CHAPTER 31
CLASSIFICATION SYSTEMS

Dell K. Allen
Manufacturing Engineering Department
Retired from Brigham Young University
Provo, Utah

31.1 PART FAMILY CLASSIFICATION AND CODING

31.1.1 Introduction

History

Classification and coding practices are as old as the human race. They were used by Adam, as recorded in the Bible, to classify and name plants and animals, by Aristotle to identify basic elements of the earth, and in more modern times to classify concepts, books, and documents. But the classification and coding of manufactured pieceparts is relatively new. Early pioneers associated with workpiece classification are Mitrafanov of the USSR, Gombinski and Brisch, both of the United Kingdom, and Opitz of Germany. In addition, there are many who have espoused the principles developed by these men, adapted them and enlarged upon them, and created comprehensive workpiece classification systems. It is reported that over 100 such classification systems have been created specifically for machined parts, others for castings or forgings, and still others for sheet metal parts, and so on. In the United States there have been several workpiece classification systems commercially developed and used, and a large number of proprietary systems created for specific companies.

Why are there so many different part-classification systems? In attempting to answer this question, it should be pointed out that different workpiece classification systems were initially developed for

Mechanical Engineers' Handbook, 2nd ed., Edited by Myer Kutz.
ISBN 0-471-13007-9

different purposes. For example, Mitrafanov apparently developed his system to aid in formulating group production cells and in facilitating the design of standard tooling packages; Opitz developed his system for ascertaining the workpiece shape/size distribution to aid in designing suitable production equipment. The Brisch system was developed to assist in design retrieval. More recent systems are production-oriented.

Thus, the intended application perceived by those who have developed workpiece classification systems has been a major factor in their proliferation. Another significant factor has been personal preferences in identification of attributes and relationships. Few system developers totally agree as to what should or should not be the basis of classification. For example: Is it better to classify a workpiece by function as "standard" or "special" or by geometry as "rotational" or "non-rotational"? Either of these choices makes a significant impact on how a classification system will be developed.

Most classification systems are hierarchal, proceeding from the general to the specific. The hierarchal classification has been referred to by the Brisch developers as a monocode system. In an attempt to derive a workpiece code that addressed the question of how to include several related, but non-hierarchal, workpiece features, the feature code or polycode concept was developed. Some classification systems now include both polycode and monocode concepts.

A few classification systems are quite simple and yield a short code of five or six digits. Other part-classification systems are very comprehensive and yield codes of up to 32 digits. Some part codes are numeric and some are alphanumeric. The combination of such factors as application, identified attributes and relationships, hierarchal versus feature coding, comprehensiveness, and code format and length have resulted in a proliferation of classification systems.

31.1.2 Application

Identification of intended applications for a workpiece classification system are critical to the selection, development, or tailoring of a system.

It is not likely that any given system can readily satisfy both known present applications and unknown future applications. Nevertheless, a classification system can be developed in such a way as to minimize problems of adaptation. To do this, present and anticipated applications must be identified. It should be pointed out that development of a classification system for a narrow, specific application is relatively straightforward. Creation of a classification system for multiple applications, on the other hand, can become very complex and costly.

Figure 31.1 is a matrix illustrating this principle. As the applications increase, the number of required attributes also generally increases. Consequently, system complexity also increases, but often at a geometric or exponential rate, owing to the increased number of combinations possible. Therefore, it is important to establish reasonable application requirements first while avoiding unnecessary requirements and, at the same time, to make provision for adaptation to future needs.

In general, a classification system can be used to aid (1) design, (2) process planning, (3) materials control, and (4) management planning. A brief description of selected applications follows.

Design Retrieval

Before new workpieces are introduced into the production system, it is important to retrieve similar designs to see if a suitable one already exists or if an existing design may be slightly altered to accommodate new requirements. Potential savings from avoiding redundant designs range in the thousands of dollars.

Design retrieval also provides an excellent starting point for standardization and modularization. It has been stated that "only 10–20% of the geometry of most workpieces relates to the product function." The other 80–90% of the geometric features are often a matter of individual designer taste or preference. It is usually in this area that standardization could greatly reduce production costs, improve product reliability, increase ease of maintenance, and provide a host of other benefits.

One potential benefit of classification is in meeting the product liability challenge. If standard analytic tools are developed for each part family, and if product performance records are kept for those families, then the chances of negligent or inaccurate design are greatly reduced.

The most significant production savings in manufacturing enterprise begin with the design function. The function must be carefully integrated with the other functions of the company, including materials requisition, production, marketing, and quality assurance. Otherwise, suboptimization will likely occur, with its attendant frequent redesign, rework, scrap, excess inventory, employee frustration, low productivity, and high costs.

Generative Process Planning

One of the most challenging and yet potentially beneficial applications of workpiece classification is that of process planning. The workpiece class code can provide the information required for logical, consistent process selection and operation planning.

The various segments of the part family code may be used as keywords on a comprehensive process-classification taxonomy. Candidate processes are those that satisfy the conditions of the given

APPLICATIONS	WORKPIECE ATTRIBUTES/CHARACTERISTICS/VALUES													
	Shape	Form features	Treatments	Functions	Size envelopes	Tolerances	Surface finish	Material type/condition	Quantity	Next assembly	Raw material form			
Generative design														
Design retrieval														
Generative process planning														
Equipment selection														
Tool design														
Time/cost estimating														
Assembly planning														
Quality planning														
Production scheduling														
Parametric part programming														

Fig. 31.1 Attribute selection matrix.

basic shape *and* the special features *and* the size *and* the precision *and* the material type *and* the form *and* the quality/time requirements.

After outputting the suitable processes, economic or other considerations may govern final process selection. When the suitable process has been selected, the codes for form features, heat treatments, coatings, surface finish, and part tolerance govern computerized selection of fabrication and inspection operations. The result is a generated process plan.

Production Estimating

Estimating of production time and cost is usually an involved and laborious task. Often the results are questionable because of unknown conditions, unwarranted assumptions, or shop deviations from the operation plan. The part family code can provide an index to actual production times and costs for each part family. A simple regression analysis can then be used to provide an accurate predictor of costs for new parts falling in a given part family. Feedback of these data to the design group could provide valuable information for evaluating alternative designs prior to their release to production.

Parametric and Generative Design

Once the product mix of a particular manufacturing enterprise has been established, high-cost, low-profit items can be singled out. During this sorting and characterization process, it is also possible to establish tabular or parametric designs for each basic family. Inputting of dimensional values and other data to a computer graphics system can result in the automatic production of a drawing for a given part. Taking this concept back one more step, it is conceivable that merely inputting a product name, specifications, functional requirements, and some dimensional data would result in the generation of a finished design drawing. Workpiece classification offers many exciting opportunities for productivity improvement in the design arena.

Parametric Part Programming

A logical extension of parametric design is that of parametric part programming. Although parametric part programming or family of parts programming has been employed for some time in advanced numerical control (NC) work, it has not been tied effectively to the design database. It is believed that workpiece classification and coding can greatly assist with this integration. Parametric part programming provides substantial productivity increases by permitting the use of common program modules and reduction of tryout time.

Tool Design Standardization

The potential savings in tooling costs are astronomical when part families are created and when form features are standardized. The basis for this work is the ability to adequately characterize component pieceparts through workpiece classification and coding.

31.1.3 Classification Theory

This section outlines the basic premises and conventions underlying the development of a Part Family Classification and Coding System.

