidene fluoride copolymer, Elf Atochem North America, Inc.

Kynar (Series), Polyvinylidene fluoride, Elf Atochem North America, Inc.

Kyrovap, Monomer evaporation retardants, Kyros

L

L-55RII, Acid neutralizer for polymers, Reheis Inc.

Ladene, Plastic resins/films, SABIC

Lamal, Adhesive, Morton International Inc.

Lamisan, PVC sheet, calendered, Charlotte Chemical

Lamson, Blower, Gardner Denver Machinery Inc.

Larc-TPI, Thermoplastic polyimide resin, Mitsui Chemicals America, Inc.

Laril, Polyphenylene oxide, modified, Lati USA Inc.

Larostat, Antistatic agents, BASF Corp.

Larpeek, Polyetherether ketone, Lati USA Inc.

Larton, Polyphenylene sulfide, Lati USA Inc.

LaserMark, Decorative sheets, Rowmark

Last-A-Foam, Rigid and flexible polyurethane foam, General Plastics Mfg. Co.

Lastil, Styrene-acrylonitrile, Lati USA Inc.

Lastilac, ABS, Lati USA Inc.

Latamid 6, Nylon 6, Lati USA Inc.

Latamid 66, Nylon 6/6, Lati USA Inc.

Latamid 68, Nylon copolymer, Lati USA Inc.

Latan, Acetal, Lati USA Inc.

Latene, Polypropylene homopolymer, Lati USA Inc.

Latene EP, Polypropylene impact copolymer, Lati USA Inc.

Later, Polybutylene terephthalate, Lati USA Inc.

Latilon, Polycarbonate, Lati USA Inc.

Laurox, Organic peroxides, Akzo Nobel Chemicals

Lazer Flair, For laser marking plastics, EM Industries

Lectro-Treat, Surface treater (3-D), Lectro Engineering

Lectrofluor, Mold release coatings, General Magnaplate

Legitronic, Industrial labeling systems, Weber Marking Systems, Inc.

Lennite, Lennite XL, Ultra-high-molecular-weight polyethylene, Westlake Plastics Co.

Leucopure EGM, Fluorescent whitener for polymers, Clariant Corp., BU Additives

Levapren, EVA resins, Bayer Corp., Fibers, Additives & Rubber Div.

Levelstik, Level limit switch, Endress + Hauser

Lexan, Polycarbonate resin, film, sheet, GE Plastics

Lexcote, Organic coating for polycarbonates, Ranbar Technology Inc.

Lexolube, Ester lubricants and plasticizers, Inolex Chemical Co.

Lexorez, Polyester polyols, Inolex Chemical Co.

Lignocel, Wood flour, Rettenmaier, J., USA LP

Lime Buster III, Mold water line cleaner, IMS Co.

Limelight, Specular silver reflective film, Courtaulds Performance Films

LineIR, Electric infrared line heater, Research Inc.

Linevol, Plasticizer alcohol, Shell Chemicals

Lio Dispersions, Single pigment dispersions in PE wax carrier for polyolefins, Toyo Ink America

LioClean-A, Nonabrasive purge compound, LioChem Inc.; Toyo Ink America

LioFeeder, Color feeder, LioChem Inc.

Liquiphant, Level switch, Endress + Hauser

Liquistik, Level limit switch, Endress + Hauser

Lite-Tak, UV adhesives, Loctite Corp., North American Group

Lithol, Azo pigments, BASF Corp., Coatings & Colorants Div.

Little Tuffy, Portable-inclined conveyor, Bilt-Rite Conveyors Inc.

Living Hinge, Coextruded hinge, Petro Plastics

Llumar, Weatherable polyester film, Courtaulds Performance Films

Lo-Vel, Silica flatting agents, PPG Industries, Inc., Chemicals Group

Loadmaster, LLDPE stretch films, Borden Packaging, Div. AEP Industries

Lok Cel, Low-permeability polyurethane, Plastomer

Lomar, Pigment dispersants; emulsifier, surfactant, Henkel Corp.

Lomod, Copolyester elastomer, GE Plastics

Lonzacure, Polyurethane curing agent, Air Products and Chemicals, Inc.

Loobwax, Hydrocarbon waxes, additive lubricants, AlliedSignal/Astor

Lowilite, Hindered amine light stabilizers, Great Lakes Chemical Corp.

Lowinox, Hindered bisethiophenolics, Great Lakes Chemical Corp.

Loxamid, Slip agent, lubricant, antiblock, Henkel Corp.

Loxiol, Lubricant, mold release, Henkel Corp.

LR Level-Rite Mount, Leveling, vibration isolation antiwalking mount, Unisorb Installation Technologies

LSFR, Low-smoke flame retardant, Laurel Industries

LT III, Forced-air surface treater, Lectro Engineering

Lubol, Internal lubricant, L & L Industrial Chemicals

Lubriblend, Internally lubricated injection moldable compounds, TP Composites, Inc.

Lubricomp, Lubricated thermoplastic composites, LNP Engineering Plastics Inc.

Lubrigel, Organo clay, Akzo Nobel Chemicals

Lubrilon, Lubricated materials, ComAlloy International

Lubriloy, High-performance, low-cost lubricated composites, LNP Engineering Plastics Inc.

Lucel, POM, LG Chemical America, Inc.

Luchem, Peroxide solution, Elf Atochem North America, Inc.

Lumax, PBT/styrenic alloy, LG Chemical America, Inc.

Lumiflon, Fluoropolymer solution resins, Zeneca Resins

LuminEX, Translucent plastic alloy, American Sheet Extrusion Corp.

Luminol, Glow-in-the-dark concentrates, Matsui International

Luminova, Long-afterglow phosphorescent pigment, United Mineral & Chemical Corp.

Lumogen, Dyes, BASF Corp., Coatings & Colorants Div.

Lupan, Glass fiber-reinforced SAN, LG Chemical America, Inc.

Luperco, Solid organic peroxide, Elf Atochem North America, Inc.

Luperox, Solid organic peroxide, Elf Atochem North America, Inc.

Lupersol, Liquid organic peroxide, Elf Atochem North America, Inc.

Lupos, Glass fiber-reinforced ABS, LG Chemical America, Inc.

Lupox, PBT, LG Chemical America, Inc.

Lupoy, ABS/PC alloy, LG Chemical America, Inc.

Lupranate, Isocyanates (TDI, MDI), BASF Corp., Urethanes Specialties

Luran, Styrene-acrylonitrile copolymers, BASF Corp., Plastic Materials

Luran S, ASA, BASF Corp., Plastic Materials

Luran SC, ASA/PC blends, BASF Corp., Plastic Materials

Lustran ABS, Acrylonitrile-butadiene-styrene resin, Bayer Corp., Polymers Div.

Lustran SAN, Styrene-acrylonitrile resin, Bayer Corp., Polymers Div.

Lustrofilm, Extruded PET film and sheet, Lustro Plastics

Luxor, Central and press-slide dryers, Motan Inc.

Luxor/Alufin, Metallized hot stamping foil, Kurz-Hastings, Inc.

Lyncur-CHM, Phenolic, Maruzen America, Inc.

Lyncur-CMM, Phenolic, Maruzen America, Inc.

Lyncur-CST, Copolymer of para-vinyl phenol and styrene, Maruzen America, Inc.

Lyncur-M, Poly (para-vinyl phenol), Maruzen America, Inc.

Lyncur-MB, Brominated poly (para-vinyl phenol), Maruzen America, Inc.

Lyncur-PHMC, Hydrogenated poly (para-vinyl phenol), Maruzen America Inc.

Lytex, Thermoset high-glass epoxy-based sheet molding compound, Quantum Composites, Inc.

M

M-1 Aluminum Mold Plate, Mold plate from two- to thirty-inch thick, Alpase, Inc.

Maax, Extrusion control system unit, Maag Pump Systems Textron

Macarb, Polycarbonate/ABS alloys, M.A. Industries Inc., Polymer Div.

Machine Data Transducer, Production machine data collector, Production Process Div., Industrial Marine Electronics, Inc.

McNamee Clay, Filler, Vanderbilt, R. T., Co.

Maco, Machine control systems, Barber-Colman Co., Industrial Instruments Div.

Macrolex, Organic dyestuff, Bayer Corp., Performance Products

MagChem, Magnesium carbonates, oxides, and hydroxides, Martin Marietta Magnesia Specialties

Magflo, Electromagnetic flowmeter, EMCO Flowmeters

Magic Eye, Battery indicator, ITW Produx

Magic Wand, Static neutralizers, Sticht, Herman H.

Maglite, Heat stabilizer, Hall, C. P., Co.

Magmaster, Magnetic flowmeters, ABB Instrumentation

Magnablend, Injection moldable magnetic compound, TP Composites, Inc.

Magnifin, Magnesium hydroxide, Martinswerk GmbH, Div. of Alusuisse-Lonza

Magno-Ceram, Three-component castable epoxy/ceramic, Magnolia Plastics, Inc.

Magnobond, Epoxy-based structural adhesives, Magnolia Plastics, Inc.

Magnum, ABS, Dow Plastics; solid-walled palletized bin, Perstorp Plastic Systems

Magnum Force, Ionizing air knife system, SIMCO

Magnum-White, Calcium carbonate/magnesium hydroxide additive, RMc Industries, Inc.

MagShield, Magnesium hydroxide powder, Martin Marietta Magnesia Specialties

MAKA, Five-axis CNC routers, JRM International

Makroblend, Polycarbonate PET blends, Bayer Corp., Polymers Div.

Makrolon, Polycarbonate resin, Bayer Corp., Polymers Div.

Mallard, Nonreturn valve, Zeiger Industries

Malon, Thermoplastic polyester, M.A. Industries Inc., Polymer Div.

Maloy, Thermoplastic polyester, injection molding alloys, M.A. Industries Inc., Polymer Div.

Mamax, Thermoplastic polyester, M.A. Industries Inc., Polymer Div.

The Manufacturing Manager, Software package designed for plastics processors, Data Technical Research

Mapico, Synthetic iron oxide pigments, Mineral Pigments

Marathon, CD-production lines, Krauss-Maffei Kunststofftechnik GmbH

Marblemite, Calcium carbonate, ECC International

Mark, Vinyl heat stabilizers, Witco Corp., Polymer Chemicals Group

Mark-A-Cite, Oriented polystyrene, Kings Specialty

Mark V, Mark VI, Extruders, Davis-Standard Corp., A Crompton & Knowles Co.

Mark 2 HP, Moisture analyzer, Omnimark Instrument

Marksman, Metering unit, Gusmer Corp.

Markstats, Antistats, Witco Corp., Polymer Chemicals Group

Marlex, Polyethylene, Phillips Chemical Co.

Marpol, Plastic resin, Marco Polo International Inc.

Martinal, Aluminum hydroxide, Martinswerk GmbH, Div. of Alusuisse-Lonza

Marvaloy 750, Acrylic modified styrene alloy, Marval Industries, Inc.

Masil, Silicone, BASF Corp.

Mass Meter, Mass flowmeters, ABB Instrumentation

Massflo, Coriolis mass flowmeter, EMCO Flowmeters

Master Hole Saw, Fiber-reinforced plastics carbide hole saw, International Carbide Corp.

Master-Probe, Hot runner system, Mold-Masters

Master-Shot, Hot runner system, Mold-Masters

Masterblend, Feeder control system, Merrick Industries, Inc.

Mastercoat, Coating dies, Production Components Cloeren Inc.

Mastercolor, Plastic color concentrates, Ampacet

Mastercount, Counters, Master Electronic Controls

Masterflex, Extrusion dies, Production Components Cloeren Inc.; peristaltic tubing pumps and pump controllers, Barnant Co.

Masterflow, Coextrusion block, Production Components Cloeren Inc.

Mastermix, Polymer-based predispersions, Harwick Chemical Manufacturing Corp.

Masterset, Recipe controller, Merrick Industries, Inc.

Mastertime, Timers, Master Electronic Controls

Mathe, Metallic stearates, Norac Co.

Matline, Laminate bulker/print-barrier for fiberglass construction, Nida-Core Corp.

Matrax, Thermoplastic olefinic elastomers, M.A. Industries Inc., Polymer Div.

Matrimid, High-temperature matrix resins, Ciba Specialty Chemicals, Performance Polymers

MatVantage SMC, Needled mat for SMC, PPG Industries, Inc., Fiber Glass

Maxi-Clean, Granulated melamine mold cleaning media, Maxi-Blast, Inc.

MaxiChop, Thermoplastic reinforcements, PPG Industries, Inc., Fiber Glass

Maximum Performer, HVLP spray guns, ITW DeVilbiss

Maxsperse, Coloring aids, Chemax, Inc.

Maxxam, Engineered plastics, M.A. Hanna Engineered Materials

MBC, Conventional gun, ITW DeVilbiss

MC2, Feeder controller, Merrick Industries, Inc.

MC3, Touch screen controller, Merrick Industries, Inc.

MCG Anti-Fog, Prevents fog/mist on plastic surfaces, Merix Chemical Co.

Mearl, Pigments, Engelhard Corp.

Mearlin, Pearlescent and iridescent nonmetallic pigments, Engelhard Corp.

Mearlite, Pearl paste concentrates, Engelhard Corp.

Mearlmaid, Natural pearl essence, Engelhard Corp.

Mearlmica, Mica, Engelhard Corp.

Medithane, Thermoset urethane elastomers, Fiber Resin Corp., Subs. of H. B. Fuller Co.

Melapur MC 25, **Melapur MC 50**, Flame-retardant polyamides, DSM Fine Chemicals, Inc.

Melapur MPH, Flame-retardant intumescent coat, DSM Fine Chemicals, Inc.

Melapur P46, Flame-retardant polypropylene, DSM Fine Chemicals, Inc.

Meldin, Polyimide and reinforced polyimide, Furon Co.

Melinar, PET container resins, DuPont Polyester Resins & Intermediates

Melinex, Polyester film, DuPont Polyester Films

Melinex ECO, Recycled polyester film, DuPont Polyester Films

Menzerna, Polishing compounds in bar, liquid, and paste form, Jescar Enterprises

Merrexx Screws, High-performance feed screws, Merritt Davis Corp.

Merrol, Plasticizers, Harwick Standard Distribution

Merrox, Metallic oxides, hydroxides; phosphate plasticizers/flame retardants, Merrand International Corp.

Merva-System, Lightweight vacuum presses, Stauch Merva System GmbH & CO. KG

Meta-Link, Diesel adhesives, Mereco Products Div., Metachem Resins Corp.

Metacure, Metal-based catalysts, Air Products and Chemicals, Inc.

Metaduct, Electrically conductive compounds, Mereco Products Div., Metachem Resins Corp.

Metal Core Technology (MCT), Lost-core molding process, CoreTech Associates, Inc.

Metalite, Metal-coated hollow microspheres, PQ Corp.

Metallex, Metallized laminated sheets, New Hermes

MetallonTuff, Coextruded film, Sealed Air Corp.

Metaltector, Metal detection/auger shutdown devise, Polymer Systems, Inc.

Metapor, Machinable porous aluminum blocks, Formech Inc.

Metashine, Metal-coated glass flake, NGF Canada

Meteor, Complex inorganic color pigments, Engelhard Corp.

Meteor Plus, Complex inorganic color pigments, Engelhard Corp.

Methocel, Cellulose ethers, Dow Plastics

Metregrip, Adhesives, Mereco Products Div., Metachem Resins Corp.

Metresil, Silicone, Mereco Products Div., Metachem Resins Corp.

Metrethane, Urethane compounds, Mereco Products Div., Metachem Resins Corp.

Metro, Conveying units; material handling controls, Motan Inc.

MetroVac, Filterless vacuum receivers, Motan Inc.

MF/Cool, Cooling analysis, Moldflow Corp.

MF/Flow, Flow analysis, Moldflow Corp.

MF/Midplane, Midplane generator, Moldflow Corp.

MF/Shrink, Shrinkage analysis, Moldflow Corp.

MF/Stress, Stress analysis, Moldflow Corp.

MF/Warp, Warpage analysis, Moldflow Corp.

MGH-93, Magnesium hydroxide additive, RMc Industries, Inc.

Mica-Lyte, Granite pigments, Mica-Tek Div. of Miller and Co.

MicaFlex, Mica reinforcement/filler, Pacer Corp.

Michelxo, Antistatic agent, Michel, M., & Co., Inc.

Micral, Ultra-fine alumina trihydrate, Huber, J. M., Corp., Engineered Minerals Div.

Micro-Check, Antimicrobials for PVC, Ferro Corp., Polymer Additives Div.

Micro-Clean, Colorant in dry powder form, Teknor Color Co.

Micro-Gloss, Portable glossmeter, BYK-Gardner USA

Micro-Mica (Series), Micronized mica, Franklin Industrial Minerals

Micro-Mix, Filler compounds and filler/reinforcement blends, American Best Building Products

Micro $aver II, Micro-adjustable frequency drives, GE Fuji Drives USA, Inc.

Micro Spheres, Micro pellet/bead concentrates, Teknor Color Co.

Micro-Tec, Titanium nitride coating, Dynamic Metal Treating, Inc.

Micro Tuff, Protective coating, Plating Resources Inc.

Micro-White (Series), Calcium carbonate, ECC International

MicroAir, Air pressure controller, On Line Controls

Microfibres, Nondispersing colored fibers, Mica-Tek Div. of Miller and Co.

Microfine, Submicron antimony trioxide, Great Lakes Chemical Corp.

Microflash, Spectrophotometer, Datacolor International

Microglas, Glass flake, NGF Canada

Microglass, Milled glass fibers, Fibertec Inc.

MicroGrid, Metal foil, Delker Corp.

Microlith, Pigment preparations, Ciba Specialty Chemicals Corp., Pigments Div.

Micromesh, Mica, Engelhard Corp.

Micronite, Wollastonite fibers, Fibertec Inc.

Micropel, Antimicrobials, Burlington Biomedical & Scientific Corp.

Microperl, Glass sphere reinforcements, Cataphote

Micropulse, Linear transducer for positioning, Balluff

Microseal, Solid lubricant, E/M Corp.

Microstat, Heater voltage controls, IMS Co.

Microthene, Powdered polyolefins, Equistar Chemicals

Microtuff AG Talc, Appearance-grade talcs, Specialty Minerals Inc.

Mikro-Pulsaire, Dust collector, Hosokawa MikroPul Div.

Mikro-Pulsaire 2000, Dust collector, Hosokawa MikroPul Div.

Mikrofine, Chemical blowing agents, High Polymer Labs

Millad 3905, 3940, 3988, Clarifying nucleating agents, Milliken Chemical Co.

Millithix 925, Thixotropic thickener, Milliken Chemical Co.

Min-U-Gel, High-quality gel clays, ITC Industrials

Min-U-Sil, Micron-sized silica, U.S. Silica Co.

Mindel, Sulfone blends, alloys, resins, Amoco Polymers

Minex, Nepheline syenite filler, Unimin Specialty Minerals Inc.

Mini-Skimmer, Oil skimmer, Wayne Products Inc.

Minico, Polymer thick film, Emerson & Cuming Specialty Polymers, Div. of National Starch

MiniMatch, Reflectance and transmittance spectrophotometer, Spectronic Instruments

Minimo 'One', Mold polishing machinery, Engis Corp.

Minitest, Thickness testing gauge, Electro-Physik

Minlon, Mineral-reinforced nylon resin, DuPont Engineering Polymers

Mirage, Moisture barrier BOPP films, QPF, LLC.

MirroBrite, Metallized films, Scharr Industries, Inc.

Mirrophane, Metallized film, sheet, gomar Mfg. Co.

Mistabond, Adhesives, MarChem Corp.

Mistaflex, Flexible plastisols, MarChem Corp.

Mistafoam, Urethane foam systems, MarChem Corp.

Mistique, Frosted vinyl bottle compounds, Geon Co.

Mistron (Series), Talc, Luzenac America

Mixmill Compounder, Medium-intensity heating mixer, Processall Inc.

Mixxim, Polymer additives, Fairmount Chemical Co.

Modar, Polyester resins, Ashland Chemical Co., Composite Polymers Div.

Model Plank, Master models, Tool Chemical Co., Inc.

Moduline, Modular injection molding machines, Husky Injection Molding Systems Ltd.

Mogul, After-treated furnace carbon black, Cabot Corp., Special Blacks Div.

Mold-Ease, Nonsilicone mold lubricant, Merix Chemical Co.

Mold-Vac, Evacuates mold cavities to prevent part burns, C.A.E. Services Corp.

Mold Wiz, Mold releases and internal lubricants, Axel Plastics Research Laboratories, Inc.

Moldcool, Simulates cooling process of an injection mold, C.A.E. Services Corp.

Moldflex, Decorative in-mold coatings, Waterlac Coatings, Inc.

Moldmaker, Creation of mold and tool components, Matra Datavision

MoldMates, Mold release agents, Aervoe-Pacific

Moldmax, Beryllium copper mold alloy, Uddeholm

Moldmender, Micro welder for repair of molds and dies, Rocklin Manufacturing Co.

Molgard, Mold release agent, Lilly Industries, Inc.

Molsiv, Molecular sieve to remove water/moisture, UOP, Adsorbents Div.

Molysulfide, Lubricant grade molybdenum disulfide, Climax Molybdenum Co., Chemical Sales

Monarch, Fluffy furnace carbon black, Cabot Corp., Special Blacks Div.

Monarch, Phthalocyanine blue pigments, Ciba Specialty Chemicals Corp., Pigments Div.

Monastral, Quinacridone pigments, Ciba Specialty Chemicals Corp., Pigments Div.

Mondur, Isocyanates, Bayer Corp., Polymers Div.

Monmouth, Flame-retardant materials, M.A. Hanna Engineered Materials

Mono-Coat RPM, Release for reinforced polyester, Chem-Trend, Inc.

Monocast, Direct polymerized nylon, DSM Engineering Plastic Products, Inc.

Monolan, Dispersant, wetting agent, Henkel Corp.

Monoplex, Monomeric plasticizers, Hall, C. P., Co.

Monopoxy, One-component epoxy adhesive, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

MonoSol, Water soluble film, Chris Craft Industrial Products Inc.

Montag, Wrist strap monitor, Wescorp

Montana Brand, Antimony trioxide, HoltraChem Group/U.S. Antimony Corp.

Moplen, Polypropylene, Montell North America

Mor-Ad, Industrial adhesives, Morton International Inc.

Morgan-Press, Injection molding machine, Morgan Industries Inc.

Morplug, Wrench, Morse Mfg. Co.

Morspeed, Fork attachment for drum moving, Morse Mfg. Co.

Morstille, Antioxidants, Morton International Inc., Morton Performance Chemicals

Morthane, Thermoplastic polyurethane, Morton International Inc.

MoST, Mold release and wear coatings, Multi-Arc Inc.

mPACT, Metallocene-catalyzed PE, Phillips Chemical Co.

MuCell, Microcellular polymer materials, Trexel, Inc.

Mucon, Valves and vibratory feeder range, Kemutec

Multi-Blast, Granulated urea mold cleaning media, Maxi-Blast, Inc.

Multi Chem, PVC alloy compounds, Colorite Plastics

Multi-Flex, TPE/TPO/TPR compounds, Multibase Co.

Multi-Lens, Films, Coburn Corp.

Multi-Purge, Purge compounds, M.A. Hanna Engineered Materials

Multidyne, Corona surface treatment systems, Softal 3DT LLC

Multifex, Precipitated calcium carbonate, Specialty Minerals Inc.

Multinject, Multicomponent injection molding machines, Krauss-Maffei Kunststofftechnik GmbH

Multranol, Polyether polyols, Bayer Corp., Polymers Div.

Mx Nylon, Nylon-MXD6, Mitsubishi Gas Chemical America, Inc.

Mylar, Polyester film, DuPont

Mylar ECO, Recycled polyester film, DuPont

Mylex, Polyester films, Piedmont Plastics

N

Nacor, Waterborne pressure sensitive adhesives, National Starch and Chemical Co.

Naftex, Linear-low-density PE film, sheet, and bag products, NAFCO Corp.

NAK 55, Prehardened mold steel, International Mold Steel, Inc.

Naltex, Extruded plastic netting, Nalle Plastics, Inc.

Naphthanil, Naphthol reds, Clariant Corp., BU Additives

NAS, Acrylic-styrene copolymers, clear, NOVA Chemicals Ltd.

Natka, Clays/kaolin, Harwick Standard Distribution

Natsyn, Polyisoprene, Goodyear Tire & Rubber Co., Chemical Div.

Naugard (Series), Plastic additives and antioxidants, Uniroyal Chemical Co., Inc.

Naugawhite, Antioxidant, Uniroyal Chemical Co., Inc.

Naxell, Polycarbonate, MRC Polymers Inc.

NC Proofboard, Closed-cell PUR foam board, Goldenwest Mfg., Inc.

Nedox, Mold release coatings, General Magnaplate

Neo-Fat, Fatty acids, Akzo Nobel Chemicals Inc.

NeoCryl, Acrylic resins and resin emulsions, Zeneca Resins

Neoflex, Plasticizer alcohol, Shell Chemicals

Neolor, Complex inorganic pigments, Ferro Corp., Color Div.

Neon Lite Edge Glow, Color concentrate with edge glow, Teknor Color Co.

Neopolen, Polyethylene foam, moldable, BASF Corp., Plastic Foams

Neoprene, Polychloroprene, DuPont Dow Elastomers

NeoRez, Urethane solutions and colloidal dispersions, Zeneca Resins

Net All, Plastic netting for packaging meats, produce, and horticulture, Tipper Tie-Net

Neulon, Surface modifiers, SMC, Union Carbide Corp.

Neuthane, Compounded resins, New England Urethane, Inc.

Neutrex, Odor counteractant, Aroma Tech

Neutro-Stat, Antistatic sprays and conductive materials, SIMCO

Neutro-Vac, Web cleaning systems, SIMCO

Nevastain, Nonstaining antioxidants, Neville Chemical Co.

Newflex, Spiral reinforced PVC hose, NewAge Industries Inc., Plastics Technology Group

Nexon, Blown film, tough and highly puncture resistant, Nexus Plastics, Inc.

Nexuflex, Tough and highly flexible film and bags, Nexus Plastics, Inc.

Nexus, Synthetic surfacing veil, Precision Fabrics Group, Inc.

Niax, Amine catalysts and silicone surfactant, Witco Corp., OrganoSilicones

Nicalon, Silicon carbide fiber, Dow Corning Corp.

NiMark Alloy 250, Low-carbon, high-strength steel, Carpenter Technology Corp.

1900 UHMW PE, Linear polyethylene, Montell North America

Nipol, Nitrile elastomer, Zeon Chemicals, Inc.

NIRSystems, Near-infrared spectrophotometers, Foss Nir Systems

Nistelle, Nickel-base alloys, Deloro Stellite Inc.

Nitropore, Blowing agents, Uniroyal Chemical Co., Inc.

Nitrovin, Compression resistant alloyed nitrile rubber, Vi-Chem Corp.

Nitrowear, Corrosion-resistant surface treatment, Dynamic Metal Treating, Inc.

No-Tox, Nontoxic printing inks, Colorcon

Non-Tarnish Sparkles, Colored aluminum flakes, Eckart America LP

Nopco, Surfactant, Henkel Corp.

Nopcosize, Antiblocking agent, Henkel Corp.

Nopcostat (Series), Antistatic agents, Henkel Corp.

Noraplas, Flexible PVC compounds, North American Plastics Inc.

Norbloc, Polymerizable UV stabilizer, Janssen Pharmaceutica

Norbloc 7966, Polymerizable benzotriazole UV stabilizer, Noramco, Inc.

Norcast, Epoxy casting compounds, Insulcast

Norcure, Epoxy curing agents, Insulcast

Nordel, Hydrocarbon rubber, DuPont Dow Elastomers

Nordot, Adhesives, Synthetic Surfaces Inc.

Norex, PVC foam extrusions, Norton Performance Plastics Corp.

Norlene, HMW-HDPE film, sheet, and bag products, NAFCO Corp.

Normet, Coextruded metallized film, QPF, LLC.

Norox, Organic peroxides, Norac Co.

Norpex, PPO-based engineering thermoplastics, Custom Resins Group

Norsil, Two-component silicones, Insulcast

Noryl, Polyphenylene oxide-based resin, GE Plastics

Nourycryl, Methacrylates, Akzo Nobel Chemicals Inc.

Novablend, PVC compound (rigid and semi-rigid), Novatec Plastics & Chemicals Co. Inc.

Novaclad, Adhesiveless copper, electronic material, Sheldahl Inc.

Novacycle, Recycled rigid PVC, Novatec Plastics & Chemicals Co. Inc.

Novalar, Impact modifier for ABS and PVC, Nova Polymers, Inc.

Novalast, Thermoplastic vulcanizate (TPV), Nova Polymers, Inc.

Novalene, Impact modifier for polyolefins/masterbatch for TPOs, Nova Polymers, Inc.

Novaloy, ABS/PVC alloy, Novatec Plastics & Chemicals Co. Inc.

NOVAPOL, Polyethylene resins, NOVA Chemicals Ltd.

NovaRes, Adhesive tackifier resins, Georgia-Pacific Resins, Inc.

Novoperm, Improved performance organic pigments, Clariant Corp., BU Additives

NSC, Stress crack-resistant tubing, Action Technology

NSK, Mold polishing equipment, American Rotary Tools Co., Inc. (ARTCO)

Nu-Stone, Polyester molding compounds, Industrial Dielectrics Inc.

Nucap, Treated clay, Harwick Standard Distribution

Nucrel, Ethylene-acid copolymers, DuPont

Nulok, Treated clay, Harwick Standard Distribution

Nuocide, Fungicide, Creanova Inc.

Nuoplaz, Plasticizers, Creanova Inc.

NuPet, Recylced resins, DuPont Polyester Resins & Intermediates

NUSA, Catalysts and promoters, Merrand International

Ny-Kon, Molybdenum disulfide-lubricated nylon, LNP Engineering Plastics Inc.

Nyacol, Antimony pentoxide flame retardants, PQ Corp.

NYAD, Wollastonite, untreated from Willsboro, NY, Nyco Minerals, Inc.

NYAD M, Wollastonite, untreated from Mexican deposit, Nyco Minerals, Inc.

Nycast (Series), Cast nylon rods, sheets, and tubes, Cast Nylons Ltd.

Nycast XHA, Heat-stabilized cast nylon, Cast Nylons Ltd.

Nycoa, Nylon-6 resins and compounds, Nyltech NA Co., Inc.

Nyglos, High-aspect ratio, fine particle-size wollastonite, Nyco Minerals, Inc.

Nylaflow, Extruded nylon tubing and hose, DSM Engineering Plastic Products, Inc.

Nylamid, Nylon-based engineering thermoplastics, Custom Resins Group

NylaSteel, Gear stock, metal core, DSM Engineering Plastics Product, Inc.

Nylatron, Filled or unfilled nylons, DSM Engineering

Nylene, Nylon-based engineering thermoplastics, Custom Resins

Nylobrade, Braid reinforced PVC hose, NewAge Industries Inc., Plastics Technology Group

Nyloil, Oil-impregnated cast nylon, Cast Nylons Ltd.

Nylok, Treated clay, Harwick Standard Distribution

Nylomet, Metallized nylon, Scharr Industries, Inc.

Nylotube-11, Nylon 11 tubing, NewAge Industries Inc., Plastics Technology Group

Nylox, Adhesives for nylon, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Nymphius, Filling equipment, Foam Equipment & Consulting Co.

Nypel, Recycled nylon resin, AlliedSignal Inc., AlliedSignal Plastics

Nysynblak, NBR particulate black masterbatch, DSM copolymer, Inc.

Nytal, Talc; filler for polypropylene, PVC, Vanderbilt, R. T., Co.

O

Octa Pellet, Unique 8-sided pellet, Dicer Corp.
Octamine, Antioxidant, Uniroyal Chemical co., Inc.
Odomaster, Odor counteractants,Surco Products
Oleflex, Polyolefin film, Xebec BV
Omacide, Antimicrobial agents for PVC, Olin Corp.
Omadine, Broad-spectrum antimicrobial agents, Olin Corp.
Omnicyanine, Phthalocyanine green pigments, United Mineral & Chemical Corp.
Omnifilm, Extruded PVC film, Huntsman Packaging Corp., Sales
Omniplus, Impregnated foam, General Foam Corp.
Omyacarb (Series), Calcium carbonates, Omya, Inc., A Pluess-Staufer Co.
On Spec, Low-viscosity polyamide epoxy, Torginol
Oncor, Flame-retardant additives, Great Lakes Chemical Corp.
Ongard 2, Smoke and flame suppressant for PVC, Great Lakes Chemical Corp.
Ontex, Paintable thermoplastic olefins, Solvay Engineered Polymers
Onyx Classica, Hydrated aluminas, Alcoa Industrial Chemicals
Opacolor, Color concentrate, Colorcon
Opatint, Color concentrate, Colorcon
Optema, Ethylene-methyl acrylate, Exxon Chemical
Optiblanc, Brighteners, 3V Inc.
Opticite, Printable label films, Dow Plastics
Optiflow, Blown film die, Battenfeld Gloucester Engineering Co. Inc.
Optiload, Motorless hopper loader, Opti Temp Inc.
Optimax, Stainless mold steel, Uddeholm
Optiwhite (Series), Anhydrous aluminum silicate, Burgess Pigment Co.
Optix, Extruded film and sheet, Plaskolite, Inc.
Optum, Specialty polyolefin alloy resins, Ferro Corp., Filled & Reinforced Plastics Div.
Oracet, Solvent soluble dyes, Ciba Specialty Chemicals Corp., Pigments Div.
Orasol, Dyes, Ciba Specialty Chemicals Corp., Pigments Div.
Orevac, Polyolefin binder resins, Elf Atochem North America, Inc.
Orgasol, Fine particle-size polyamide powders, Elf Atochem North America, Inc.
Orvar Supreme, Mold steel, Uddeholm
Orzol, White mineral oil, Witco Corp., Performance Chemicals Group
Output, Thermally conductive adhesive, Loctite Corp., North American Group
Ox-Tran, Oxygen permeation testing, MOCON/Modern Controls, Inc.
OXP, Oxidized polyethylene, Cardinal companies
Oxybenzone, Ultraviolet absorber for PVC and polyester, Aceto Chemical Co.