Basic Premises

The first premise underlying the development of such a system is that a workpiece may be best characterized by its most apparent and permanent attribute, which is its basic shape. The second premise is that each basic shape may have many special features (e.g., holes, slots, threads, coatings) superimposed upon it while retaining membership in its original part family. The third premise is that a workpiece may be completely characterized by (1) basic shape, (2) special features, (3) size, (4) precision, and (5) material type, form, and condition. The fourth premise is that code segments can be linked to provide a humanly recognizable code, and that these code segments can provide pointers to more detailed information. A fifth premise is that a short code is to be adequate for human monitoring, and linking to other classification trees but that a bitstring (0's, 1's) that is computer-recognizable best provides the comprehensive and detailed information required for retrieval and planning purposes. Each bit in the bitstring represents the presence or absence of a given feature and provides a very compact, computer-processable representation of a workpiece without an excessively long code. The sixth premise is that mutually exclusive workpiece characteristics can provide unique basic shape families for the classification, and that common elements (e.g., special features, size, precision, and materials) should be included only once but accessed by all families.

E-Tree Concept

Hierarchal classification trees with mutually exclusive data (E-trees) provide the foundation for establishing the basic part shape (Fig. 31.2). Although a binary-type hierarchal tree is preferred because it is easy to use, it is not uncommon to find three or more branches.

It should be pointed out, however, that because the user must select only one branch, more than two branches require a greater degree of discrimination. With two branches, the user may say, "Is it this or that?" With five branches, the user must consider, "Is it this or this or this or this or this?" The reading time and error rate likely increase with the number of branches at each node. The E-tree is very useful for dividing a large collection of items into mainly exclusive families or sets.

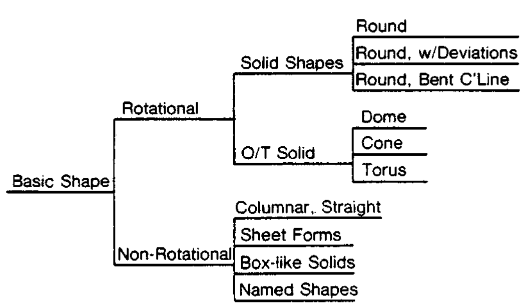


Fig. 31.2 E-tree concept applied to basic shape classification.

N-Tree Concept

The N-tree concept is based on a hierarchal tree with nonmutually exclusive paths (i.e., all paths may be selected concurrently). This type of tree (Fig. 31.3) is particularly useful for representing the common attributes mentioned earlier (e.g., form features, heat treatments, surface finish, size, precision, and material type, form, and condition).

In the example shown in Fig. 31.3, the keyword is Part Number (P/N) 101. The attributes selected are shown by means of an asterisk (*). In this example the workpiece is characterized as having a "bevel," a "notch," and a "tab."

Bitstring Representation

During the traversal of either an E-tree or an N-tree, a series of 1's and 0's are generated, depending on the presence or absence of particular characteristics or attributes. The keyword (part number) and its associated bitstring might look something like this:

$$P/N\text{-}101 = 100101 \cdots 010$$

The significance of the bitstring is twofold. First, one 16-bit computer word can contain as many as 16 different workpiece attributes. This represents a significant reduction in computer storage space compared with conventional representation. Second, the bitstring is in the proper format for rapid computer processing and information retrieval. The conventional approach is to use lists and pointers. This requires relatively large amounts of computation and a fast computer is necessary to achieve a reasonable response time.

Keywords

A keyword is an alphanumeric label with its associated bitstring. The label may be descriptive of a concept (e.g., stress, speed, feed, chip-thickness ratio), or it may be descriptive of an entity (e.g., cutting tool, vertical mill, 4340 steel, P/N-101). In conjunction with the Part Family Classification and Coding System, a number of standard keywords are provided. To conserve space and facilitate data entry, some of these keywords consist of one- to three-character alphanumeric codes. For example, the keyword code for a workpiece that is rotational and concentric, with two outside diameters and one bore diameter, is "B11." The keyword code for a family of low-alloy, low-carbon steels is A1. These codes are easy to use and greatly facilitate concise communication. They may be used as output keys or input keys to provide the very powerful capability of linking to other types of hierarchal information trees, such as those used for process selection, equipment selection, or automated time standard setting.

31.1.4 Part Family Code

Purpose

Part classification and coding is considered by many to be a prerequisite to the introduction of group technology, computer-aided process planning, design retrieval, and many other manufacturing activ-

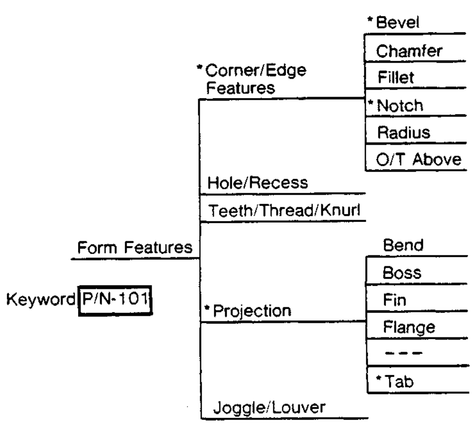


Fig. 31.3 N-tree concept applied to form features.

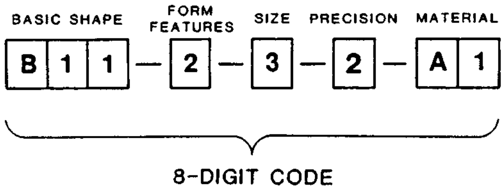


Fig. 31.4 Part family code.

ities. Part classification and coding is aimed at improving productivity, reducing unnecessary variety, improving product quality, and reducing direct and indirect cost.

Code Format and Length

The part family code shown in Fig. 31.4 is composed of a five-section alphanumeric code. The first section of the code gives the basic shape. Other sections provide for form features, size, precision, and material. Each section of the code may be used as a pointer to more detailed information or as an output key for subsequent linking with related decision trees. The code length is eight digits. Each digit place has been carefully analyzed so that a compact code would result that is suitable for human communication and yet sufficiently comprehensive for generative process planning. The three-digit basic shape code provides for 240 standard families, 1160 custom families, and 1000 functional or named families. In addition, the combination of 50 form features, 9 size ranges, 5 precision classes, and 79 material types makes possible 2.5×10^{71} unique combinations! This capability should satisfy even the most sophisticated user.

Basic Shape

The basic shapes may be defined as those created from primitive solids and their derivatives (Fig. 31.5) by means of a basic founding process (cast, mold, machine). Primitives have been divided into rotational and nonrotational shapes. Rotational primitives include the cylinder, sphere, cone, ellipsoid, hyperboloid, and toroid. The nonrotational primitives include the cube (parallelepiped), polyhedron, warped (contoured) surfaces, free forms, and named shapes. The basic shape families are subdivided on the basis of predominant geometric characteristics, including external and internal characteristics.

The derivative concentric cylinder shown in Fig. 31.5 may have several permutations. Each permutation is created by merely changing dimensional ratios as illustrated or by adding form features. The rotational cylindrical shape shown may be thought of as being created from the intersection of a negative cylinder with a positive cylinder.

Figure 31.5*a*, with a length/diameter (L/D) ratio of 1:1, could be a spacer; Fig. 31.5*b*, with an L/D ratio of 0.1:1, would be a washer; and Fig. 31.5*c*, with an L/D ratio of 5:1, could be a thin-walled tube. If these could be made using similar processes, equipment, and tooling, they could be said to constitute a family of parts.

Name or Function Code

Some geometric shapes are so specialized that they may serve only one function. For example, a crankshaft has the major function of transmitting reciprocating motion to rotary motion. It is difficult to use a crankshaft for other purposes. For design retrieval and process planning purposes, it would

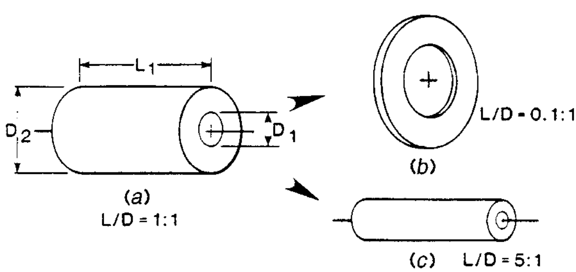


Fig. 31.5 Permutations of concentric cylinders.

probably be well to classify all crankshafts under the code name "crankshaft." Of course, it may still have a geometric code such as "P75," but the descriptive code will aid in classification and retrieval. A controlled glossary of function codes with cross references, synonyms, and preferred labels would aid in using name and function codes and avoid unnecessary proliferation.