P

P84, High-temperature polyimide, HP Polymer Inc.
Pac Guard, Pinhole leak detection, MOCON/Modern Controls, Inc.
Padflex, Pad printing machines, Autoroll Machine
Pak, Packaged extruders, Akron Extruders, Inc.
Palatinol, Plasticizers, BASF Corp., Plasticizers
Paliogen, Organic pigments, BASF Corp., Coatings & Colorants Div.
Paliotol, Organic pigments, BASF Corp., Coatings & Colorants Div.
Palomar, Organic pigment, Bayer Corp., Performance Products
Panax, Organic pigments, United Mineral & Chemical Corp.
PanellR, Electric infrared panel heater, Research Inc.
Panelmaster, Waterborne contact adhesives, National Starch and Chemical co.
Panlite, Polycarbonate resin, Calsak Corp.
Papermatch, Paperlike concentrates, Schulman, A., Inc.
Papi, Polymeric MDI (PMDI), Dow Plastics
PAPI, Polymeric MDI, Dow Chemical Co., Polyurethanes
Parabolix-100, Super concentrate for light luminaires, Merix Chemical Co.
Paraclor, Chlorinated paraffin, Charlotte Chemical Inc./CCI
Paracolor, Pigment encapsulate, Teknor Color Co.

Paragon, Induced draft cooling towers, Delta Cooling Towers Inc.

Paraloid, Acrylic and MBS modifiers for PVC/engineering resins; processing aids, Rohm and Haas

ParaPlast, Mold materials, Fiber Resin Corp., Subs. of H. B. Fuller Co.

Paraplex, Polymeric plasticizers, Hall, C. P., Co.

Paratherm GR, Nontoxic glycol replacement chiller fluid, Paratherm Corp.

Paratherm HE, High-efficiency heat transfer fluid, Paratherm Corp.

Paratherm NF, Nonfouling, nontoxic heat transfer fluid, Paratherm Corp.

Paratherm OR, Oxidation-resistant, high-efficiency heat transfer fluid, Paratherm Corp.

Paricin, Mold lubricant and release agent, CasChem

Paroil, Liquid chloroparaffins, Dover Chemical Corp., Subs. ICC Industries, Inc.

Part Adviser, Flow simulation using solid models, Moldflow Corp.

Partinakote, Mold release agents, external, Fiber Resin Corp., Subs. of H. B. Fuller Co.

Paste Wiz, Mold release agent, Axel Plastics Research Laboratories, Inc.

Pationic, Glycerol esters and lactate salts, American Ingredients Co., Patco Polymer Additives Div.

Pattern Plank, Patterns, core boxes, gating, Tool Chemical Co., Inc.

PC/Work-Station, Interactive computer/control system, ASC Systems

PDI dispersions, Paste color dispersions, Ferro Corp., Liquid Coatings & Dispersions Div. (NJ plant)

PDM Ejector Pins, Thru-hardened ejector pins, Performance Alloys and Services, Inc.

PDQ, Oxidative and UV degradable concentrate, Willow Ridge Plastics, Inc.

PDS Fence Products, Chain-link fence accessories, A & B Plastics, Inc.

Pearlcoat, Thermoplastic polyurethane (coating and melt coating), Merquinsa

Pearlite, Color concentrate H/M/F pearls, Teknor Color Co.

Pearlstick, Urethane elastomers for adhesives, Merquinsa

Pearlthane, Thermoplastic polyurethane (injection and extrusion), Merquinsa

Pebax, Thermoplastic elastomers, Elf Atochem North America, Inc.

PEEK, Polyaryletherketone polymer, Victrex USA

Peel Ply, Synthetic release/bleeder-breather fabric, Precision Fabrics Group, Inc.

Pegosperse, Polyethylene glycol esters, Lonza Inc.

Pekutherm, Purging compound, Unitemp

Pelaspan Mold-a-Pac, Resilient molded packaging products, Dow Plastics

Pellethane, Thermoplastic polyurethane elastomers, Dow Plastics

Pennite, Sheets, coils, strips, and fabricated parts, Penn Fibre & Specialty Co. Inc.

Pennlon, Molecularly oriented polyolefin, Furon Co.

Pentacard, Credit card film and sheet, Klockner Pentaplast of America, Inc.

Pentafood, Food grade film and sheet, Klockner Pentaplast of America, Inc.

Pentaform, Thermoform film and sheet, Klockner Pentaplast of America, Inc.

Pentamed, Medical device film and sheet, Klockner Pentaplast of America, Inc.

Pentaphan, Adhesive, Morton International Inc.

Pentapharm, Pharmaceutical film and sheet, Klockner Pentaplast of America, Inc.

Pentaprint, Printing film and sheet, Klockner Pentaplast of America, Inc.

Pentastat, Static control film and sheet, Klockner Pentaplast of America, Inc.

Pentia, Three- and 5-axis routers, Ferry Industries Inc.

Pepco-Flex, Tubing, Plastic Extruded Products Co. (PEPCO)

Performamide, Nylon 6 and 6/6, Performance Polymers Inc.

Performance^{10}, Thermoplastic reinforcements, PPG Industries, Inc., Fiber Glass

Performance Core Pins, Copper alloy core pins, Performance Alloys and Services, Inc.

Performance Sprue Bushing, Copper alloy sprue bushing, Performance Alloys and Services, Inc.

Perkacit, Sodium dimethyl dithiocarbamate, Akzo Nobel Chemicals Inc.

Perkadox, Organic peroxides, Akzo Nobel Chemicals Inc.

Perkalink, Allyl compounds, Akzo Nobel Chemicals Inc.

Perkasil, Matting agent, silica, Akzo Nobel Chemicals Inc.

Perl Mill, Ultra-fine grinding system, Draiswerke Inc.

Perma-Cap, Vinyl bleacher covers, Crane Plastics

Perma-Lok, Anaerobic adhesives/sealants, Permabond, Div. National Starch & Chem. Co.

Permalease, Mold release, Mann, George, & Co.; Smooth-On, Inc.

Permanax, Nonstaining antioxidants, Akzo Nobel Chemicals Inc.

PermaStat, Permanently antistatic compounds, RTP

Permatran-W, Water vapor permeation testing, MOCON/Modern Controls, Inc.

Permyl, Ultraviolet absorbers, Ferro Corp., Polymer Additives Div.

Perrindo, Organic pigment, Bayer Corp., Performance Products

Perspex, Acrylic polymer, ICI Acrylics Inc.

Perspex CP, Acrylic sheet, ICI Acrylics Inc.

Petaflex, Laminating adhesives, solvent-borne, National Starch and Chemical Co.

Petcat, Antimony trioxide, Laurel Industries, Inc.

Petra, Post-consumer recycled PET resin, AlliedSignal Inc., AlliedSignal Plastics

Petrac, Metallic stearates, waxes, fatty amides, Ferro Corp., Polymer Additives Div.

Petrothene, Low-, medium- and high-density polyethylene and polypropylene resins, Equistar Chemicals

Petrothene XL, Crosslinkable polyethylene compounds, Equistar Chemicals

Pfinyl, Coated product for PVC applications, Specialty Minerals Inc.

Phase Alpha, SMC body panel resin, Ashland Chemical Co., Composite Polymers Div.

Phenolex, Industrial laminated plastic sheets, Oliner Fibre Co., Inc.

Phenoweld, Phenolic adhesives, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Pherostatic, Electrostatic baffle coating, Electrostatic Technology, Inc.

PhilJo, Polyolefin films, Phillips-Joanna Co.

Phillips, Blender, A. O. Smith engineered Storage Products Co.

Phoenix, Ionizing air blowers, SIMCO

Phospholan, Antistatic agent, wetting agent, Henkel

Photocap, EVA-based PV encapsulants, Springborn Testing & Research, Inc. (STR)

Photoglaze, UV and EB curable coatings, Lord Corp., Chemical Products Div.

Photopia, Photochromic concentrates, Matsui International

Photoplas, Ultraviolet curable coatings, Red Spot Paint & Varnish Co.

Picariko, Phosphorescent pigments, Bass, F. W., International

Picco 6000, Hydrocarbon resins, Hercules Inc.

Piccodiene, Polydicyclopentadiene resins, Hercules Inc.

Piccolastic, Polystyrene resins, Hercules Inc.

Piccolyte, Terpene hydrocarbon resins, Hercules Inc.

Piccopale, Aliphatic-type hydrocarbon resins, Hercules Inc.

Piccotex, Vinyl toluene copolymer, Hercules Inc.

Piccovar, Alkyl-aromatic resins, Hercules Inc.

Pilot SF-4, Ground oyster shells with platy morphology, Oyster Shell Products, Div. Martin Marietta Magnesia

PinSens, Low-cost, behind-the-pin sensor, Kistler Instrument Corp.

Pioneer, Forced draft cooling towers, Delta Cooling Towers Inc.

Pioneer Talc, Industrial talc, Zemex Industrial Minerals, Inc.

Pipcar, Fountains, heat pipes, Injection Molding Industries

PIX-A, Thermoplastic polyimide prepreg, Mitsui Chemicals America, Inc.

PlantVision, Mold and part inspection software, Avalon Imaging Inc.

Plas-Chek, Epoxy plasticizers, Ferro Corp., Polymer Additives Div.

Plas-Glas, Bulk molding cmopound, Plaslok Corp.

Plaslube, Lubricated thermoplastics, DSM Engineering Plastics

Plasmadize, Abrasion-resistant mold release, General Magnaplate

Plasmec, Bulk mixing systems, Construction Technology Div.

Plastbau, EPS boards/hollow-cored, Construction Technology Div.

PlastHall, Monomeric and polymeric plasticizers, Hall, C. P., Co.

Plasti-Corder, Computerized torque rheometer system, Brabender, C. W., Instruments, Inc.

Plasti-Grit, Plastic blasting media, Composition Materials Co., Inc.

Plasti-Shield, Nuclear shielding material, King Plastic

Plastiblend, Injection moldable thermoplastic alloys, TP Composites, Inc.

Plasticel, Coatings, Strathmore Products Inc.

Plastigel, Liquid thickeners, Plasticolors, Inc.

Plastilease, Mold release agent, Lilly Industries, Inc.

Plastisan, Flame retardants, 3V Inc.

Plastishield, Post-applied coating for plastic, Lilly Industries, Inc.

Plastisperse, Custom dispersion, Plasticolors, Inc.

PlastiStab, Heat stabilizers, OMG Americas, Inc.

Plastite, Fasteners for thermoplastics, Camcar Textron

Plastitoy, Decorative lacquers, Ruscoe, W. J., Co.

Plasto-Joint Stik, Pipe thread compound, La-Co Industries, Inc.

Plastoflex, Epoxy-based stabilizers/plasticizer, Akzo Nobel Chemicals Inc.

Plastomag, Oil-containing magnesium oxide composition, Morton International Inc., Morton Performance Chemicals

Platamid, Hot-melt adhesives, Elf Atochem North America, Inc.

Platherm, Copolyester hot-melt adhesives, Elf Atochem North America, Inc.

Platilon, Polyurethane films, Elf Atochem North America, Inc.

Play Color, Marble colors and stone colors, Calsak Corp.

Plei-Tech 22, Abrasion and cut-resistant polyurethane, Pleiger Plastics Co.

Plei-Tech 95, High-load-bearing roller and wheel, polyurethane, Pleiger Plastics Co.

Plenco, Thermoset resins and molding compounds, Plastics Engineering Co.

Plenex, Thermoplastic polymer, CONDEA Vista Co.

Plexar, Tie-layer resins for coextrusion, Equistar Chemicals

Plexiglas, Acrylic sheets and molding powders, AtoHaas Americas Inc.

Pliabrac, Flame retarding plasticizers, Albright & Wilson Americas

Plioflex, Emulsion styrene-butadiene-rubbers, Goodyear Tire & Rubber Co., Chemical Div.

Pliolite, Coatings, Goodyear Tire & Rubber Co., Chemical Div.

Pluracol, Polyether polyols, BASF Corp., Urethanes Specialties

Pluracol HP, Polyether polyols, BASF Corp., Urethanes Specialties

Plyamul, Polyvinyl acetate emulsions, Reichhold

Plytrax, Laminates, Norton Performance Plastics

PoleStar (Series), Calcined clay, ECC International

Poliflex, Polymeric plasticizer, Charlotte Chemical Inc./CCI

Politen, Glass-reinforced polyester sheet, Iten Industries

Poly 76, Poly 84, Cast acrylic sheet, Polycast Technology Corp.

Poly-Bond, Polyester-based syntactic adhesives, ATC Chemical Corp.

Poly-Carb-VII, Polycarbonate deflashing media, Composition Materials Co., Inc.

Poly-Cure, Catalysts, OMG Americas, Inc.

Poly-Eth, Low-density polyethylene, Chevron Chemical Co., U.S. Chemicals, Polyethylene Group

Poly-Eth-Hi-D, High-density polyethylene, Chevron Chemical Co., U.S. Chemicals, Polyethylene Group

Poly-Fair, Polyester fairing compounds, ATC Chemical Corp.

Poly*Flake Glitter, Precision-cut decorative polyester flakes, Glitterex Corp.

Poly Foam, Internal/external surface treater, Lectro Engineering

Poly-Stone, Granite-effect masterbatch, Plastics Color Chip, Div. of PMC Inc.

Poly II, Cast acrylic sheet, Polycast Technology Corp.

Polybatch, Color concentrates, Schulman, A., Inc.

Polyblak, Black concentrates, Schulman, A., Inc.

Polyblast, Abrasive, Pangborn Corp.

Polybloc, UV barrier concentrate, Schulman, A., Inc.

PolyBloc Antiblock Talc, Antiblock product, Specialty Minerals Inc.

Polybond, Adhesive, Morton International Inc.

Polybond, Chemical coupling agents, Uniroyal Chemical Co., Inc.

PolyCap, Barrier bubble cushioning, Sealed Air Corp.

Polycat, Amine catalysts, Air Products and Chemicals

Polycizer, Plasticizers, Harwick Standard Distribution

Polyclay, Hydrous aluminum silicate, Burgess Pigment Co.

Polycolor, Liquid colorants, Strathmore Products Inc.

Polycool, Air ring, Battenfeld Gloucester Engineering Co. Inc.

POLYcor, Endothermic/exothermic chemical foaming agent, EPI Environmental Products Inc.

Polycure, Modified polyolefin crosslinkable compositions, NOVA-BOREALIS Compounds LLC

Polycycle, Complete reclaim systems, Merritt Davis Corp.

Polydyne, Corona surface treatment systems, Softal 3DT LLC

Polyfabs, ABS compounds, Schulman, A., Inc.

Polyfil, Kaolin clay, Huber, J. M., Corp., Engineered Minerals Div.

Polyfin (Series), SBS, Crowley Chemical Co.

Polyfine, Sliding grade polymers, Calsak Corp.

Polyflam, Flame-retardant compounds, Schulman, A., Inc.

Polyflex, Oriented and biaxially oriented polystyrene, Plastic Suppliers

Polyflex, Polyethylene tapes, Scapa Tapes North America

Polyflo, Color concentrate (LDPE), Indol Color, Div. of Magruder Color Co. Inc.

Polyfort, Polypropylenes and polyethylenes, Schulman, A., Inc.

Polyglas, Polytruded shapes, Resolite, A United Dominion Co.

Polygrade, Photodegradable masterbatches, Ampacet Corp.

PolyGusset, Custom-blended extrusion coating films, Industrial Coatings Group, Inc.

Polyholyn, Release-coated high density film, Industrial Coatings Group, Inc.

Polyiff, Polymeric fragrance masterbatch, International Flavors & Fragrances Inc.

Polylac, ABS resin, Calsak Corp.

Polylite, Polyester resins, Reichhold

Polylite, Antioxidant, Uniroyal Chemical Co., Inc.

Polylite ProCast, Cultured marble resin, Reichhold

Polylite Profile, Mold-making resin, Reichhold

Polylube, PTFE micropowder, Custom Compounding, A Div. of Dyneon LLC

Polyman, ABS alloys, Schulman, A., Inc.

Polymeric Series Foams, Synthetic rubber substitute, Gaska-Tape Inc.

Polymica, Mica reinforcements for resin systems, Franklin Industrial Minerals

Polymist, Polytetrafluoroethylene (PTFE), Ausimont USA, Inc.

Polyox, Polyethylene oxide water-soluble resins, Union Carbide Corp.

Polypenco, Thermoplastic shapes and fabricated parts, DSM Engineering Plastic Products, Inc.

Polypur, Polyurethane compounds, Schulman, A., Inc.

Polyrex, Compounding gear pump for polyolefins, Maag Pump systems Textron

Polyscent, Fragranced cellulose acetate, Rotuba Extruders, Inc.

Polyseal, Polyolefin films, Industrial Coatings Group, Inc.

Polyslick, UHMW-PE sheet and rod, Polymer Industries

Polysorb, Liquid reservoirs, polyester, Action Technology Co.

Polystarch, Degradable starch masterbatch, Willow Ridge Plastics, Inc.

Polystone, Proprietary polyolefins, Roechling Engineered Plastics

Polysynthrsn, Dyes for spindyeing of polyester, Clariant Corp., BU Additives

Polytal, Talc for polyolefins, Whittaker, Clark & Daniels, Inc.

Polytron, Static dissipative alloys, Geon Co.

Polytrope, Thermoplastic elastomeric compounds, Schulman, A., Inc.

Polyvin, Thermoplastic PVC compounds, Schulman, A., Inc.

Polywax, Low molecular-weight polyethylene, Baker Petrolite, Polymers Div.

Pomalux, Acetal copolymer, Westlake Plastics Co.

Pomarez, Olefin/maleic copolymers, Baker Petrolite, Polymers Div.

Pool King, Swimming pool vacuum hose, Plastiflex

Poraver, Expanded glass multicellular spheres, Construction Technology Div.

Porcerax II, Self-venting mold steel, International Mold Steel, Inc.

Porofelt, Pleated stainless steel fiber felt filter media, Purolator Products Co., Facet Filter Products Div.

Porofor, Foaming agents, Bayer Corp., Fibers, Additives & Rubber Div.

Poromesh, Pleated stainless steel wire mesh filter media, Purolator Products Co., Facet Filter Products Div.

Poromet, Cleanable stainless steel filter elements, Purolator Products Co., Facet Filter Products Div.

Poroplate, Diffusion-bonded multilayer stainless steel wire mesh filter media, Purolator Products Co., Facet Filter Products Div.

Porotest, Pinhole detection device, Electro-Physik

Porta Shell, Lab size double cone and V blenders, Patterson Process Equipment Div.

Power Miser, Energy-saving controls for molding, Digital Technologies

Power Pin, Ejector pins, Choice Mold Components

Powercat, Pultrusion machines, Martin Pultrusion Group, Inc.

Powergrip, fastener, sheet metal to plastic attachment, Camcar Textron

PowerMILL, Three-axis machining, Delcam International Inc.

Powerpul, Pultrusion machines, Martin Pultrusion Group, Inc.

Powerseal, Adhesive, Surebond, Inc.

PowerSHAPE, Modeling for manufacture, Delcam International Inc.

PProtints, Tints for clarified polypropylene, M.A. Hanna Color

Preform Quality Tester, Monitors blowability, TopWave International, Inc.

Perform Thickness Gauge, Wall thickness measurement of preforms, TopWave International, Inc.

Preform Vision Gauge, Automatic measuring system for preform dimensions, TopWave International, Inc.

Premi-Glas, Thermoset polyester-based molding compounds, Premix, Inc.

Premi-Ject, Thermoset polyester injection molding compounds, Premix, Inc.

Premier, Ultramarine pigments, Whittaker, Clark & Daniels, Inc.

Premier, Large-capacity induced draft cooling Towers, Delta Cooling Towers Inc.

Prep Center, DC drive motor for sample preparation, Brabender, C. W., Instruments, Inc.

Prep Mill, Laboratory two-roll mill, Brabender, C. W., Instruments, Inc.

Prep Mixer, Sample preparation mixer, Brabender, C. W., Instruments, Inc.

Pressurex, Pressure indicating film, Sensor Products

Prestige, Ultramarine pigments, Whittaker, Clark & Daniels, Inc.

Prevail, Thermoplastic resins, Dow Plastics

Prima-Solder, Hyper-conductive adhesive, A.I. Technology, Inc.

Primacor, Adhesive copolymers, Dow Plastics

Primax, Surface-treated polyethylene particles, Air Products and Chemicals

Prime ABS, Extruded ABS sheet, Primex Plastics Corp.

Prime Co-ex, Coextruded polystyrene sheet, Primex Plastics Corp.

Prime Cor-x, Corrugated polyethylene or polypropylene, Primex Plastics Corp.

Prime HDPE, Extruded polyethylene sheet, Primex Plastics Corp.

Prime Impax, Extruded polystyrene sheet, Primex Plastics Corp.

Prime Wrap, Cast PVC film, Huntsman Packaging Corp., Sales

Primeweld, Plastic welding rod, Prime Plastics, Inc.

Primid XL-552, Hydroxyalkylamide hardener, EMS-American Grilon Inc.

Prism, Solid polyurethane RIM systems, Bayer Corp., Polymers Div.

Prism, Precolored plastic resins, Federal Plastics Corp.

Prism Series, Instant adhesives, Loctite Corp., North American Group

Pro-fax, Polypropylene, Montell North America

Pro Grip, Cyanoacrylate adhesives, Fel-Pro Chemical Products L.P.

Pro Lock, Anaerobic sealer/adhesive, Fel-Pro Chemical Products L.P.

Pro-Pad, Plastic cutting pads, International Industrial Products Corp.

Pro Series Capacitance Probes, Point-level sensor, Bin-Master, Div. Garner Industries

Pro-Tech 400 Plus, Stretch film, DuPont

ProBond 2K, Adhesive spray gun system, ITW DeVilbiss

Procaid, Polymeric process aid, Colortech Inc.

Procheck "Advantage", Leak testing system, Proco Machinery Inc.

Procor, Acrylic-coated film (two sides), Mobil Chemical Co., Films Div.

Prodex, Coatings for polyolefins, Dexter Automotive & Specialty Coatings

Prodox, Antioxidants, PMC Specialties Group

Profiler, Film thickness gauging, MOCON/ Modern Controls, Inc.

proFLOW, Specialty polypropylene resins, PolyVISIONS, Inc.

Prolastic, Proprietary TPE compounds, Discas, Inc.

Prolon, Engineering grade resins, Teknor Color Co.

Propamet, Metallized oriented polypropylene film, Scharr Industries, Inc.

Propylux, Polypropylene, Westlake Plastics Co.

Prosperse, Specialty elastomeric compounds, Discas, Inc.

ProTherm, CPVC compound for fittings and pipe, Georgia Gulf corp., PVC Div.

Protherm, Beryllium copper mold alloy, Uddeholm

Protol, White mineral oil, Witco Corp., Performance Chemicals Group

Provox, Process automation system, Fisher-Rosemount Systems, Inc.

PTA, Heat stabilizers, EPI Environmental Products Inc.

PTZ Phenothiazine, Antioxidant for polyurethanes and vinyl ester resins, Zeneca Specialties

Pulse, Engineering resins, Dow Plastics

Pulse Pleat, Filter elements, BHA Group, Inc.

Pulstar, Pultrusion machinery and equipment, Strongwell Corp.

Pur-Fect Lok, Reactive structural adhesives, National Starch and Chemical Co.

Pura, Release agents for polyurethanes, Chem-Trend, Inc.

Pureline, FEP-lined LDPE tubing, Furon Co.

Purgex Blends, Purging agents, Neutrex

Purgex Concentrates, Purging compound, Neutrex

PVI, Thermoforming equipment, Plasti-Vac, Inc.

PX5, Prehardened mold steel, International mold Steel, Inc.

Pyrax, Filler for polypropylene, Vanderbilt, R. T., Co.

Pyro-chek, Flame-retardant additives, Ferro Corp., Keil Chemical Div.

Pyrobloc, Antimony flame retardants, Great Lakes Chemical Corp.

Pyronil, Plasticizers, Laurel Industries, Inc.

Q

Q-Cel, Inorganic hollow microspheres, PQ Corp.

QA/S GainSeeker SPC, Network-based software, Hertzler Systems Inc.

QPET, Aroma barrier BOPP films, QPF, LLC.

QSC Bushing, Externally heated hot runner bushings, Incoe Corp.

QSO Valve, Quick shut-off nonreturn valve, Glycon Corp.

Quality Analyst, SQC/SPC software, Northwest Analytical

Quarite, Textured acrylic sheet, Aristech Acrylics LLC

Questra, Crystalline polymers, Dow Plastics

Quick Lock, Spool holding device, Progressive Machine Co.

Quickbond 612, Structural acrylic adhesive, Permabond, Div. National Starch & Chem. Co.

Quickset, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Quidur, Urethane prepolymer crosslinking agents, Merquinsa

Quik-Seal, Thermoplastic bag sealer, National Instrument Co., Inc.

Quilastic, Water-based urethanes (adhesives, films, etc.), Merquinsa

Quincat, Polyurethane catalyst; triethylene amine, Enterprise Chemical Co.

Quindo, Organic pigment, Bayer Corp., Performance Products

Quinsorb, UV absorbers, Enterprise Chemical Co.

Quintsonic, Coating thickness testing gauge, Electro-Physik

Qwik Mold Release, Mold release spray, Reed, Roger A., Inc.

R

R-Cast, Special technology applied to cast acrylic, Reynolds Polymer Technology, Inc.

R1 Fast Cast, Rigid urethane casting resin, Goldenwest Mfg., Inc.

Racoplast, Phenolic molding compound, Raschig Corp.

Radel, Polyethersulfone, Amoco Polymers

Radilon, Nylon compounds, Polymers International

Radipol, Nylon base resins, Polymers International

Ralox, Antioxidants, Raschig Corp.

Ralox, Antioxidants, PMC Specialties Group

Ram-Part, Mold release agent, Lilly Industries, Inc.

Ramax S, Stainless holder steel, Uddeholm

RAP, Heat shrinkable BOPP films, QPF, LLC.

Raven 430 Ultra, General purpose carbon black, Columbian Chemicals Co.

Raven 1190 Ultra, Carbon black for fiber applications, Columbian Chemicals Co.

Raven 2000, High mass-tone color carbon black, Columbian Chemicals Co.

Raven 2500 Ultra, High mass-tone color carbon black, Columbian Chemicals, Co.

Raven C Ultra, arbon black for weatherability, Columbian Chemicals Co.

Reactint, Reactive polymeric colorants, Milliken Chemical Co.

Recite, Window films, Dow Plastics

Recotech 2300 Series, Silicone rubber compound, Silicone Products & Technology Inc.

Recyclostab, Stabilizer package for recycling, Ciba Specialty Chemicals Corp., Additives Div.

Redimix, Custom powder blends, Harwick Chemical Manufacturing Corp.

REED, Injection molding machines, Package Machinery Co.

Reed Lite, Heavy-metal free-standard concentrates, Clariant, ReedSpectrum

Reemay, Synthetic surfacing veil, Precision Fabrics Group, Inc.

Reflexal, Pasted aluminum pigments, Eckart America

Regal, Pelletized and fluffy furnace carbon black, Cabot Corp., Special Blacks Div.

Regalrez, Hydrogenated hydrocarbon resins, Hercules Inc.

Regaltech, Medical grade sheeting and film (PVC and PP), O'Sullivan Corp.

Regulus, Thermoplastic polyimide film, Mitsui Chemicals America, Inc.

Relaymaster, Relays, Master Electronic Controls

Release & Paint, Paintable mold release agent, Stoner Inc.

Remafin, color concentrates for polyolefines, Clariant Corp., Masterbatches Div.

Remanit, Stainles steel products, Thyssen Specialty Steels, Inc.

Renaissance, Recyclable vinyl sheets, O'Sullivan Corp.

Reno-Vel, Sueded expanded vinyl, American Renolit

Renol, Color concentrates for nonpolyolefines, Clariant Corp., Masterbatches Div.

Renoprop, Nonoriented polypropylene film, American Renolit

Reny, Nylon-MXD6 compound, Mitsubishi Gash Chemical America, Inc.

Reoflam, Brominated phosphate ester, FMC Corp., Process Additives Div.

Reofos, Isopropylated triaryl phosphate ester, FMC Corp., Process Additives Div.

Reolosil, Fumed silica, Royal, H. M., Inc.

Repaltainer, Blow-molded bottle inside cage, Hoover Materials Handling Group, Inc.

Replay, Postconsumer recycled polystyrene, Huntsman Corp., Headquarters

Reprean, Recycled thermoplastics, Discas, Inc.

Resbond, High-temperature adhesive, Cotronics

Resi-Lam, Resins for plastic and electrical laminating, Georgia-Pacific Resins, Inc.

Resi-Set, Phenolic resins for industrial applications, Georgia-Pacific Resins, Inc.

Resilifoam, Flexible polyurethanes, Plastomer

Resimene, Melamine resins, Solutia Inc.

Resin Release N, Release compounds, Specialty Products Co.

Resinite, Flexible PVC food packaging films, Borden Packaging, Div. AEP Industries

Resipol, Polyester molding compound, Raschig Corp.

Resist, Gold-bronze pigments, Eckart America

Resiten, Industrial laminates, Iten Industries

Resiweld, Epoxy adhesive, Fiber Resin Corp., Subs. of H. B. Fuller Co.

Resoflex, Polymeric plasticizers for health-sensitive applications, Cambridge Industries of America Inc.

ResTech Systems, Custom potting and encapsulating systems, Fel-Pro Chemical Products L.P.

Resyn, Polyvinyl acetate, National Starch and Chemical Co.

Retain, ABS, PC/ABS, PCR content resins, Dow Plastics

Retix, Thermally reticulated foams, General Foam Corp.

Retractable Melt, Thermocouple, Noral, Inc.

Rexflex, Flexible polyolefin, Huntsman Corp., Headquarters

Rexolite, Cross-linked polystyrene, C-Lec Plastics

Rextac, Amorphous polypropylene, Huntsman Corp., Headquarters

Reylease, Mold release, Taurus Industries, Inc.

Rez-O-Sperse, Water-dispersed chloroparaffins, Dover Chemical Corp., Subs. ICC Industries, Inc.

Rheolub, Paraffin and hydrocarbon lubricants, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Rheolub 710, Complex ester lubricant, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Rheolub 1800, Calcium stearate/fatty acid ester system, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Rhodafac, Phosphate ester antistats, Rhodia

Rhodotron, Electron accelerators, IBA SA

Ricacryl, Acrylated polybutadiene, Ricon Resins, Inc.

Ricobond, Maleinized polybutadiene, Ricon Resins, Inc.

RICS, Impregnated, chopped glass strand, NGF Canada Ltd.

Rigidite, Advanced composite, Cytec Fiberite Inc.

Rilsan, Nylon-11 and -12 resins, Elf Atochem North America, Inc.

Rimbond, In-mold coatings for RIM, RRIM, SRIM, and foam, Lilly Industries, Inc.

RimCell Series, Reaction injection molding machine, Gusmer-Admiral, Inc.

RIMline, Polyurethane RIM systems, ICI Polyurethanes Group

Rimpact, Polyurethane elastomer, Foam Molders & Specialties

Rins, Prevents static on plastic-coated photographic films, Merix Chemical Co.

Riteflex, Copolyester elastomer, Ticona

RO99, Direct roving, Vetrotex CertainTeed Corp.

RO-20, Antistatic chemical concentrate, Rogers Anti-Static Chemicals

Robopik, Automated take-out system, Proco Machinery Inc.

Robotarm, Robots, Sterling, Detroit

Robotware, Robot programming software, Husky Injection Molding Systems, Ltd.

Rocket Release, Food-grade mold release agent, Stoner Inc.

Rocklinizer, Electronic tungsten carbide application equipment, Rocklin Manufacturing Co.

Rodyne, Transparant color and opaque films, Coburn Corp.