Special Features

To satisfy product design requirements, the designer creates the basic shape of a workpiece and selects the engineering material of which it is to be made. The designer may also require special processing treatments to enhance properties of a given material. In other words, the designer adds special features. Special features of a workpiece include form features heat treatments, and special surface finishes.

Form features may include holes, notches, splines, threads, and so on. The addition of a form feature does not change the basic part shape (family), but does enable it to satisfy desired functional requirements. Form features are normally imparted to the workpiece subsequent to the basic founding process.

Heat treatments are often given to improve strength, hardness, and wear resistance of a material. Heat treatments, such as stress relieving or normalizing, may also be given to aid in processing the workpiece.

Surface finishing treatments, such as plating, painting, and anodizing, are given to enhance corrosion resistance, improve appearance, or meet some other design requirement.

The special features are contained in an N-tree format with an associated complexity-evaluation and classification feature. This permits the user to select many special features while still maintaining a relatively simple code. Basically, nine values (1–9) have been established as the special feature complexity codes. As the user classifies the workpiece and identifies the special features required, the number of features is tallied and an appropriate complexity code is stored. Figure 31.6 shows the number count for special features and the associated feature code.

The special feature complexity code is useful in conveying to the user some idea of the complexity of the workpiece. The associated bitstring contains detailed computer-interpretable information on all features. (Output keys may be generated for each individual feature.) This information is valuable for generative process planning and for estimating purposes.

Size Code

The size code is contained in the third section of the part family code. This code consists of one numeric digit. Values range from 1 to 9, with 9 representing very large parts (Fig. 31.7). The main purpose of the size code is to give the code user a feeling for the overall size envelope for the coded part. The size code is also useful in selecting production equipment of the appropriate size.

Precision Class Code

The precision class code is contained in the fourth segment of the part family code. It consists of a single numeric digit with values ranging from 1 to 5. Precision in this instance represents a composite

FEATURE COMPLEXITY CODE	NO. SPECIAL FEATURES
1	1
2	• 2
3	3
4	5
5	8
6	13
7	21
8	34
9	GT 34

Fig. 31.6 Complexity code for special features.

PART FAMILY SIZE CLASSIFICATION

SIZE CODE	MAXIMUM DIMENSION ENGLISH (in.)	METRIC (mm)	DESCRIPTION	EXAMPLES
1	.5	10	Sub-miniature	Capsules
2	2	50	Miniature	Paper clip box
3	4	100	Small	Large match box
4	10	250	Medium-small	Shoe box
5	20	500	Medium	Bread box
6	40	1000	Medium-large	Washing machine
7	100	2500	Large	Pickup truck
8	400	10000	Extra-large	Moving van
9	1000	25000	Giant	Railroad box-car

Fig. 31.7 Part family size classification.

of tolerance and surface finish. Class 1 precision represents very close tolerances and a precision-ground or lapped-surface finish. Class 5, on the other hand, represents a rough cast or flame-cut surface with a tolerance of greater than 1/32 in. High precision is accompanied by multiple processing operations and careful inspection operations. Production costs increase rapidly as closer tolerances and finer surface finishes are specified. Care is needed by the designer to ensure that high precision is warranted. The precision class code is shown in Fig. 31.8.

Material Code

The final two digits of the part family code represent the material type. The material form and condition codes are captured in the associated bitstring.

Seventy-nine distinct material families have been coded (Fig. 31.9). Each material family or type is identified by a two-digit code consisting of a single alphabetic character and a single numeric digit.

The stainless-steel family, for example, is coded "A6." The tool steel family is "A7." This code provides a pointer to specification sheets containing comprehensive data on material properties, availability, and processability.

The material code provides a set of standard interface codes to which may be appended a given industry class code when appropriate. For example, the stainless-steel code may have appended to it a specific material code to uniquely identify it as follows: "A6-430" represents a chromium-type, ferritic, non-hardenable stainless steel.

PRECISION CLASS CODE

CLASS CODE	TOLERANCE	SURFACE FINISH
1	LE .0005"	LE 4 RMS
2	.0005"-.002"	4-32 RMS
3	.002"-.010"	32-125 RMS
4	.010"-.030"	125-500 RMS
5	GT .030"	GT 500 RMS

Fig. 31.8 Precision class code.

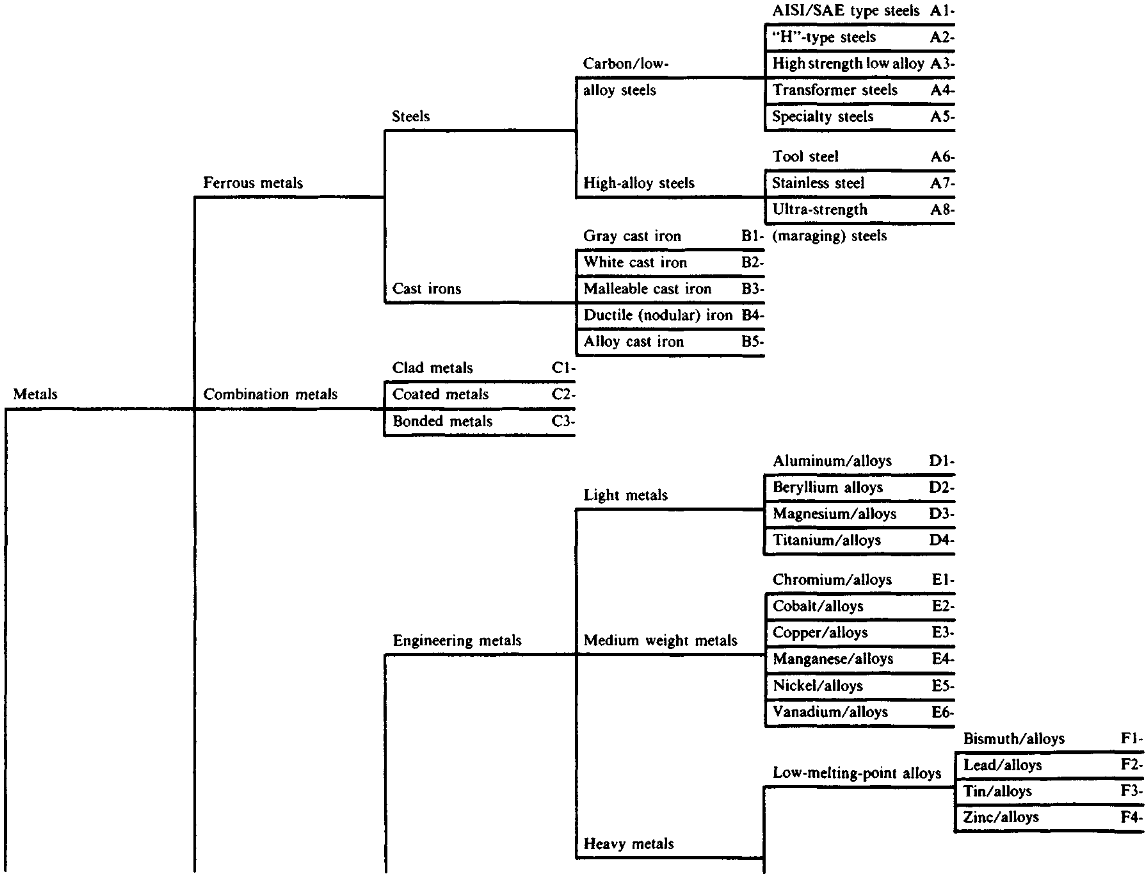


Fig. 31.9 Engineering materials.