Rolglide Clutch Bearings, One-way clutch for use in plastic components, Seitz Corp.

Roll-A-Glass, Transparent flexible plastic material in sheet form, O'Sullivan Corp.

RollerMate, Nonstick release tape, Scapa Tapes North America

Rolox, Two-part epoxy compounds, Elements Performance Polymers, Div. Harcros Chemicals, Inc.

Rosite, Thermoset molding compounds, Rostone, Div. of Oneida Rostone Corp.

Rotator, Roller to mix in closed drums, Morse Mfg. Co.

Roto-Grind, Single-rotor shredder, Granutech-Saturn System, Div. MAC Corporation of America

Rotoblend, Colorants for rotational molders, Chroma Corp.

Rotocast, Rotational molding machines, Ferry Industries Inc.

RotoFlame, Flame-retardant polyethylene for rotational molding, Rototron Corp.

Rotoflex, Powder slush molding compound, CONDEA Vista Co.

Rotoform, Rotoform 3000, Solidification unit of molten products, Sandvik Process Systems, Inc.

Rotolite, One-shot rotomolding foam, WedTech Inc.

Rotospeed, Rotational molding machines, Ferry Industries Inc.

Rotothene, Polyethylene resins for rotational molding, Rototron Corp.

Rotothon, Polypropylene resins for rotational molding, Rototron Corp.

Rototuf, Rotomolding compounds, WedTech Inc.

Rovcloth, Woven glass roving, Fiber Glass Industries

Rovmat, Chopped glass mat, Fiber Glass Industries

Rowlux, Illusion film, Rowland Technologies, Inc.

Royalex, ABS foam core sheet, Royalite Thermoplastics Div., Uniroyal Technology Corp.

Royalstat, Static control sheet, Royalite Thermoplastics Div., Uniroyal Technology Corp.

Royaltuf, Impact modifiers, Uniroyal Chemical Co.

RR5Hot, Release for thermoset molding, Releasomers, Inc.

Rubiflex, Polyurethane flex foam systems, ICI Polyurethanes Group

Rubinate, MDI isocyanate, ICI Polyurethanes Group

Rubinol, Polyols, ICI Polyurethanes Group

Ruco, Printing ink, Comdec, Inc.

Rucoflex, Polyester polyols, Ruco Polymer Corp.

Rucoplex, Polyester, Ruco Polymer Corp.

Rucote, Powder coating resins and curatives, Ruco Polymer Corp.

Rucothane, Polyurethane coatings and latexes, Ruco Polymer Corp.

Rudol, White mineral oil, Witco Corp., Performance Chemicals Group

Rufco, High-density reinforced film, Raven Industries Inc., Engineered Films Div.

Rufco Wrap, Reinforced HPDE housewrap, Raven Industries Inc., Engineered Films Div.

Rulon, Proprietary-filled PTFE, Furon Co.

Rx Molding Materials, Thermoset molding compounds, Rogers Corp.

RxLoy, Specialty polyolefin alloys, Ferro Corp., Filled & Reinforced Plastics Div.

Rychiger, Filling and heat sealing, PTI Packaging Technologies & Inspection

Rylex, Crosslinking agent, Ferro Corp., Polymer Additives Div.

Rynite, Thermoplastic polyester resin (PET), DuPont Engineering Polymers

Ryton, Polyphenylene sulfide, Phillips Chemical Co.

S

S-Cutter, Sprue/runner return system, Size Reduction Specialists Corp.

S-Cutter, Sprue/runner return system, FBE Corp.

S-Maz, Sorbitan esters, BASF Corp.

S-Series Coatings, Silicone hard coatings, Exxene Corp.

S-2 Armor Systems, Ballistic armor systems, Owens Corning

S-2 Glass, High-performance glass fibers, Owens Corning

S-Wax 1, 2, 3, 4, 5, Combination calcium stearate/paraffin wax, Cardinal Companies

Sachtolen, White pigment concentrates, Sachtleben Corp.

Sachtolith, White pigment, flame retardant syngergist, Sachtleben Corp.

Safe-FR, Nonhalogenated FR polyolefins, UVTEC, Inc.

Safe-Glo, Phosphorescent films, Coburn Corp.

Safe-T-Vue, Acrylic and styrene glazing, ICI Acrylics Inc.

SafeCide, Antimicrobial powder, Sangi America, Inc.

Saflex, Polyvinyl butyral film, Solutia Inc.

Safoam, Endothermic nucleating and foaming agent, Reedy International Corp.

Sag, Silicone antifoams, Witco Corp., OrganoSilicones

Samson Extra Steel, Plastic mold steel with easy hobbing, Carpenter Technology Corp.

Sancure, Water-borne urethane, BFGoodrich Specialty Chemicals

Sandofil, Pigments and dyes, Clariant Corp., BU Additives

Sandoflam, Flame retardants, PP/acrylics/polyester, Clariant Corp., BU Additives

Sandoplast, Polymer soluble dyes, Clariant Corp., BU Additives

Sandorin, High-performance organic pigments, Clariant Corp., BU Additives

Sandostab, Nucleating agents, Clariant Corp., BU Additives

Sandostab PEPQ, Phosphonite processing stabilizer, Clariant Corp., BU Additives

Sandozin, Pigment/dye dispersants, Clariant Corp., BU Additives

Sanduvor, UV absorbers/HALS, Clariant Corp., BU Additives

Saniseal, Bacteriocide, fungicide for plastics, Sanitized Inc.

Sanres, Solvent-borne urethane, BFGoodrich Specialty Chemicals

Santicizer, Plasticizers, Solutia Inc.

Santoflam, Antimony oxide, Charlotte Chemical Inc./CCI

Santoflex, Epoxidized soybean oil, Charlotte Chemical Inc./CCI

Santonox, Antioxidant, Flexsys America LP

Santoprene, Polypropylene EPDM-based vulcanizate, Advanced Elastomer Systems LP

Santowhite, Antioxidant, Flexsys America LP

Saran, Barrier resins, Dow Plastics

Saran Films, Plastic films, Dow Plastics

Saranex, Coextruded film, Dow Plastics

Saret, Crosslinking agents, Sartomer Co. Inc.

Sarlink, Dynamically vulcanized thermoplastic elastomers, DSM Thermoplastic Elastomers Inc.

SatinGlass, SMC roving, Vetrotex CertainTeed Corp.

Satintone, Anhydrous aluminum silicate, calcined kaolin, Engelhard Corp.

Saturn Air Ring Technology, Cooling rings, blown film foam, Future Design Inc.

Saytex, Flame retardants, Albemarle Corp.

Scan-Master, Temperature controller, Mold-Masters

ScanIR, Line scanner thermal imager, Ircon, Inc.

Schulaflex, Flexible elastomers, Schulman, A., Inc.

Schulamid, Nylon alloys and compounds, Schulman, A., Inc.

Schulink, Crosslinkable polyethylene rotational molding compound, Schulman, A., Inc.

SCLAIR, Polyethylene resins, NOVA Chemicals Ltd.

Sclairfilm, Cast film and sheet (PE); blown film, DuPont

Scoremaster, Total machine control for injection molding, Solid Controls, Inc.

Scrapper, Recycle/reclaim extruder, Davis-Standard Corp., A Crompton & Knowles Co.

Scutter, Sprue runner grinder, Nissui Corp.

SDS Screw, Extruder screw, Scientific Process & Research Inc.

Sea Thru Blue, Lay-flat backwash hose, Action Technology Co.

Seacast, Cast transom, Seawolf Industries, Inc.

Seacore, Sprayable lightweight core, Seawolf Industries, Inc.

Sealam, Low-roll, high-impact laminate, Seawolf Industries, Inc.

Sealbrite, Non-VOC mold sealer for glossy surfaces, Zyvax, Inc.

Sealed Air Cellu-Plank, Extruded foam plank, Sealed Air Corp.

Sealed Air Stratocell, Laminated plank foam, Sealed Air Corp.

Sealer GP, Surface sealer, Zyvax, Inc.

Sealproof, Water-based mold sealer, non-VOC, Zyvax, Inc.

SealScience, Adhesive coating technology, Tolas Health Care Packaging corp.

SealWeld, Silos, A. O. smith Engineered Storage Products Co.

SeamMaster Series, Cuts/seals thin plastic films, Sonobond Ultrasonics, Inc.

Seaskin, Fast, no-roll, skin coat, Seawolf Industries, Inc.

Seaspray, Sprayable wood replacement, Seawolf Industries, Inc.

Semitron, Electrostatic dissipative, DSM Engineering Plastic Products, Inc.

Sensitech, Odor counteractant with fragrance compound, Aroma Tech

Sequel, Engineered polyolefins, Solvay Engineered Polymers

Serfene, PVdC barrier coatings, Morton International Inc.

Shape Memory Polymer, Thermoplastic polyurethane elastomer, Mitsubishi Heavy ndustries America

Sheetmaster, Material dispenser, Rosenthal Mfg. Co.

Sheetrol, Total control of sheet extrusion, Harrel

Shelblast, Soft grit deflashing media, Agrashell, Inc.

Shinite, PBT resin, Calsak Corp.

Shirt-Pocket, Compact programmable controller, Aromat Corp., Subs. of Matsushita Electric Works

Shurfeed, Cutting chamber design, Polymer Systems, Inc.

Si-Link, Low-voltage wire and cable insulation compounds, Union Carbide Corp.

Sicopal, Pigments (mixed metal oxides), BASF Corp., Coatings & Colorants Div.

Sicotan, Pigments (titanates), BASF Corp., Coatings & Colorants Div.

Sicotrans, Transparent iron oxides, BASF Corp., Coatings & Colorants Div.

Sign-Ad, White flex vinyl with adhesive, Catalina Plastics & Coating Corp.

Sil-Co-Sil, Ground silica, U.S. Silica Co.

Silaprene, Adhesives and sealants, Uniroyal Adhesives & Sealants, Div. of UTC

Silastic, Silicone rubber, Dow Corning Corp.

Silcat, Modified vinyl functional silanes, Witco Corp., OrganoSilicones

Silcroma, Black high-purity iron flake, Silberline Mfg. Co., Inc.

Silcron, Micronized amorphous silica gel, Millennium Specialty Chemicals, Colors and Silica

Silenator, Soundproof enclosure for granulators, Polymer Systems, Inc.

Silentex, Muffler filling system, Owens Corning

Silicone Systems, One-component silicones, Insulcast

Siliquarzite, Glass grinding beads, Draiswerke

Sillum, Mineral fillers; thixotropic thickener, D. J. Enterprises, Inc.

Silo, Synthetic iron oxide pigments, Mineral Pigments

Silplus, Silicone rubber system, GE Silicones

Silquest, Organofunctional silanes, Witco Corp., OrganoSilicones

Siltemp, High-temperature textile, Ametek, Inc., Chemical Products Div.

Siltherm, Silicone-modified polyester, Industrial Dielectrics Inc.

Silver Bond, Ground silica, Unimin Specialty Minerals

Silver Bullet, Filterless vacuum receivers, Motan Inc.

Silvet, Resin-based aluminum pigment, Silberline Mfg. Co., Inc.

Silvex, Plasticizer damp aluminum pigment, Silberline Mfg. Co., Inc.

Silvue, Abrasion-resistant coatings, SDC Coatings

Silwet, Surface active copolymers, Witco Corp., OrganoSilicones

Simichrome Polish, Mold cleaning compound, Competition Chemicals

Simpol, Molding simulation and flow analysis, part quoting, Injection Molding Industries

Sintimid, Polyimides, Ensinger, Inc.

Sintra, PVC sheet, Alusuisse Composites, Inc.

Sintrex, Polystyrene foam-centered board, Alusuisse Composites, Inc.

Sioplas, Crosslinking technology, Dow Corning Corp.

Sipernat, Precipitated silica, Degussa Corp.

Siveras, Liquid crystal polyester resin, Toray Marketing & Sales (America), Inc.

Skid, External lubricant, Stoner Inc.

Skin-Coat, Bonded glass mat and various veils, Fiber Glass Industries, Inc.

SL-25, Lubricant/stabilizer system, Cardinal Companies

Slic-Tite, Pipe thread sealant, La-Co Industries, Inc.

Slip-Ayd, Polyethylenes and polymeric waxes, Elementis Specialties Colorants & Additives Business

Slip-Eze, Oleamide, slip, mold releae agent, Ferro Corp., Polymer Additives Div.

Smart Box 1000, Injection molding data acquisition, Hunkar Laboratories, Inc.

Smart Box 2000, Blow molding control, Hunkar Laboratories, Inc.

Smart Elbow, Elbow for carefree conveying, HammerTek Corp.

Smart-Pak Systems, Lubricant systems for PVC, AlliedSignal Inc., AlliedSignal Specialty Chemicals

Smartflow, Water manifolds and flowmeters, Burger Engineering Inc.

Smikasuper, Liquid crystal polymers, Calsak Corp.

Smokebloc, Smoke suppressants, Great Lakes Chemical Corp.

Smokeguard, Low-smoke, low-flame vinyl and olefin alloys, AlphaGary Corp.

Smooth-Cast 300, Liquid plastic, Smooth-On, Inc.

Smooth-Sil 912, Liquid rubber, Smooth-On, Inc.

Sniamid, Nylon-6 resins and compounds, Nyltech NA

Snow*Tex, Calcined kaolin, U.S. Silica Co.

Snow White Filler, Anhydrous calcium sulfate, United States Gypsum Co.

Snowflake P. E., Calcium carbonate, ECC International

S'Office, Flexible vinyl sheets, O'Sullivan Corp.

Soft-Aire, Tension control brakes-clutches, P/A Industries Inc., Web Processing Equipment Div.

Soft Feel, Leatherlike coating, Red Spot Paint & Varnish Co.

Soft-Tech, Composite for soft-part fabrication, Futura Coatings, Inc.

Softbelly, Dual-durometer silicone rubber compound, Silicone Products & Technology Inc.

Softdex, Soft-feel coatings, Dexter Automotive & Specialty Coatings

Softflex, Thermoplastic elastomer alloys, Network Polymers, Inc.

Softline, Nozzles, hot runner systems, Unitemp

SoftStrand, Optic-cable reinforcement, Owens Corning

Solacryl, Cast acrylic sheet, Polycast Technology

Solef, Polyvinylidene fluoride, Solvay Polymers, Inc.

Solex, Cleaning powders, Neutrex, Inc.

SolidView, View 3D design data, Solid Concepts Inc.

Solimide Polyimide Foam, Lightweight insulating foam, Inspec Foams Inc.

Solka-Floc, Powdered cellulose, Fiber Sales & Dev. Corp.

Solubond, Polyurethane adhesives, Soluol Chemical Co. Inc.

Solucote, Polyurethane resins, Soluol Chemical Co. Inc.

Solvaperm, Polymer soluble dyes, Clariant Corp., BU Additives

Sonatorq, Ultrasonic tension controls, P/A Industries Inc., Web Processing Equipment Div.

Sonite, Epoxy resin compound, Smooth-On, Inc.

Source CIM, Computer integrated manufacturing, Hunkar Laboratories, Inc.

Sparkle-Brite, Glitter films, Coburn Corp.

Sparkle Silvet, Resin-based aluminum pigment, Silberline Mfg. Co., Inc.

Sparkle Silvex, Plasticizer damp aluminum pigment, Silberline Mfg. Co., Inc.

Sparklon, Gloss coatings, Morton International Inc.

Specflex, Polyurethane components, Dow Chemical

Specline, Polymer compounds and alloys, Polymart Inc.

Spectar, Copolyester thermoplastics, Eastman Chemical Co.

Spectra, Humidity sensor for resin dryer, General Eastern Instruments

Spectraflash SF300, SF600 Plus, Spectrophotometer, Datacolor International

Spectraflo, Liquid colors (thermoplastics); chemical blowing agents, Ferro Corp.

Spectralight II, Color-matching booth, GretagMacbeth

Spectrapurge, Liquid purging compound, Ferro Corp.

Spectratech, Color and additive concentrates, Equistar Chemicals

Spectrim, Reaction moldable products, Dow Plastics

Spectrum, Polyolefin sheet, Royalite Thermoplastics Div., Uniroyal Technology Corp.

Specular, Special-effects colorants, Mica-Tek Div. of Miller and Co.

Speed-Flow, Portable-inclined conveyor, Bilt-Rite Conveyors Inc.

SpeedBonder, Anaerobic structural adhesive, Loctite Corp., North American Group

Speedryer, Thermodynamic hopper dryer, Webb Technologies Ltd.

SpeedSert, High pull-out insert, Groov-Pin Corp.

Sphere-Shot, Spherical polystyrene beads for deflashing, Maxi-Blast, Inc.