- Engineering materials
  - Combination materials
    - Nonferrous metals
      - High-melting-point alloys
        - Niobium (columbium) G1-
        - Molybdenum/alloys G2-
        - Tantalum/alloys G3-
        - Tungsten/alloys G4-
      - Specialty metals
        - Precious metals
          - Noble metals H1-
          - Platinum group H2-
        - Semiconductor/specialty metals
          - Gallium/alloys J1-
          - Germanium/alloys J2-
          - Indium/alloys J3-
          - Silicon/alloys J4-
          - Tellurium/alloys J5-
        - Nuclear metals
          - Control materials K1-
          - Fuel material K2-
          - Liquid coolants K3-
          - Structural materials K4-
        - Rare-earth metals L1-
    - Composites
      - Fiber composite M1-
      - Particle composite M2-
      - Dispersion composite M3-
    - Foams, microspheres
      - Foams M4-
      - Microspheres M5-
    - Laminates
      - Clad laminates
      - Bonded laminates
      - Honeycomb laminates
      - M6-
    - Crystalline nonmetals
      - Minerals
        - Crystals N1-
        - Crystal/earth mixture N2-
      - Ceramics
        - Refractory ceramics
          - Furnace refractories N3-
          - Super-refractories N4-
        - Nonrefractory ceramics
          - Structural ceramics N5-
          - Nonstructural
            - Whiteware ceramics N6-
            - Technical ceramics N7-

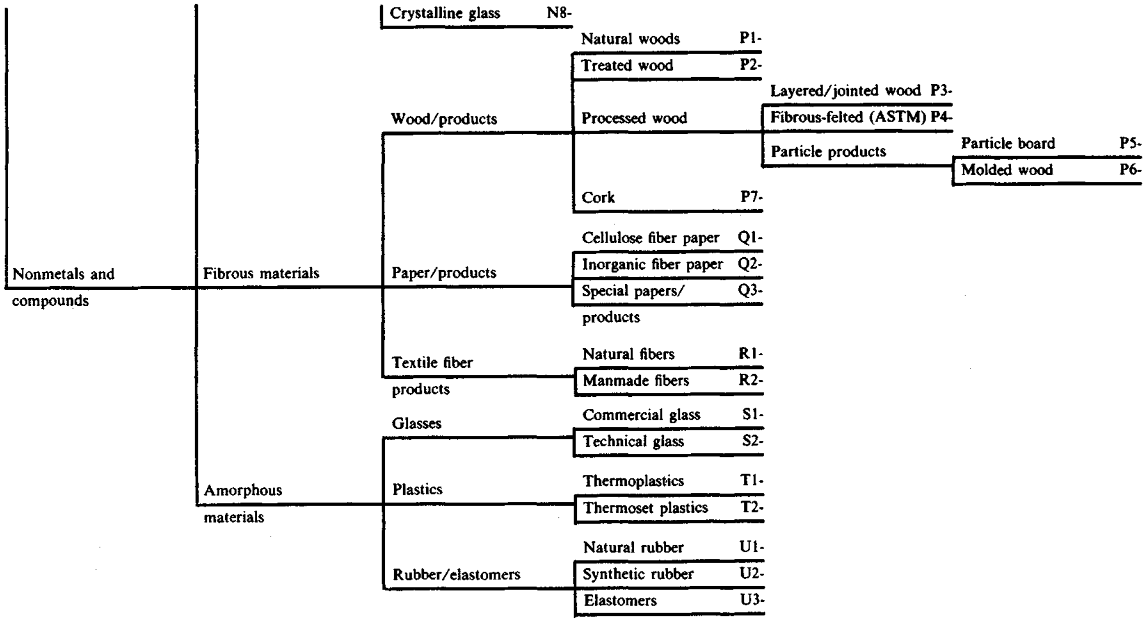


Fig. 31.9 *(Continued)*

31.1.5 Tailoring the System

It has been found that nearly all classification systems must be customized to meet the needs of each individual company or user. This effort can be greatly minimized by starting with a general system and then tailoring it to satisfy unique user needs. The Part Family Classification and Coding System permits this customizing. It is easy to add new geometric configurations to the existing family of basic shapes. It is likewise simple to add additional special features or to modify the size or precision class ranges. New material codes may be readily added if necessary.

The ability to modify easily an existing classification system without extensively reworking the system is one test of its design.

31.2 ENGINEERING MATERIALS TAXONOMY

31.2.1 Introduction

Serious and far-reaching problems exist with traditional methods of engineering materials selection. The basis for selecting a material is often tenuous and unsupported by defensible selection criteria and methods. A taxonomy of engineering materials accompanied by associated property files can greatly assist the designer in choosing materials to satisfy a design's functional requirements as well as procurement and processing requirements.

Material Varieties

The number of engineering materials from which a product designer may choose is staggering. It is estimated that over 40,000 metals and alloys are available, plus 250,000 plastics, uncounted composites, ceramics, rubbers, wood products, and so on. From this list, the designer must select the one for use with the new product. Each of these materials can exhibit a wide range of properties, depending on its form and condition. The challenge faced by the designer in selecting optimum materials can be reduced by a classification system to aid in identifying suitable material families.

Material Shortages

Dependency on foreign nations for certain key alloying elements, such as chromium, cobalt, tungsten and tin, points up the critical need for conserving valuable engineering materials and for selecting less strategic materials wherever possible. The recyclability of engineering materials has become another selection criterion.

Energy Requirements

The energy required to produce raw materials, process them, and then recycle them varies greatly from material to material. For example, recycled steel requires 75% less energy than steel made from iron ore, and recycled aluminum requires only about 10% of the energy of primary aluminum. Energy on a per-volume basis for producing ABS plastic is 2×10^6 Btu/in.^{3}, whereas magnesium requires 8×10^6 Btu/in.^{3}

31.2.2 Material Classification

Although there are many specialized material classification systems available for ferrous and nonferrous metals, there are no known commercial systems that also include composites and nonmetallics such as ceramic, wood, plastic, or glass. To remedy this situation, a comprehensive classification of all engineering materials was undertaken by the author. The resulting hierarchal classification or taxonomy provides 79 material families. Each of these families may be further subdivided by specific types as desired.

Objectives

Three objectives were established for developing an engineering materials classification system, including (1) minimizing search time, (2) facilitating materials selection, and (3) enhancing communication.

Minimize Search Time. Classifying and grouping materials into recognized, small subgroups having similar characteristic properties (broadly speaking) minimizes the time required to identify and locate other materials having similar properties. The classification tree provides the structure and codes to which important procedures, standards, and critical information may be attached or referenced. The information explosion has brought a superabundance of printed materials. Significant documents and information may be identified and referenced to the classification tree to aid in bringing new or old reference information to the attention of users.

Facilitate Materials Selection. One of the significant problems confronting the design engineer is that of selecting materials. The material chosen should ideally meet several selection criteria, including satisfying the design functional requirements, producibility, availability, and the more recent constraints for life-cycle costing, including energy and ecological considerations.

Materials selection is greatly enhanced by providing materials property tables in a format that can be used manually or that can be readily converted to computer usage. A secondary goal is to reduce material proliferation and provide for standard materials within an organization, thus reducing unnecessary materials inventory.

Enhance Communication. The classification scheme is intended to provide the logical grouping of materials for coding purposes. The material code associated with family of materials provides a pointer to the specific material desired and to its condition, form, and properties.

Basis of Classification

Although it is possible to use a fairly consistent basis of classification within small subgroups (e.g., stainless steels), it is difficult to maintain the same basis with divergent groups of materials (e.g., nonmetals). Recognizing this difficulty, several bases for classification were identified, and the one that seemed most logical (or that was used industrially) was chosen. This subgroup base was then cross-examined relative to its usefulness in meeting objectives cited in the preceding subsection.

The various bases for classification considered for the materials taxonomy are shown in Fig. 31.10. The particular basis selected for a given subgroup depends on the viewpoint chosen. The overriding viewpoint for each selection was (1) Will it facilitate material selection for design purposes? and (2) Does it provide a logical division that will minimize search time in locating materials with a predominant characteristic or property?

Taxonomy of Engineering Materials

An intensive effort to produce a taxonomy of engineering materials has resulted in the classification shown in Fig. 31.11. The first two levels of this taxonomy classify all engineering materials into the broad categories of metals, nonmetals and compounds, and combination materials. Metals are further subdivided into ferrous "nonferrous" and combination metals. Nonmetals are classified as crystalline, fibrous, and amorphous.

Combination materials are categorized as composites, foams, microspheres, and laminates. Each of these groups is further subdivided until a relatively homogeneous materials family is identified. At this final level a family code is assigned.

Customizing

The Engineering Materials Taxonomy may be easily modified to fit a unique user's needs. For example, if it were desirable to further subdivide "fiber-reinforced composites," it could easily be done

Base		Example
A.	State	Solid–liquid–gas
B.	Structure	Fibrous–crystalline–amorphous
C.	Origin	Natural–synthetic
D.	Application	Adhesive–paint–fuel–lubricant
E.	Composition	Organic–inorganic
F.	Structure	Metal–nonmetal
G.	Structure	Ferrous–nonferrous
H.	Processing	Cast–wrought
I.	Processing response	Water-hardening–oil-hardening–air-hardening, etc.
J.	Composition	Low alloy–high alloy
K.	Application	Nuclear–semiconducting–precious
L.	Property	Light weight–heavy
M.	Property	Low melting point–high melting point
N.	Operating environment	Low-temperature–high-temperature
O.	Operating environment	Corrosive–noncorrosive

Fig. 31.10 Basis for classifying engineering materials.

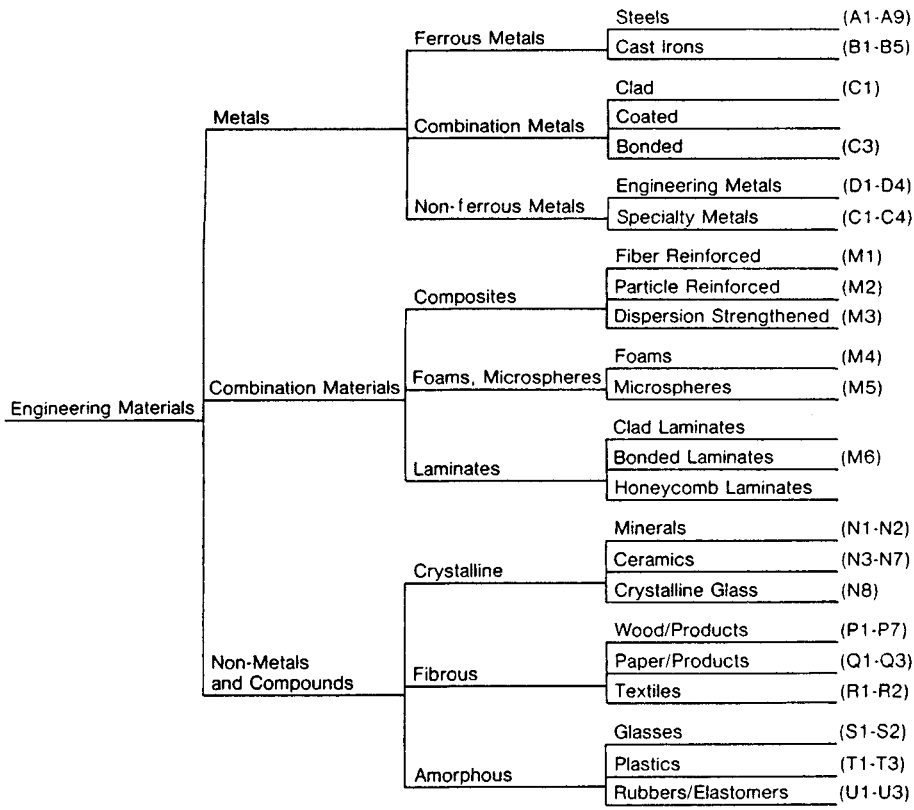


Fig. 31.11 Engineering materials taxonomy—three levels.

on the basis of type of filament used (e.g., boron, graphite, glass) and further by matrix employed (polymer, ceramic, metal). The code "M1," representing fiber-reinforced composites, could have appended to it a dash number uniquely identifying the specific material desired. Many additional material families may also be added if desired.

31.2.3 Material Code

As was mentioned earlier, there are many material classification systems, each of which covers only a limited segment of the spectrum of engineering materials available. The purpose of the Engineering Materials Taxonomy is to overcome this limitation. Furthermore, each of the various materials systems has its own codes. This creates additional problems. To solve this coding compatibility problem, a two-character alphanumeric code is provided as a standard interface code to which any industry or user code may be appended. This provides a very compact standard code so that any user will recognize the basic material family even though perhaps not recognizing a given industry code.

Material Code Format

The format used for the material code is shown in Fig. 31.12. The code consists of four basic fields of information. The first field contains a two-character interface code signifying the material family. The second field is to contain the specific material type based on composition or property. This code may be any five-character alphanumeric code. The third field contains a two-digit code containing the material condition (e.g., hot-worked, as-cast, ¾-hard). The fourth and final field of the code contains a one-digit alphabetic code signifying the material form (e.g., bar, sheet, structural shape).

Material Families

Of the 79 material families identified, 13 are ferrous metals, 30 are nonferrous metals, 6 are combination materials (composites, foams, laminates), and 26 are nonmetals and compounds.

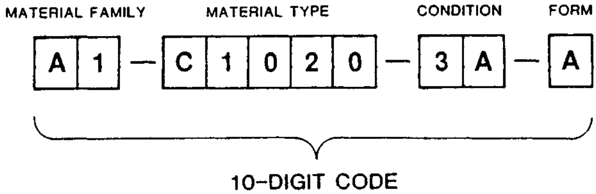


Fig. 31.12 Format for engineering materials code.

The five-digit code space reserved for material type is sufficient to accommodate the UNS (Unified Numbering System) recently developed by ASTM, SAE, and others for metals and alloys. It will also accommodate industry or user-developed codes for nonmetals or combination materials. An example of the code (Fig. 31.10) for an open-hearth, low-carbon steel would be "A1-C1020," with the first two digits representing the steel family and the last five digits the specific steel alloy.

Material Condition

The material condition code consists of a two-digit code derived for each material family. The intent of this code is to reflect processes to which the material has been subjected and its resultant structure. Because of the wide variety of conditions that do exist for each family of materials, the creation of a D-tree for each of the 79 families seems to be the best approach. The D-tree can contain processing treatments along with resulting grain size, microstructure, or surface condition if desired. Typical material condition codes for steel family "Al" are given in Fig. 31.13.

Material form code consists of a single alphabetic character to represent this raw material form (e.g., rod, bar, tubing, sheet, structural shape). Typical forms are shown in Fig. 31.14.

31.2.4 Material Properties

Material properties have been divided into three broad classes: (1) mechanical properties, (2) physical properties, and (3) chemical properties. Each of these will be discussed briefly.

Mechanical Properties

The mechanical properties of an engineering material describe its behavior or quality when subjected to externally applied forces. Mechanical properties include strength, hardness, fatigue, elasticity, and plasticity. Figure 31.15 shows representative mechanical properties. Note that each property has been identified with a unique code number to reduce confusion in communicating precisely which property is intended. Confusion often arises because of the multiplicity of testing procedures that have been devised to assess the value of a desired property. For example, there are at least 15 different penetration hardness tests in common usage, each of which yields different numerical results from the others. The code uniquely identifies the property and the testing method used to ascertain it.

Each property of a material is intimately related to its composition, surface condition, internal condition, and material form. These factors are all included in the material code. A modification of any of these factors, either by itself or in combination, can result in quite different mechanical properties.

Thus, each material code combination is treated as a unique material. As an example of this, consider the tensile strength of a heat-treated 6061 aluminum alloy: in the wrought condition, the ultimate tensile strength is 19,000 psi; with the T4-temper, the ultimate tensile strength is 35,000 psi; and in the T913 condition, the ultimate tensile strength is 68,000 psi.