Sphericel, Hollow glass spheres, Potters Industries Inc.

Spheriglass, Solid glass spheres, Potters Industries Inc.

Spherilene, Clarity LLDPE, Montell North America

Spheripol, Process for producing polypropylene, Montell North America

Spinner, Locking ring valve, Zeiger Industries

Spiral Mixer, Motionless static mixer, TAH Industries, Inc.

Spiralock, Vacuum hose and ducting, Plastiflex

Spiratube, Spirally cut tubing, Hudson Extrusions, Inc.

SpotIR, Electric infrared spot heater, Research Inc.

SPR Friction Tester, Instrument for measuring polymer friction, Scientific Process & Research Inc.

Spray Graph, Graphite lubricant, American Resin Corp.

Spraymaster, Solvent-borne contact adhesives, National Starch and Chemical Co.

Sprayset, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group

Spraywelder, Hard-surfacing application system, Wall Colmonoy Corp.

Sprincol, Textured colorants, FM Group

Spring Lock, Plastic anchor, Southco, Inc.

SQMS, Quality management training/assistance, TopWave International, Inc.

Squaremaster, Interchangeable mold bases, Sinitron

SR-2420, Extrusion high abrasion-resistant barrels, New Castle Industries, Inc.

SRC, Abrasion-resistant, UV curable coatings, Red Spot Paint & Varnish Co.

ST Series, Antifogging agents, photocatalyst, Ishihara Corp. (U.S.A)

Stabilite, Antioxidant, Arizona Chemical

Stabilux, Ultra-high-molecular-weight PBT, Westlake Plastics Co.

Stabiol, Heat stabilizer, Henkel Corp.

Staflex, Monomeric and polymeric plasticizers, hall, C. P., Co.

Stanclere, Organotin stabilizers and urethane catalysts, Akzo Nobel Chemicals Inc.

Stanuloy, PET/PC blend, MRC Polymers Inc.

Stanyl, Nylon 4/6, DSM Engineering Plastics

Stapron C, ABS/PC blends, DSM Engineering Plastics

Stapron N, ABS/PA blends, DSM Engineering Plastics

Stapron S, Modified SMA, DSM Engineering Plastics

Star Disperser, Dispersing equipment, Draiswerke

StarMark, Laser marking systems, A-B Lasers, Inc.

StarRov, Fiberglass roving, Johns Manville

StarStran, Fiberglass chopped strand, Johns Manville

Starweld, Plasma-transferred arc welding equipment, Stellite Coatings

Stat-Kon, Fortified static-conductive thermoplastics, LNP Engineering Plastics Inc.

Stat-Loy, Antistatic compounds, LNP Engineering Plastics Inc.

Stat-Rite, Static-dissipative alloys, BFGoodrich

Stata-Tube Mixer, Static/motionless mixing, TAH Industries, Inc.

Statexan K1, Antistats, Bayer Corp., Fibers, Additives & Rubber Div.

Statiblend, Statically conductive injection moldable compounds, TP Composites, Inc.

StatiCon Glazing, Static dissipative rigid plastic, SC Technologies LLC

Statik-Block, Industrial antistat, Amstat Industries, Inc.

Stavax ESR, Stainless mold steel, Uddeholm

Stearates, Metallic stearates, Witco Corp., Polymer Chemicals Group

Stellar (Series), Talc, Luzenac America

Stepanpol, Polyester and polyether polyols, Stepan Co., Urethane Dept.

Stereon, Styrenic block polymers, Firestone Synthetic Rubber & Latex Co.

Sterling, Furnace carbon black, Cabot Corp., Special Blacks Div.

Sternpulse, Jet pulse cartridge dust collector, Sternvent Co., Inc.

Steward Barrier Screws, High-performance barrier screws, American Kuhne Inc.

Stitchmat, Combination woven roving and mat, Vetrotex CertainTeed Corp.

Strandfoam, Plastics foam, Dow Plastics

Stratoclad, Glass-reinforced phenolic, Spaulding Composites Co.

Stress Vectured Composites, Fiber-reinforced shapes, Polygon Co.

StripIR, Electric infrared strip heater, Research Inc.

Stycast, One- and two-component encapsulants, Emerson & Cuming Specialty Polymers, Div. of National Starch

Styraclear, Polystyrene, Westlake Plastics Co.

Styresol, Styrenated resins, Reichhold

Styrex, Styrene films, Piedmont Plastics

Styrid, Styrene suppressant additive, Specialty Products Co.

Styrofoam, Insulation, extruded polystyrene board, sheet, Dow Plastics

Styrolux, SBS block copolymer, BASF Corp., Polystyrene Business Group

Styron, Polystyrene resins, Dow Plastics

Styropor, Polystyrene expandable beads, BASF Corp., Plastic Foams

Styrothane, Coating for rigid EPS foam, Futura Coatings, Inc.

Styrovap, Monomer evaporation retardants, Kyros

Sudan, Dyes, BASF Corp., Coatings & Colorants Div.

Sufex, Glass/carbon or aramid fiber/PPS pultruded shapes, Thermoplastic Pultrusions, Inc.

Sullvac, Blend of PVC/ABS for fabrication by thermoforming, O'Sullivan Corp.

Sumipex, PMMA resin, Calsak Corp.

Sumiplast, Pigments, GCA Chemical Corp.

Sun, Mold temperature controller, Nissui Corp.

Sun-Gard, PVC sun control film, Continental Plastic Co., Div. CPI, Inc.

Sundowner, Spiral wound corrugated hose, Action Technology Co.

Sunfrost, Controlled low-gloss PVC compounds, Schulman, A., Inc.

SunPreg, Light cure prepregs and patches, Sunrez Corp.

Sunprene, PVC thermoplastic elastomers, Schulman, A., Inc.

Sunshield, Coextruded pool vacuum hose, Action Technology Co.

Supec, PPS-based engineering resin, GE Plastics

Super Dryer, Plastic resin dryer, Cactus Machinery

Super-Fil, Coated product, Specialty Minerals Inc.

Super Floss, White flux-calcined diatomite, antiblock additive, Celite Corp., c/o World Minerals Inc.

Super Loader, Pneumatic resin loader, Cactus Machinery

Super-Pflex, Treated submicron PCC, Specialty Minerals Inc.

Super Samson Alloy, Plastic mold steel with high-mechanical properties, Carpenter Technology Corp.

SuperBonder, Instant adhesives, Loctite Corp., North American Group

Superbridge, Communication interface, Merrick Industries, Inc.

Superbulk, Wire and cable filler yarn, Ensign-Bickford Industries Inc., Film Fibers Div.

Supercarb, Injection high abrasion-resistant barrels, New Castle Industries, Inc.

Supercarb Barrel, High-carbide, wear-resistant bimetallic liner for injection molding, Bimex Industries, Subs. of New Castle Industries

Superclean, Crosslinkable insulation compounds, NOVA-BOREALIS compounds LLC

Supercoat, Calcium carbonate, ECC International

SuperFast, Nitrile, Reichhold

Superflex, Silicone adhesive/sealants, Loctite Corp., North American Group

Superflow Chopper, Flow-coat chopper unit, GS Manufacturing

SuperGrip 2000, Urethane adhesive, Bostik

SuperKleen, DEHP-free flexible PVC, AlphaGary Corp.

Superlink, Crosslink polyethylene, WedTech Inc.

Supermite, Calcium carbonate, ECC International

SuperNova, Chemical purging compound, Novachem

SuperNova-CX, Chemical purging compound for clear PC and acrylic, Novachem

SuperNova-HT, Chemical purging compound for resins, Novachem

SuperNova XB, Chemical purging compound for blow molders, Novachem

Superohm, EPR cable insulation compositions, Schulman, A., Inc.

Superox, Peroxide catalyst, Reichhold

SuperQuench, High-performance spray cooling tanks, ESI Extrusion Services, Inc.

Supersil, Silicone rubber formulation, United Silicone Inc., An Illinois Tool Works Co.

Supersmooth, Crosslinkable semi-conductive compounds, NOVA-BOREALIS Compounds LLC

SuperTak, Aerosol adhesive, Bostik

Superthane, Polyurethane tubing, NewAge Industries Inc., Plastics Technology Group

Supralate, Sodium alcohol suprate, Witco Corp., Performance Chemicals Group

Suprel, Engineered thermoplastic polymer, CONDEA Vista Co.

Sur-Cut, Guillotine knife assemblies, AZCO Corp.

Sur-Flex, Ionomer film, Flex-O-Glass, Inc.

Sur-Size, Cut-to-length assemblies, AZCO Corp.

Sureglaze, Polyurethane; polysulfide, Surebond, Inc.

SureWeld Series, Ultrasonically bonds plastic parts, Sonobond Ultrasonics, Inc.

Surface Cleaner, High-performance cleaner, Zyvax, Inc.

Surlyn, Ionomer resins, DuPont

Surmat, Continuous filament surfacing mat, Nicofibers

Sutorbilt, Blower, Gardner Denver Machinery Inc.

Suzorex Mica, Treated mica, Zemex Industrial Minerals, Inc.

Suzorite Mica, Mica, Zemex Industrial Minerals, Inc.

Switchmaster, Switches, Master Electronic Controls

SwOptions, Plastics price protection programs, Koch Chemical International

SX-Flex, Online empty container tester, Air Logic Power Systems, Inc.

Sylfat, Emulsifiers, lubricant additives, Arizona Chemical

Sylobloc, Micronized silica, Grace Davison, W. R. Grace & Co.

Syloff, Release agents, Dow Corning Corp.

Syloid, Micronized silica, Grace Davison, W. R. Grace & Co.

Syltherm, Heat transfer fluids, Dow Chemical Co., Polyglycols

Sylvares, Terpene-phenolic resins, Arizona Chemical

Sylvatac, Rosin ester resins, tackifiers, Arizona Chemical

Synchroblend, Synchronous digital disc blender, Colortronic, Inc.

SynCore, Syntactic film core, Dexter Adhesive & Coating Systems (CA)

Synergy, High-performance molding machine, Netstal Machinery Inc.

Synergy, Statistical process control software, Zontec

Synpro, Metallic stearates, Ferro Corp., Polymer Additives Div.

Synpron, PVC heat stabilizer, Ferro Corp., Polymer Additives Div.

SynSkin, Composite surfacing film, Dexter Adhesive & Coating Systems (CA)

SynSpand, Expandable syntactic core, Dexter Adhesive & Coating Systems (CA)

Synthemul, Nitrile, Reichhold

Syntron, Parts feeders, FMC Corp., Material Handling Equipment

System Leader, Leader pin and bushings, Choice Mold Components, Inc.

T

T-Maz, Ethoxylated sorbitan esters, BASF Corp.

T-Rim, Reinforced rigid urethane, Tempress, Inc.

T-Skin, Integral-skin urethane, Tempress, Inc.

Tabcoat, Siloxane polyimide encapsulants and coatings, Ablestik Laboratories

Taktene, Polybutadiene impact modifer, Bayer Corp., Fibers, Additives & Rubber Div.

Tamsil, Micronized microcrystalline silica, Unimin Specialty Minerals Inc.

Tandem, Two-station injection molding machines, Husky Injection Molding Systems Ltd.

Tap-Lok, High pull-out insert for thermosets, Groov-Pin Corp.

Taskmaster Shredder, Plastics and solid waste shredder, Franklin Miller Inc., Delumper Mixer Div.

TC Probe, Nondestructive thermal properties testing instrument, Mathis Instruments Ltd.

Techfil 7599, Talc, Luzenac America

Techmates, Stock color concentrates, Color Technology, Inc.

TechniMet, Metallized polyester, Scharr Industries

Technyl, Nylon-6/6 resins and compounds, Nyltech NA Co., Inc.

Techseal, Blended polyolefin films, Industrial Coatings Group, Inc.

Techtron, Polyphenylene sulfide (PPS), DSM Engineering Plastic Products, Inc.

Tecoflex, Alphatic polyurethane, Thermedics Inc.

Tecothane, Aromatic polyurethane, Thermedics Inc.

TEDA, Urethane catalysts, triethylenediamine, Tosoh USA Inc.

Tedlar, Polyvinyl fluoride products, DuPont

Tedlar SP, Polyvinyl fluoride cast film, DuPont

Teflon, FEP, TFE, and PFA fluoroplastic resins and films, DuPont

Tefzel, Fluoropolymer resin and film, DuPont

TegMeR, Monomeric plasticizers, Hall, C. P., Co.

Tekron, Styrenic TPEs, Teknor Apex International

Tekspeks, Granite/speck color concentrates, Teknor Color Co.

Telalloy, ABS resin, Kaneka Texas Corp.

Telcar, Olefin elastomers, Teknor Apex International

Telene, Liquid engineering resin systems, BFGoodrich Specialty Chemicals

Telesensor, Free-loop speed controller, Progressive Machine Co.

Temp-Master, Temperature controller, Mold-Masters

Temp-Plate, Temperature recording labels, Wahl Instruments Inc.

Temp-R-Glass, PTFE-coated glass fiber, CHR Div. of Furon Co.

Temp-R-Tape, Pressure-sensitive adhesive tape, CHR Div. of Furon Co.

Tempalloy, High-temperature materials, ComAlloy International Co.

Tempalux, Polyetherimide shapes, Westlake Plastics

Temposonics, Position sensors, MTS Systems Corp., Sensors Div.

TempRite, Chlorinated PVC, BFGoodrich Specialty Chemicals

TempShield, Reflective foil bubble insulation, Sealed Air Corp.

Tenite, Cellulosic molding and extrusion compounds, Eastman Chemical Co.

Tenox, Antioxidants, Eastman Chemical Co.

Terasod, Ester-imide resins, George, P. D.

Tergitol, Surface-active agents, Union Carbide Corp.

Terluran, ABS, BASF Corp., Plastic Materials

Terlux, Clear ABS resin, BASF Corp., Plastic Materials

Terrathan, E-glass/PP pultruded shapes, Thermoplastic Pultrusions, Inc.

Tetrabond, Amorphous diamond coating for molds, Multi-Arc Inc.

Teubert, Shape molding machines, Foam Equipment & Consulting Co.

Texadril, Surfactant, Henkel Corp.

Texalon, Nylon resins, M. A. Hanna Engineered Materials, Texapol Products

Texapol, Engineering resins, M. A. Hanna Engineered Materials

Texapon, Surfactant, Henkel Corp.

Texchem, Calcium carbonate extender/filler, Franklin Industrial Minerals

Texin, Thermoplastic urethane elastomers, Bayer Corp., Polymers Div.

Texliner, Surfacing, Nalle Plastics, Inc.

Texo, Textured glass fiber strand and yarn, PPG Industries, Inc., Fiber Glass

Texstrand, Glass strand air jet texturized, Fiber Glass Industries, Inc.

Texweave, Woven texturized roving, Fiber Glass Industries, Inc.

Therm-Chek, Heat and light stabilizers for PVC, Ferro Corp., Polymer Additives Div.

Therma Sleeve, Insulation for dryer hose, Unitherm

Thermal Pin, Heat conductors, Noren Products Inc.

Thermalate, Mold and platen thermal insulation, Haysite Reinforced Plastics

Thermalert, Infrared temperature sensors, Raytek Corp.

Thermalux, Polysulfone, Westlake Plastics

Thermark, Decorative finish for plastic, Avery Dennison Corp.

Thermatech 4300 Series, Silicone rubber compound, Silicone Products & Technology Inc.

Thermatic, Extruder, Davis-Standard Corp., A Crompton & Knowles Co.

Thermax, Medium thermal carbon black, Cancarb

Thermcon, Acetylene-based organic conductive resin, National Starch and Chemical Co.

Thermelec, Electrical and dielectric coatings, Ranbar Technology Inc.

Thermex, Thermal indicating material, Sensor Products

Thermex-1, Heat-dissipation materials, ComAlloy International Co.

Thermid, Polyimide, thermoset, National Starch and Chemical Co.

Thermo-Purge, Clear cast acrylic reground for purging, AFCO Products Inc.

Thermobrite, Cadmium pigments, Engelhard Corp.

Thermocomp, Thermoplastics fortified with predispersed glass fibers, LNP Engineering Plastics Inc.

Thermofilm, Heat-reactive adhesive in film form, Scapa Tapes North America

Thermoflite, Heavy-duty extruder, Entwistle Co.

Thermofoam, Foam concentrates for rigid plastics, Thermofil, Inc.

Thermogrip, Hot melt adhesives, Bostik

Thermoguard, Antimony flame retardants, Laurel Industries, Inc.

Thermold, Hot-melt mold material, RCV Industries

Thermolite, Stabilizers, Elf Atochem North America

Thermolube, Processing aids, Thermofil, Inc.