Physical Properties

The physical properties of an engineering material have to do with the intrinsic or structure-insensitive properties. These include melting point, expansion characteristics, dielectric strength, and density. Figure 31.16 shows representative physical properties.

Again, each property has been coded to aid in communication. Magnetic properties and electrical properties are included in this section for the sake of simplicity.

Chemical Properties

The chemical properties of an engineering material deal with its reactance to other materials or substances, including its operating environment. These properties include chemical reactivity, corrosion characteristics, and chemical compatibility. Atomic structure factors, chemical valence, and related factors useful in predicting chemical properties may also be included in the broad category of chemical properties. Figure 31.17 shows representative chemical properties.

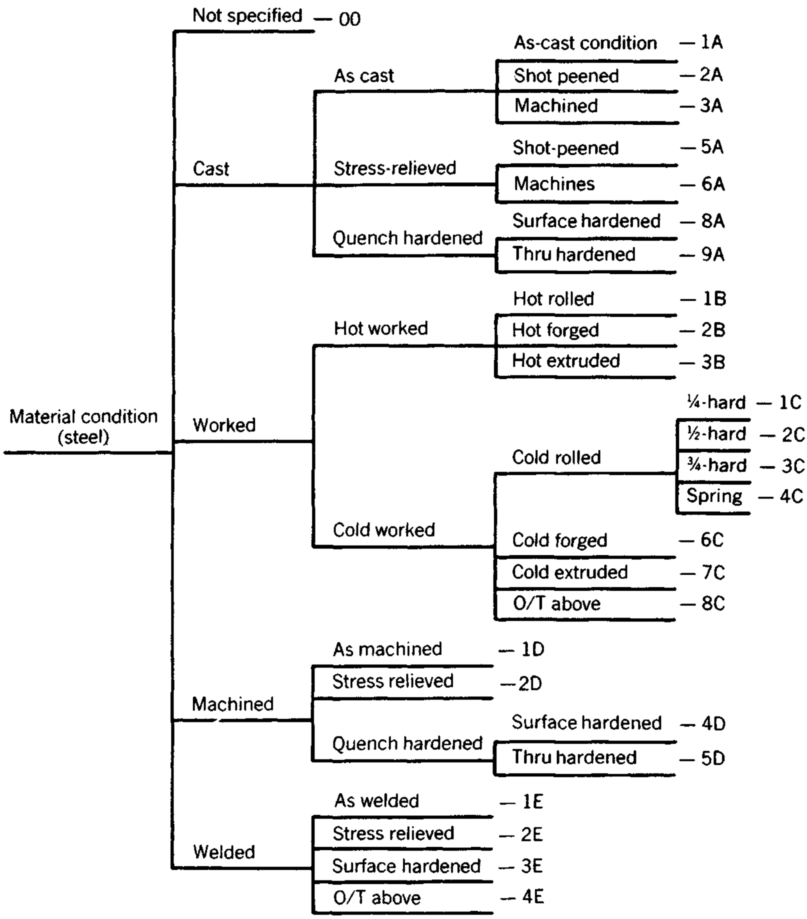


Fig. 31.13 Material condition for steel family "A1."

31.2.5 Material Availability

The availability of an engineering material is a prime concern in materials selection and use. Material availability includes such factors as stock shapes, sizes, and tolerances; material condition and finish; delivery; and price.

Other factors of increasing significance are energy requirements for winning the material from nature and recyclability. Figure 31.18 shows representative factors for assessing material availability.

31.2.6 Material Processability

Relative processability ratings for engineering materials in conjunction with material properties and availability can greatly assist the engineering designer in selecting materials that will meet essential design criteria. All too often, the processability of a selected engineering material is unknown to the designer. As likely as not, the materials may warp during welding or heat treatment and be difficult to machine, which may result in undesirable surface stresses because of tearing or cracking during drawing operations. Many of these problems could be easily avoided if processability ratings of various materials were ascertained, recorded, and used by the designer during the material selection process. Figure 31.19 shows relative processability ratings. These ratings include machinability, weldability, castability, moldability, formability, and heat-treatability. Relative ratings are established through experience for each family. Ratings must not be compared between families. For example, the machinability rating of two steels may be compared, but they should not be evaluated against brass or aluminum.

O—Unspecified

Rotational Solids

A—Rod/wire
B—Tubing/pipe

Flat Solids

C—Bar, flats
D—Hexagon/octagon
E—Sheet/plate

Structural Shapes

F—Angle
G—T section
H—Channel
I—H, I sections
J—Z sections
K—Special sections (extruded, rolled, etc.)

Fabricated Solid Shapes

L—Forging
M—Casting/ingot
N—Weldment
P—Powder metal
Q—Laminate
R—Honeycomb
S—Foam

Special Forms

T—Resin, liquid, granules
U—Fabric, roving, filament
V—Putty, clay
W—Other
Y—Reserved
Z—Reserved

Fig. 31.14 Raw material forms.

31.3 FABRICATION PROCESS TAXONOMY

31.3.1 Introduction

Purpose

The purpose of classifying manufacturing processes is to form families of related processes to aid in process selection, documentation of process capabilities, and information retrieval. A taxonomy or classification of manufacturing processes can aid in process selection by providing a display of potential manufacturing options available to the process planner.

Documentation of process capabilities can be improved by providing files containing the critical attributes and parameters for each classified process. Information retrieval and communication relative to various processes can be enhanced by providing a unique code number for each process. Process information can be indexed, stored, and retrieved by this code.

Classification and coding is an art and, as such, it is difficult to describe the steps involved, and even more difficult to maintain consistency in the results. The anticipated benefits to users of a well-

Mechanical Properties	D 1 - 0 6 0 6 1 - 1 B - C		
Material Family/Type: Aluminum 6061-T6			
Prepared by:	Date:	Approved by:	Date:
Revision No./Date:			
Code	**Description**	**Value**	**Units**
11.02	Brinell hardness number	95	HB
12.06	Yield strength, 0.2% offset	40,000	psi
12.11	Ultimate tensile strength	45,000	psi
12.20	Ultimate shear (bearing) strength	30,000	psi
12.30	Impact energy (Charpy V-notch)		ft-lb
12.60	Fatigue (endurance limit)	14,000	psi
12.70	Creep strength		psi
13.01	Modulus of elasticity (tensile)	10.0×10^6	psi
13.02	Modulus of elasticity (compressive)	10.2×10^6	psi
13.20	Poisson's ratio	—	—
14.02	Elongation	15	%
14.10	Reduction of area	—	%
14.30	Strain hardening coefficient	—	%
14.40	Springback	—	%

Fig. 31.15 Representative mechanical properties.

planned process classification outweigh the anticipated difficulties, and thus the following plan is being formulated to aid in uniform and consistent classification and coding of manufacturing processes.

Primary Objectives

There are three primary objectives for classifying and coding manufacturing processes: (1) facilitating process planning, (2) improving process capability assessment, and (3) aiding in information retrieval.

Facilitate Process Selection. One of the significant problems confronting the new process planner is process selection. The planner must choose, from many alternatives, the basic process, equipment, and tooling required to produce a given product of the desired quality and quantity in the specified time.

Although there are many alternative processes and subprocesses from which to choose, the process planner may be well acquainted with only a small number of them. The planner may thus continue to select these few rather than become acquainted with many of the newer and more competitive processes. The proposed classification will aid in bringing to the attention of the process planner all the processes suitable for modifying the shape of a material or for modifying its properties.

Improve Process Capability Assessment. One of the serious problems facing manufacturing managers is that they can rarely describe their process capabilities. As a consequence, there is commonly a mismatch between process capability and process needs. This may result in precision parts being produced on unsuitable equipment, with consequent high scrap rates, or parts with no critical tolerances being produced on highly accurate and expensive machines, resulting in high manufacturing costs.

Process capability files may be prepared for each family of processes to aid in balancing capacity with need.

Aid Information Retrieval. The classification and grouping of manufacturing processes into subgroups having similar attributes will minimize the time required to identify and retrieve similar processes. The classification tree will provide a structure and branches to which important information may be attached or referenced regarding process attributes, methods, equipment, and tooling.

The classification tree provides a logical arrangement for coding existing processes as well as a place for new processes to be added.

Physical Properties	D 1 - 0 6 0 6 1		
Material Family/Type: Aluminum 6061-T6			
Prepared by:	Date:	Approved by:	Date:
Revision No./Date:			
Code	**Description**	**Value**	**Units**
21.01	Coefficient of linear expansion	13×10^{-6}	in./in./°F
21.05	Thermal conductivity	1070	Btu/in./ft²/°F/hr
21.40	Minimum service temperature	−320	°F
21.50	Maximum service temperature	700	°F
21.66	Melting range	1080–1200	°F
21.80	Recrystallization temperature	650	°F
21.90	Annealing temperature	775	°F, 2–3 hr
21.92	Stress-relieving temperature	450	°F, 1 hr
21.95	Solution heat treatment	970	°F
21.96	Precipitation heat treatment	350	°F, 6–10 hr
22.01	Electrical conductivity (weight)	40	%
22.02	Electrical conductivity (volume)	135	%
22.10	Electrical resistivity (volume)	26	ohms mil, ft
26.01	Specific weight	0.098	lb/in.³
26.03	Specific gravity	270	gm/cm³
26.35	Crystal (lattice) system	f.c.c.	—
26.70	Damping index	0.03	Very low
26.71	Strength-to-weight ratio		
26.72	Basic refining energy	100,000	Btu/lb
26.73	Recycling energy	10,000	Btu/lb

Fig. 31.16 Representative physical properties.

31.3.2 Process Divisions

Manufacturing processes can be broadly grouped into two categories: (1) shaping processes and (2) nonshaping processes. Shaping processes are concerned primarily with modifying the shape of the plan material into the desired geometry of the finished part. Nonshaping processes are primarily concerned with modifying material properties.

Shaping Processes

Processes available for shaping the raw material to produce a desired geometry may be classified into three subdivisions: (1) mass-reducing processes, (2) mass-conserving processes, and (3) mass-increasing or joining processes. These processes may then be further subdivided into mechanical, thermal, and chemical processes.

Mass-reducing processes include cutting, shearing, melting or vaporizing, and dissolving or ionizing processes. Mass-conserving processes include casting, molding, compacting, deposition, and laminating processes. Mass-increasing or, more commonly, joining, processes include pressure and thermal welding, brazing, soldering, and bonding. The joining processes are those that produce a megalithic structure not normally disassembled.

Nonshaping Processes

Nonshaping processes that are available for modifying material properties or appearance may be classified into two broad subdivisions: (1) heat-treating processes and (2) surface-finishing processes.

Heat-treating processes are designed primarily to modify mechanical properties, or the processability ratings, of engineering materials. Heat-treating processes may be subdivided into (1) annealing (softening) processes, (2) hardening processes, and (3) other processes. The "other" category includes sintering, firing/glazing, curing/bonding, and cold treatments. Annealing processes are designed to

Chemical Properties	D 1 - 0 6 0 6 1		
Material Family/Type: Aluminum 6061-T6			
Prepared by:	Date:	Approved by:	Date:
Revision No./Date:			
Code	**Description**	**Value[a]**	**Units**
32.01	Resistance to high-temperature corrosion	C	
32.02	Resistance to stress corrosion cracking	C	
32.03	Resistance to corrosion pitting	B	
32.04	Resistance to intergranular corrosion	B	
32.10	Resistance to fresh water	A	
32.11	Resistance to salt water	A	
32.15	Resistance to acids	A	
32.20	Resistance to alkalies	C	
32.25	Resistance to petrochemicals	A	
32.30	Resistance to organic solvents	A	
32.35	Resistance to detergents	B	
33.01	Resistance to weathering	A	

[a] *Key:* A = fully resistant; B = slightly attacked; C = unsatisfactory.

Fig. 31.17 Representative chemical properties.

soften the work material, relieve internal stresses, or change the grain size. Hardening treatments, on the other hand, are often designed to increase strength and resistance to surface wear or penetration. Hardening treatments may be applied to the surface of a material or the treatments may be designed to change material properties throughout the section.

Surface-finishing processes are those used to prepare the workpiece surface for subsequent operations, to coat the surface, or to modify the surface. Surface-preparation processes include descaling, deburring, and degreasing. Surface coatings include organic and inorganic; metallic coatings applied by spraying, electrostatic methods, vacuum deposition, and electroplating; and coatings applied through chemical-conversion methods.

Surface-modification processes include burnishing, brushing, peening, and texturing. These processes are most often used for esthetic purposes, although some peening processes are used to create warped surfaces or to modify surface stresses.

31.3.3 Process Taxonomy

There are many methods for classifying production processes. Each may serve unique purposes. The Fabrication Process Taxonomy is the first known comprehensive classification of all processes used for the fabrication of discrete parts for the durable goods manufacturing industries.

Basis of Classification

The basis for process classification may be the source of *energy* (i.e., mechanical, electrical, or chemical); the *temperature* at which the processing is carried out (i.e, hot-working, cold-working); the type of material to be processed (i.e., plastic, steel, wood, zinc, or powdered metal); or another basis of classification.

The main purpose of the hierarchy is to provide functional groupings without drastically upsetting recognized and accepted families of processes within a given industry. For several reasons, it is difficult to select only one basis for classification and apply it to all processes and achieve usable results. Thus, it will be noted that the fabrication process hierarchy has several bases for classification, each depending on the level of classification and on the particular family of processes under consideration.

Classification Rules and Procedures

Rule 1. Processes are classified as either shaping or nonshaping, with appropriate mutually exclusive subdivisions.

Availability	D 1 - 0 6 0 6 1
Material Family/Type: Aluminum 6061-T6	
Prepared by: Date:	Approved by: Date:
Revision No./Date:	
Surface Condition Cold worked Hot worked Cast Clad Peened Chromate Anodized Machined	
Internal Condition Annealed Solution treated—naturally aged Solution treated—artificially aged Stress relieved Cold worked	
Forms Available Sheet Plate Bar Tubing Wire Rod Extrusions Ingot	

Fig. 31.18 Factors relating to material availability.

Rule 2. Processes are classified as independent of materials and temperature as possible.

Rule 3. Critical attributes of various processes are identified early to aid in forming process families.

Rule 4. Processes are subdivided at each level to show the next options available.

Rule 5. Each process definition is in terms of relevant critical attributes.

Rule 6. Shaping process attributes include

- **6.1** Geometric shapes produced
- **6.2** Form features or treatments imparted to the workpiece
- **6.3** Size, weight, volume, or perimeter of parts
- **6.4** Part precision class
- **6.5** Production rates
- **6.6** Set-up time

Processability	D 1 - 0 6 0 6 1 - 1 B - C			
Material Family/Type: Aluminum 6061-T6				
Prepared by: Date: Approved by: Date:				
Revision No./Date:				
Processability Type	Rating			
	Poor 1	Fair 2	Good 3	Excellent 4
Machinability				X
Grindability (silicon carbide adhesive)			X	
Shear behavior				X
EDM rating	X			
Chemical etch factor		X		
Forgeability			X	
Extrudability				
Formability			X	
Weldability				X
Heat-treatability				X

Fig. 31.19 Relative processability ratings.

6.7 Tooling costs
6.8 Relative labor costs
6.9 Scrap and waste material costs
6.10 Unit costs versus quantities of 10, 100, 1 K, 10 K, 100 K

Rule 7. All processes are characterized by
7.1 Prerequisite processes
7.2 Materials that can be processed, including initial form
7.3 Basic energy source: mechanical, thermal, or chemical
7.4 Influence of process on mechanical properties such as strength, hardness, or toughness
7.5 Influence of process on physical properties such as conductivity, resistance, change in density, or color
7.6 Influence of process on chemical properties such as corrosion resistance

Rule 8. At the operational level, the process may be fully described by the operation description and sequence, equipment, tooling, processing parameters, operating instructions, and standard time.