Thermoplast, Dyes, BASF Corp., Coatings & Colorants Div.

Thermorex, Gear pump for prepolymers and high-viscosity polymer melts, Maag Pump Systems Textron

Thermosil, High-temperature, quick-heat recovery formulation, United Silicone Inc., An Illinois Tool Works

Thermotuf, Super-toughened nylon composites, LNP Engineering Plastics Inc.

Thermx, Copolyester, Eastman Chemical Co.

Thinline, Belling small-diameter pipe, United Plastics Machinery Inc.

Thinswitch, Mold limit switch, Burger Engineering Inc.

"Thompson" Strainer, Cooling water filter/strainer, Miller-Leaman, Inc.

ThoroBlender, Double cone and V blenders, Patterson Process Equipment Div.

3D QuickFill, Desktop molding simulation; solids-based, C-MOLD

Thyrapid, High-speed steel (conventional), Thyssen Specialty Steels, Inc.

Thyrapid P, High-speed steel (powder-metallurgically manufactured), Thyssen Specialty Steels, Inc.

Thyrodur, Cold work tool steel, Thyssen Specialty Steels, Inc.

Thyroplast, Plastic mold steel, Thyssen Specialty Steels, Inc.

Thyrotherm, Hot work die steel, Thyssen Specialty Steels, Inc.

Ti Gold, Titanium nitride wear-resistant coatings, Ulvac Technologies, Inc.

Ti-Pure, Titanium dioxide rutile pigments, DuPont

Ticomp, Wear-resistant coatings, Tiodize Co. Inc.

Tilt-A-Mix, Laboratory pilot plant processor, Processall Inc.

TimberTech, Wood polymer composite, Crane Plastics, Co.

TimeSaver, Statistical process control software, Zontec

Timesaver Mold Base, Finished pocket mold base, Precision Mold Base Corp.

Timonox, Compounds and concentrates, Great Lakes Chemical Corp.

Tinopal, Fluorescent whitening agents, Ciba Specialty Chemicals Corp., Additives Div.

Tint-Ayd, Stable, free-flowing color concentrates, Elementis Specialties Colorants & Additives Business

Tinuvin, Ultraviolet absorbers; hindered amine light stabilizer, Ciba Specialty Chemicals Corp., Additives Div.

Tiolon, Mold release agents, Tiodize Co. Inc.

Tiolube, Dry film lubricants, Tiodize Co. Inc.

Tiona, Titanium dioxide, Millennium Inorganic Chemicals

Tipaque, Titanium dioxide, ultrafine, antifogging agent, Ishihara Corp. (U.S.A)

TirePlast, Polyolefin and ground tires, B & F Plastics

Titan, Extrusion control system, Processing Technologies Inc.

Titan-2000, Tungsten carbide bimetallic lining, Wisconsin Bimetallic Corp.

Titankote C, Titanium nitride, PVD coating, Richter Precision Inc.

Titankote + C5, Titanium carbonitride, PVD coating, Richter Precision Inc.

Titankote + C6, Chromium carbide, PVD coating, Richter Precision Inc.

Titanox, Titanium dioxide pigments, Kronos, Inc.

TMconcept, Injection molding simulation software system, Plastics & Computer Inc.

TMS, Antimony oxide, Great Lakes Chemical Corp.

Tone, Polycaprolactone polymers, Union Carbide Corp.

Tonen RPP, Polypropylene compounds, TCA Plastics

Tonox, Epoxy curative, Uniroyal Chemical Co., Inc.

Toolcast, Casting resins, American Resin Corp.

Toolmaster, Tooling prepregs and resins, AirTech Advanced Materials Group

ToolMates, Lubricants, cleaners, Aervoe-Pacific Co., Inc.

Topaq, Advanced imaging system, Sensor Products

Topas, Cyclo-olefin copolymers, Ticona

TopLoad Tester, Vertical strength with volume option, TopWave International, Inc.

TopSoft, Software for bottle/preform manufacturing, TopWave International, Inc.

Torayfan, BOPP clear and metallized films, Toray Plastics America Inc.

Torelina, Polyphenylene sulfide film, Toray Marketing & Sales (America), Inc.

Torlon, Polyamide-imide resin, Amoco Polymers

Toronita, Densifiers, Precision Machinery Systems

Touchwood, Printed transfer finishes, Kurz-Hastings

Toughguard Plus, Cast coextruded PE stretch film, Huntsman Packaging Corp., Sales

Tower Klean, Cooling water treatment systems, Innovative Water Technologies, Inc.

Toyocat, Urethane catalysts, Tosoh USA Inc.

Toyoflon, FEP and PFA films, Toray Marketing & Sales (America), Inc.

Toyolac, ABS resin, Toray Marketing & Sales (America), Inc.

TPX, Polymethylpentene, Mitsui Petrochemical Industries Ltd.

Tra-Bond, Epoxy adhesives, Tra-Con, Inc.

Tra-Cast, Casting compounds, Tra-Con, Inc.

Tra-Duct, Conductive adhesives, Tra-Con, Inc.

Tracer, Electronic flowmeter, Burger Engineering Inc.

Trailblazer, Total machine control for injection molding, Solid Controls, Inc.

Transback Belts, Profiled backings, Belt Technologies

Translink, Surface-treated kaolin, Engelhard Corp.

Traversanip, Oscillating haul-off, Battenfeld Gloucester Engineering Co. Inc.

Traytuf, PET resin, Shell Chemicals

TreadPlast, TPR and ground tires, B & F Plastics

Treafilm, Clear PP films, Toray Plastics America Inc.

Treax Film, OPP films, Toray Plastics America Inc.

Trefsin, Low-gas permeability thermoplastic elastomer, Advanced Elastomer Systems LP

Tream, Viscosity depressant, Henkel Corp.

Trenchcoat, Protective films (heavy gauge), Dow Plastics

Trepol, Hydrophilic polyurethane prepolymer, Rynel

Triax, Polyamide/ABS blends, Bayer Corp., Polymers Div.

Tribo/Comp, Self-lubricating composites, Tiodize Co. Inc

Trident Series, Heavy-duty extrusion equipment, Processing Technologies Inc.

Trigger Bond, Adhesives, Epoxies, Etc.

Trigonal, Organic petroxides, Akzo Nobel Chemicals Inc.

Trigonox, Plastics and rubber catalysts, Akzo Nobel Chemicals Inc.

Trimax, Triaxial reinforced broad goods, A & P Technology Inc.

Tritherm, Amide-imide resins, George, P. D.

Triton, Surface-active agents, Union Carbide Corp.

Trivin, High-heat, exterior, rigid PVC alloy, Vi-Chem Corp.

Trogamid-T, Transparent nylon, Creanova Inc.

Tronox, Titanium dioxide pigments, Kerr-McGee Chemical LCC

Tru-Pearl, Specialized pearl, custom extruded sheet, New Hampshire Plastics, Inc.

Tru Profile Gauge, Web measurement online, full web profiling, statistical process control, Adaptive Technologies, Inc.

Trudex, Extrusion gear pump for high pressure (750 bar), Maag Pump Systems Textron

TrueCap, Point level sensors, Monitor Mfg.

Trutint 50, 80, Low-tint antimony oxides, Great Lakes Chemical Corp.

Trycite, Window films, Dow Plastics

TSG Flake, UV-shielded glass flake, NGF Canada Ltd.

Tubetrol, Total control of tubing extrusion, Harrel Inc.

Tuf-Lube, Fluorocarbon release, Specialty Products

Tufcote, Faced acoustical foams, E-A-R Specialty Composites

Tuff Tank II, Rotationally molded bottle inside steel cage, Hoover Materials Handling Group, Inc.

Tuffak, Polycarbonate sheet, AtoHaas Americas Inc.

Tuflin, High-strength LLDPE film resin, Union Carbide Corp.

Tufram, Mold release for aluminum, General Magnaplate

TufRov, Thermoplastic reinforcements, PPG Industries, Inc., Fiber Glass

Turbo-Bar, Insertion turbine flowmeter, EMCO Flowmeters

Turbulent Mixer, Batch/continuous mixing system, Draiswerke

Turbutherm, Turbulent fluid bed dryer, Draiswerke

2 Plex, Laminated acrylic sheets, New Hermes Inc.

Ty-Ply, Elastomeric adhesives, Lord Corp., Chemical Products Div.

Tybrite, Packaging films, Dow Plastics

Tygon, Extruded tubing, Norton Performance Plastics

Tylac, Nitrile, Reichhold

Tymor, Extrudable adhesive resins, Morton International Inc.

Type 30, Single-end glass fiber rovings, Owens Corning

Tyril, SAN resins, Dow Plastics

Tyrin, Chlorinated polyethylene, DuPont Dow Elastomers

Tyrmer, Insulation; polyisocyanurate foam, Dow Plastics

U

U-Max Dryer, Rotary vacuum jacketed dryer, Processall Inc.

UBAC, Bright acid copper process, Enthone-OMI Inc., Subs. Asarco Inc.

Ucar, Solution vinyl resins, Union Carbide Corp.

Ucarlox, Laser-engraved ceramic rolls, Praxair Surface Technologies, Inc.

Udel, Polysulfone, Amoco Polymers

Ultem, Polyetherimide resin, sheet, GE Plastics

Ultimax, Purging compound, Bamberger, Claude P., Molding Compounds Corp.

Ultisil, Treated silica textiles, Ametek, Inc., Chemical Products Div.

Ultra Black, RTV silicone, Loctite Corp., North American Group

Ultra-Ethylux, Linear polyethylene, Westlake Plastics

Ultra-Mold, Mold-in insert threaded, Dodge, Emhart Fastening Teknologies

Ultra-Pflex, PCC for rigid PVC applications, Specialty Minerals Inc.

Ultra-Tuflin, Extra-high-strength film resins, Union Carbide Corp.

Ultrablend, Gain-in-weight graimetric, Colortronic, Inc.

Ultracarb, Hydrated MAG/CAL carbonate, AluChem

Ultracarb, Hydrated magnesiun carbonate, Great Lakes Chemical Corp.

Ultracast, Polyurethane preploymers, Air Products and Chemicals, Inc.

Ultrachem, Prehardened stainless steel, International Mold Steel, Inc.

Ultrachrome, Urethane gel coat, Futura Coatings, Inc.

Ultracolor, Color concentrate, Teknor Color Co.

Ultracore, Spray-applied foam core, Futura Coatings, Inc.

Ultradex, UV-cured coatings, Dexter Automotive & Specialty Coatings

Ultradur B, PBT thermoplastic polyester, BASF Corp., Plastic Materials

Ultradur S, PBT/ASA alloys, BASF Corp., Plastic Materials

Ultrafilm, Specialty unsupported transfer films, Scapa Tapes North America

Ultrafine, Antimony trioxide, Laurel Industries, Inc.

Ultraform, Acetal copolymer, BASF Corp., Plastic Materials

UltraGage, Measurement and control, On Line Controls, Inc.

Ultralite, Pressed polished sheet (PVC), O'Sullivan Corp.

Ultramarine, Pigments, Ferro Corp., Color Div.

Ultramid, Nylon resins, BASF Corp., Plastic Materials

Ultranox, Phosphite antioxidant, GE Co., GE Specialty Chemicals

Ultraseal, Sealing threaded insert, Dodge, Emhart Fastening Teknologies

Ultrashield, Scratch-resistant back lights and rear windows; automotive, O'Sullivan Corp.

Ultrasil, High-temperature silicone rubber formulation, United Silicone Inc., An Illinois Tool Works Co.

Ultrason E, Polyethersulfone, BASF Corp., Plastic Materials

Ultrason S, Polysulfone, BASF Corp., Plastic Materials

Ultrathane, Structural polyurethane resin, Futura Coatings, Inc.

Ultrathene, Ethylene-vinyl acetate resins and copolymers, Equistar Chemicals

Ultratherm, Imide resins and solutions, George, P. D.

Ultratrac, High-track electrical grade sheet, Haysite Reinforced Plastics

Ultratuf, Extruded polycarbonate film and sheet, Lustro Plastics
Ultros, Extruded PETG sheet, Lustro Plastics
Ultros UV, Coextruded film and sheet, Lustro Platics
Ultryl, Low-pressure class A SMC, AOC
Umax, Optimization methodology, Ultramax Corp.
Una-Dyn, Auxiliary equipment, Universal Dynamics Inc., Co. of MANN + HUMMEL
Uni-Kote, Surface modification method for wide range of filler materials, United Minerals Corp.
Unibond, Ethyl silicate, United Development Corp.
Unicell D200-D2500, Azodicarbonamide, Dong Jin (USA), Inc.
Unicell 5 PT, High-temperature foaming agent, Dong Jin (USA), Inc.
Unicell H (TSH-XP), Toluenesulfonylhydrazide, Dong Jin (USA), Inc.
Unicell OH, Oxybisbenzenesulfonylhydrazide, Dong Jin (USA), Inc.
Unichem, Flexible and rigid vinyl compounds, Colorite Plastics Co.
Unicolor, Color concentrate, Ametek/Westchester
Unifilm, Unsupported pressure-sensitive transfer tape, Scapa Tapes North America
Unifilo, Continuous strand mat, Vetrotex CertainTeed
Uniflex, Flexible molding compound, Unicast Development Corp.
Uniflex, Monomeric and polymeric plasticizers, Union Camp Corp., Chemical Products Div.
Unifoam, Polyurethane foam, Burnett, William T., & Co., Inc., Polyurethane Div.
Unigard HP, High performance, FR wire and cable compounds, Union Carbide Corp.
Unigard RE, Reduced emission, FR wire and cable compounds, Union Carbide Corp.
Unilac, Protective coatings, Unicast Development Corp.
Unilin, Long-chain linear alcohols, Baker Petrolite, Polymers Div.
Unilink, Chain extender for polyurethanes, UOP Adsorbents Div.
Uniloy, Blow molding systems, parts, and services, Johnson Controls, Inc., Plastics Machinery Div.
Uniloy Springfield, Structural foam and/or web molding systems, parts, and services, Johnson Controls, Inc., Plastics Machinery Div.
Unilube, Lubricants, Unitex Chemical Corp.
Unimax, Braided undirectional reinforced goods, A & P Technology Inc.
UniMix Screw, Low-shear mixing screew, Glycon Corp.
Uniplex, Plasticizers/impact modifiers/smoke suppressants, Unitex Chemical Corp.
Unipol, PE gas-phase process technology, Univation Technologies
Uniprene, Thermoplastic vulcanizate, Teknor Apex International
Unipurge, Polyethylene purging compound, Union Carbide Corp.
Uniseal, Plaster and ceramic mold materials, Unicast Development Corp.
Unisens, Instruments, uniform sensitivity, Kistler Instrument Corp.
Unisperse, Aqueous dispersions, Ciba Specialty Chemicals Corp., Pigments Div.
Unitane, Titanium dioxide, Kemira Pigments Inc.
Unithox, Ethoxylated long-chain alcohols, Baker Petrolite, Polymers Div.
Uniti, Titanium chemicals, Kemira Pigments Inc.
Unival, HDPE blow molding resins, Union Carbide Corp.
Unoflex, Laminating adhesives, Morton International Inc.
Uracure, Thermoset urethane curatives, Fiber Resin Corp., Subs. of H. B. Fuller Co.
Uralite, Thermoset urethane elastomers, Fiber Resin Corp., Subs. of H. B. Fuller Co.
Urebrade, Braid reinforced polyurethane hose, NewAge Industries Inc., Plastics Technology Group
Uresolve, Removal of urethanes and silicones, Dynaloy Inc.
UrethHall, Polyesters for urethanes, Hall, C. P., Co.
USP, Organic peroxide catalyst, Witco Corp., Polymer Chemicals Group
UV, UV degradable concentrate, Willow Ridge Plastics, Inc.
UV-Chek, UV absorbers, Ferro Corp., Polymer Additives Div.
UV Cure, UV curable coating and adhesives, Epoxies, Etc.
Uvasil, Hindered amine light stabilizers, Great Lakes Chemical Corp.
Uvasorb, UV light absorber/stabilizer, 3V Inc.
Uveda, UV and IR fluorescent pigments, United Mineral & Chemical Corp.
Uvinox, UV light stabilizer, PMC Specialties Group
Uvinox, Antioxidant, Rhodia
Uvinul, UV absorbers and hindered amines, BASF Corp., Coatings & Colorants Div.

Uvitex, Fluorescent whitening agents, Ciba Specialty Chemicals Corp., Additives Div.

Uvithane, UV oligomers, Morton International Inc.

Uvonyl, UV curing ink for plastic cards, Akzo Nobel Inks

Uvorapid, UV curing ink for cups, tubes, containers, Akzo Nobel Inks

V

V-Bar, Insertion vortex flowmeter, EMCO Flowmeters

V-Cutter, Large or solid parts and purgings, Size Reduction Specialists Corp.

V-Cutter-Weima, Large or solid parts and purgings, FBE Corp.

Vacorex, Discharge gear pump for high-viscosity polymer melts, Maag Pump Systems Textron

Vacuren, Furniture lamination vinyl films, American Renolit Corp.

Valox, PBT film, GE plastics

Valtra, Styrenic polymers, Chevron Chemicals Co., U.S. Chemicals, Styrenic Polymers

Valu-Fil, Calcium sulfate dihydrate (gypsum), Plastic Filler Sales, Inc.

Vancide, Bacteriostat, fungicides, Vanderbilt, R. T., Co.

Vandar, Modified thermoplastic polyester; alloys, Ticona

Vanox, Antioxidants, mineral deactivator, Vanderbilt, R. T., Co.

Vansil W, Wollastonite, Vanderbilt, R. T., Co.

Vanstay, Stabilizers for PVC, Vanderbilt, R. T., Co.

Vantalc, Talc filler, Vanderbilt, R. T., Co.

VaporSep, Separates vapors from gas streams, Membrane Technology & Research, Inc.

Varatorq, Follower-arm tension control, P/A Industries Inc., Web Processing Equipment Div.

Vardex, Steel-wire reinforced PVC hose, NewAge Industries Inc., Plastics Technology Group

Varex Optifil P2, Blown film extrusion, Windmoeller & Hoelscher Corp.

Varimat, Sheet molding compound, Interplastic Corp., Molding Products Div.

Vectra, Liquid crystal polymers, Ticona

Vedoc, Organic powder coatings, Ferro Corp., Powder Coatings Div.

VEGlaze, Protective coating, Sauereisen

Vekton, Cast nylon 6 products, Ensinger, Inc.

Velve, Filter foams, General Foam Corp.

Venus Fire Gold, Bronze flake, United States Bronze Powders, Inc.

Verilon, PVC flexible film and sheet, Continental Plastic Co., Div. CPI, Inc.

Versacel, Rigid PVC foam board, HPG International

Versadur, PVC and PE sheeting; flame retardant, HPG International

Versaflex, Thermoplastic rubber alloy, GLS Corp., Thermoplastic Elastomers Div.

Versalink, Diamine curative; oligomeric diamine curatives, Air Products and Chemicals, Inc.

Versamag, Magnesium hydroxide, Morton International Inc., Morton Performance Chemicals

Versamid, Epoxy curing agents, Henkel Corp.

Versamine, Epoxy curing agents, Henkel corp.

Versaswitch, Mold limit switch, Burger Engineering

Versatec, Corrugated vinyl panels, Crane Plastics, Co.

Versathane, Polyurethane prepolymers, Air Products and Chemicals, Inc.

Versene, Chelating agents, Dow Chemical Co., Polyglycols

Versilok, Modified acrylic adhesives, Lord Corp., Chemical Products Div.

Verta-Turret, Primary or secondary extruder, Entwistle

Vertal (Series), Talc, Luzenac America

Vertipile, Natural and synthetic flock fiber, Claremont Flock Corp.

Verton, Long fiber composites, LNP Engineering Plastics Inc.

Vespel, Polyimide parts and shapes, DuPont Engineering Polymers

Vessel, Tools (air nippers, screw drivers), JDV

Vestamelt, Thermoplastic polyester copolymers, Creanova Inc.

Vestamid, Nylon 12, 6/12, Creanova Inc.

Vestodur, PBT thermoplastic polyester, Creanova Inc.

Vestolit, Polyvinyl chloride, Creanova Inc.

Vestosint, Nylon 12 coating powders, Creanova Inc.

Vexar, Netting, DuPont

Vibraclean, Shaker-type dust collector, Sternvent Co.

Vibrasert, Standard and special brass insert, Groov-Pin Corp.

Vibrathane, Polyurethane elastomer, Uniroyal Chemical Co., Inc.

Vibratrol, Level switch, Endress + Hauser

Vibrox, Packers, Gump Div., Buffalo Technologies

Vicast, Polyester resins for cultured marble and solid surface, AOC

Vicron, Finely ground limestone, Specialty Minerals

Victawet, Phosphate esters, Akzo Nobel Chemicals

Vigot, Cubic-shaped, surface-treated, precipitated calcium carbonate, Royal, H. M., Inc.

Vikaex, Stabilizers, Elf Atochem North America, Inc.

Vikoflex, Epoxy plasticizers, Elf Atochem North America, Inc.

Vikolox, Epoxidized alpha-olefins, Elf Atochem North America, Inc.

Vinac, Polyvinyl acetate beads, Air Products and Chemicals, Inc.

Vinacron, Plastisol, Loes Enterprises Inc.

Vinika, High-quality PVC compounds, Schulman, A., Inc.

Vinyl Bond, PVC alloy compounds, Colorite Plastics Co.

Vinylex, Calendered vinyl films, Piedmont Plastics

Vinyzene, Antimicrobial, Morton International Inc., Morton Plastics Additives

Viper, Static neutralizing blowoff gun, SIMCO

Viplex (Series), Plasticizers, Crowley Chemical Co.

Vircol (Series), Reactive polyurethane flame retardants, Albright & Wilson Americas

Virgaloy, PC/PMMA blend, MRC Polymers Inc.

Virtual Gibbs, CAM software, Gibbs and Associates

Virtual-Vision, Automated imaging/vision system, ASC Systems

Viscobyk, Viscosity depressants; low-emission products, Byk-Chemie U.S.A.

Viscolas, Viscoelastic materials, E-A-R Specialty Composites

Viscorex, Discharge gear pump for viscous polymer melts, Maag Pump Systems Textron

Visi-Pack, Machine vision systems, PTI Packaging Technologies & Inspection

Vision Bottle Gauge, Dimensions measurement on extrusion blow bottles,TopWave International, Inc.

VisionScope, Mold monitoring controller, Avalon Imaging Inc.

Vista R, Thermoplastic ducting, Federal Hose Manufacturing

Vista U, Urethane ducting, Federal Hose Manufacturing

Vista V, PVC ducting, Federal Hose Manufacturing

VistaFlex, Thermoplastic elastomer, Advanced Elastomer Systems LP

Vistanex, Polyisobutylene, Exxon Chemical Co.

Vistel, Rigid injection molding compound, CONDEA Vista Co.

Vitafilm, Extruded PVC film, Huntsman Packaging Corp., Sales

Viton, Fluoroelastomer, DuPont Dow Elastomers

Vitron, Fiberglass staple fiber, Johns Manville

Vivak, Extruded copolyester sheet, PETG, DSM Sheffield

Vivak UV, UV-resistant PETG, DSM Sheffield

Voloy, Flame-retardant materials, ComAlloy International Co.

Volume Tester, Capacity test with topload option, TopWave International, Inc.

Volumerik, Volumetric feeders, Merrick Industries

Voracor, Rigid systems, Dow Plastics

Voranate, Specialty isocyanates, Dow Chemical

Voranate T-80, Toluene diisocyanates, Dow Chemical

Voranol, Polyether polyols, Dow Chemical

Vorasurf, Surfactants, Dow Chemical

Voratec, Rigid systems (polyurethane), Dow Plastics

Vortex, Rotary grinders, Nordfab Systems, Inc.

Vortex PhD, Inline vortex flowmeter, EMCO Flowmeters

Vortice L Elbow, Elbow for carefree conveying, HammerTek Corp.

Vul-Cup, Peroxide Catalyst, Hercules Inc.

Vulcan, Pelletized furnace carbon black, Cabot Corp., Special Blacks Div.

Vulcan, Organic pigment for rubber, Clariant Corp., BU Additives

Vulcanex, Vulcanized fiber, Oliner Fibre Co., Inc.

Vulcastop, Sodium dimethyl dithiocarbamate, Akzo Nobel Chemicals Inc.

Vulkollan, Polyurethane cast elastomer, Bayer Corp., Polymers Div.

Vult-Acet, Polyvinyl acetate latices, General Latex & Chemical

Vult-Acryl, Acrylic latices, General Latex & Chemical

Vultafoam, Urethane foam systems, General Latex & Chemical

Vy-Lok, Vinyl laminating adhesives, National Starch and Chemical Co.

Vydax, Release agent, DuPont

Vydyne, Nylon resins, Solutia Inc.

Vyn-Eze, Stearamide mold release agent, Ferro Corp., Polymer Additives Div.

Vynaprene, Elastomer alloy, CONDEA Vista Co.

Vynite, PVC/nitrile rubber alloy, AlphaGary Corp.

Vyram, Mid-range performance thermoplastic elastomer, Advanced Elastomer Systems, LP

Vysun, Proprietary compounds and tubing, Sunlite Plastics, Inc.

Vythene, PVC/urethane alloy, AlphaGary Corp.

W

Walk-On Graphics, Vinyl floor graphics and overlaminate, Catalina Plastics & Coating Corp.

Wareflex, Adipate ester plasticizer, Sartomer Co. Inc.

WatchDog, Mold temperature regulator, Burger Engineering

Watchung, Colorants, 2B Reds, Clariant Corp., BU Additives

Waterclean, Water-based mold and/or part cleaner, non-VOC, Zyvax, Inc.

WaterFall, PVC gutter guard system, Crane Plastics

Watershield, Water-based release agent (non-flammable), non-VOC, Zyvax, Inc.

Waterworks, Garden hose, PureTec Corp.

Watt-Flex, Split-sheath cartridge heater, Dalton Electric Heating Co., Inc.

WeatherEX, Weatherable impact polystyrene, American Sheet Extrusion Corp.

WeatherFlex, PVC alloys for special low-temperature applications, Cybertexh Polymers

WebCore, Fiberglass web reinforced foam, Elliott Corp.

Wedge, Differential pressure flowmeters, ABB Instrumentation

Weima, Reducers, Akhurst Machinery Ltd.

Weld-On, Industrial adhesives, IPS Corp.

Weldox, UV cure adhesives, Elementis Performance Polymers, Div. Harcros Chemicals, Inc.

Wellamid (Series), Nylon 6 and 66 molding resins, Wellman, Inc., Engineering Resins Div.

Westat, Conductive plastics, Wescorp

Weston, Phosphites, GE Co., GE Specialty Chemicals

Wet-Ground Mica, High-aspect-ratio mica, Franklin Industrial Minerals

Wetstick, PSA tapes; resist moisture, Avery Dennison, Specialty Tape Div.

White Mica Pearls, Pearlescents, Eckart America LP

White Mist, White flux-calcined diatomite, antiblock additive, Celite Corp., c/o World Minerals Inc.

Whitetex, Calcined kaolin, Engelhard Corp.

Wilflex, Vinyl plastisols, Flexible Products Co.

Wingstay, Antioxidants, Goodyear Tire & Rubber Co., Chemical Div.

Wingtack, Hydrocarbon resins, Goodyear Tire & Rubber Co., Chemical Div.

WinMatch, Formulation software, Spectronic Instruments

Winwrap, Cast coextruded PE stretch film, Huntsman Packaging Corp., Sales

Winwrap Bold, Cast coextruded PE stretch film, Huntsman Packaging Corp., Sales

Wipe, De-staticizer for heat-exposed plastics, Merix Chemical Co.

Witcobond, Polyurethane latices, aqueous polyurethane dispersions, Witco corp., Performance Chemicals Group

Woku, Quick mold change system, Unitemp

Wollastocoat, Chemically surface-modified wollastonite, Nyco Minerals, Inc.

Wonder Drill, Drill bit, International Carbide

Wonderouter, Fiberglass router, International Carbide

WoodPlast, Polyolefin and wood flour, B & F Plastics

Wrightlon, Vacuum bagging film, AirTech Advanced Materials Group

Wytox, Antioxidant, Uniroyal Chemical Co., Inc.

X

X-Coat, EMI/RFI coatings, E/M Corp.

X-Tone, Stone colorants, FM Group

Xantar, Polycarbonate, DSM Engineering Plastics

Xenoxyl Stabilizer, Antioxidant and monomer stabilizer for acrylics, Zeneca Specialties

Xenoy, Thermoplastic alloys, GE Plastics

XRC Bushing, Externally heated hot runner bushings, Incoe Corp.

XRC III Cast Heaters, Cast hot runner bushing heaters, Incoe Corp.

XT Polymer, Acrylic-based multipolymer compounds, Cyro Industries

Xydar, Liquid crystal polymer, Amoco Polymers

Xylac, High-temperature phenolic coating, Whitford

Xylan, Low-friction wear-resistant coating, Whitford

Xytec, Collapsible palletized bin, Perstorp Plastic Systems

Y

Yellow Jacket, Extruders, floor models, and table-top extruders, Wayne Machine & Die Co.

Z

Z-Light Spheres, Low-density hollow ceramic microspheres, Zeelan Industries, Inc., Subs. of 3M

Z-Link, Anisotropic adhesive system, Sheldahl Inc.

Zealloy, Impact modifiers, Zeon Chemicals, Inc.

Zeeospheres, Fine particle size, high-strength ceramic microspheres, Zeelan Industries, Inc., Subs. of 3M

Zelar, Transparency films, Multi-Plastics, Inc.

Zelec, Antistatic agents, DuPont

Zelite, Linear low-density polyethylene tubing, NewAge Industries Inc., Plastics Technology Group

Zelux, Polycarbonate shapes, Westlake Plastics Co.

Zenite LCP, Liquid crystal polymer resins, DuPont Engineering Polymers

ZenTron, High-strength single-end roving, Owens Corning

Zeofree, Anticaking agent, Huber, J. M., Corp., Chemicals Div.

Zeolex, Silica pigment, Huber, J. M., Corp., Chemicals Div.

Zeomatt, Antiblocking and flatting agents, Huber, J. M., Corp., Chemicals Div.

Zeosyl, Silica pigment, Huber, J. M., corp., Chemicals Div.

Zeothix, Antiblocking and flattening agents, thixotropic thickness, Huber, J. M., Corp., Chemicals Div.

Zero Gate, Valve gate systems, Incoe Corp.

Zero Stick, Food-grade paintable mold release, Stoner Inc.

Zerogen, Magnesium hydroxide, Huber, J. M., Corp., Engineered Minerals Div.

Zetabon, Coated steel armor, Dow Plastics

Zinstabe, Stabilizer, Zin Corp. of America

Zip Board, Pressure-sensitive adhesive backings, Plastomer

Zylar, Acrylic terpolymers, impact, clear, NOVA Chemicals Ltd.

Zylar ST, Acrylic alloys, impact, clear NOVA Chemicals Ltd.

Zypet, PETG copolyester, southern Plastics Co.

Zytel, Nylon resins (6, 6/6, 6/12, copolymers), DuPont

Zytel HTN, High-temperature nylon, DuPont

Zytel ST, Super-tough nylon, DuPont

Zytocal, Injection/blow molding additives, ECC International

APPENDIX O

Conversion Units*

CONVERSION FACTORS

To convert . . .	To . . .	Multiply by . . .
Area		
in^2	mm^2	$6.451600 \times 10^{+2}$
in^2	cm2	6.451600
ft^2	m^2	9.290304×10^{-2}
Force		
dyne	N	1.000000×10^{-5}
lbf	N	4.44822
Force per unit area		
lb/in^2 (psi)	MPa	6.894757×10^{-3}
MN/m^2	MPa	1.000000
kg/mm^2	MPa	9.806650
dyne/cm^2	Pa	1.000000
Force per unit length		
lb/in (piw)	N/m	$1.751268 \times 10^{+2}$
dyne/cm	mJ/m^2	1.000000
lb/ft	kg/m	1.488

Source: Handbook of Adhesives and Sealants, E. M. Petrie, ed., McGraw-Hill, New York, 2000.

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To convert . . .	To . . .	Multiply by . . .
Impact energy		
ft-lbf	J	1.355818
N-m	J	1.000000
Length		
A (Angstroms)	m	1.000000×10^{-10}
in	mm	25.4
mil	in	1.000000×10^{-3}
Mass		
lb	kg	4.5359237×10^{-1}
oz	gm	28.35
Pressure		
atm	Pa	$1.013250 \times 10^{+5}$
atm	torr	760
psi	Pa	$6.894757 \times 10^{+3}$
torr (mm Hg @ 0°C)	Pa	$1.333220 \times 10^{+2}$
Temperature		
°F	°C	5/9 × (°F − 32)
°C	°F	((°C × 9)/5) + 32
Viscosity		
poise	Pa-s (pascal second)	1.000000×10^{-1}
poise	g/cm-sec	1.000000
m^2/sec	stokes	$1.000000 \times 10^{+4}$

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