The procedure followed in creating the taxonomy was first to identify all the processes that were used in fabrication processes. These processes were then grouped on the basis of relevant attributes. Next, most prominent attributes were selected as the parent node label. Through a process of selection, grouping, and classification, the taxonomy was developed. The taxonomy was evaluated and found to readily accommodate new processes that subsequently were identified. This aided in verifying the generic design of the system. The process taxonomy was further cross-checked with the equipment and tooling taxonomies to see if related categories existed. In several instances, small modifications were required to ensure that the various categories were compatible. Following this method for cross-checking among processes, equipment, and tooling, the final taxonomy was prepared. As the taxonomy was subsequently typed and checked, and large charts were developed for printing, small remaining discrepancies were noted and corrected. Thus, the process taxonomy is presented as the best that is currently available. Occasionally, a process is identified that could be classified in one or more categories. In this case, the practice is to classify it with the preferred group and cross-reference it in the second group.

31.3.4 Process Code

The process taxonomy is used as a generic framework for creating a unique and unambiguous numeric code to aid in communication and information retrieval.

The process code consists of a three-digit numeric code. The first digit indicates the basic process division and the next two digits indicate the specific process group. The basic process divisions are as follows:

000	Material identification and handling
100	Material removal processes
200	Consolidation processes
300	Deformation processes
400	Joining processes
500	Heat-treating processes
600	Surface-finishing processes
700	Inspection
800	Assembly
900	Testing

The basic process code may be extended with the addition of an optional decimal digit similar to the Dewey Decimal System. The process code is organized as shown in Fig. 31.20.

The numeric process code provides a unique, easy-to-use shorthand communication symbol that may be used for manual or computer-assisted information retrieval. Furthermore, the numeric code can be used on routing sheets, in computer databases, for labeling of printed reports for filing and retrieval purposes, and for accessing instructional materials, process algorithms, appropriate mathematical and graphical models, and the like.

31.3.5 Process Capabilities

Fundamental to process planning is an understanding of the capabilities of various fabrication processes. This understanding is normally achieved through study, observation, and industrial experience. Because each planner has different experiences and observes processes through different eyes, there is considerable variability in derived process plans.

Fabrication processes have been grouped into families having certain common attributes. A study of these common attributes will enable the prospective planner to learn quickly the significant characteristics of the process without becoming confused by the large amount of factual data that may be available about the given process.

Also, knowledge about other processes in a given family will help the prospective planner learn about a specific process by inference. For example, if the planner understands that "turning" and "boring" are part of the family of single-point cutting operations and has learned about cutting-speed calculations for turning processes, the planner may correctly infer that cutting speeds for boring operations would be calculated in a similar manner, taking into account the rigidity of each setup. It is important at this point to let the prospective planner know the boundaries or exceptions for such generalizations.

A study of the common attributes and processing clues associated with each of these various processes will aid the planner. For example, an understanding of the attributes of a given process and recognition of process clues such as "feed marks," "ejector-pin marks," or "parting lines" can help the prospective planner to identify quickly how a given part was produced.

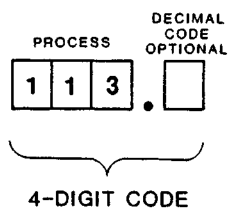


Fig. 31.20 Basic process code.

Figures 31.21 and 31.22 show a process capability sheet that has been designed for capturing information relative to each production process.

31.4 FABRICATION EQUIPMENT CLASSIFICATION

31.4.1 Introduction

Utilization of Capital Resources

One of the primary purposes for equipment classification systems is to better utilize capital resources. The amount of capital equipment and tooling per manufacturing employee has been reported to range from $30,000 to $50,000. An equipment classification system can be a valuable aid in capacity planning, equipment selection, equipment maintenance scheduling, equipment replacement, elimination of unnecessary equipment, tax depreciation, and amortization.

PROCESS CAPABILITY SHEET

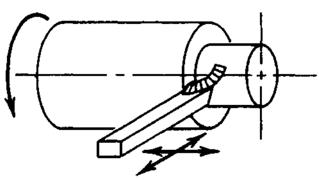
Process: Turning/Facing	Code: 101
Prepared by: Date:	Approved by: Date:
Revision No. & Date:	
Schematic: 	Attributes: • Single point cutting tool • Chips removed from external surface • Helical or annular (tree-ring) feed marks are present.
Basic Shapes Produced: Surfaces of revolution (cylindrical, tapered, spherical) or flat shoulders or ends. May have discontinuities in surfaces (interrupted cut).	
Form Features or Treatments: Bead, boss, chf'r, groove , lip, radius, thread	
Size Range: 1-6	
Precision Class: 1-4	
Raw Material Type: Steel, cast iron, light metals, non-ferrous engineering metals, low-m.p. metals, refractory metals, nuclear metals, composites, refractories, wood, polymers, rubbers and elastometers	

Fig. 31.21 Process capability sheet.

Process: Turning/Facing							Code: 101
Raw Material Condition: Hot-rolled, cold-rolled, forged, cast							
Raw Material Form: rod, tubing, forgings, castings							
Production Rate		1 A	10 B	100 C	1,000 D	10,000 E	100,000 F
Tooling Costs	High-3						
	Med-2						
	Low-1						
Set-up Time	High-3						
	Med-2						
	Low-1						
Labor Costs	High-3						
	Med-2						
	Low-1						
Scrap & Waste Material Costs	High-3						
	Med-2						
	Low-1						
Unit Costs	High-3						
	Med-2						
	Low-1						
Prerequisite Processes: Hot-rolling, cold rolling, forging, casting, p/m compacting							
Influence on Mechanical Properties: Creates very thin layer of stressed work material. Grains may be slightly deformed, and built-up edge may be present on work surface.							
Influence on Physical Properties: N/A							
Influence on Chemical Properties: Highly stressed work surface may promote corrosion.							

Fig. 31.22 Process capability sheet.

Equipment Selection

A key factor in equipment selection is a knowledge of the various types of equipment and their capabilities. This knowledge may be readily transmitted through the use of an equipment classification tree showing the various types of equipment and through equipment specification sheets that capture significant information regarding production capabilities.

Equipment selection may be regarded as matching—the matching of production needs with equipment capabilities. Properly defined needs based on current and anticipated requirements, when coupled with an equipment classification system, provide a logical, consistent strategy for equipment selection.

Manufacturing Engineering Services

Some of the manufacturing engineering services that can be greatly benefitted by the availability of an equipment classification system include process planning, tool design, manufacturing development, industrial engineering, and plant maintenance. The equipment classification code can provide an index pointer to performance records, tooling information, equipment specification sheets (mentioned previously), and other types of needed records.

Quality Assurance Activities

Acceptance testing, machine tool capability assessment, and quality control are three important functions that can be enhanced by means of an equipment classification and coding system. As before, the derived code can provide a pointer to testing and acceptance procedures appropriate for the given family of machines.

31.4.2 Standard and Special Equipment

The classification system described below can readily accommodate both standard and special equipment. *Standard fabrication equipment* includes catalog items such as lathes, milling machines, drills, grinders, presses, furnaces, and welders. Furthermore, they can be used for making a variety of products. Although these machines often have many options and accessories, they are still classified as standard machines. *Special fabrication machines,* on the other hand, are custom designed for a special installation or application. These machines are usually justified for high-volume production or special products that are difficult or costly to produce on standard equipment. Examples of special machines include transfer machines, special multistation machines, and the like.

31.4.3 Equipment Classification

The relationship among the fabrication process, equipment, and tooling is shown graphically in Fig. 31.23 The term *process* is basically a concept and requires equipment and tooling for its physical embodiment. For example, the grinding process cannot take place without equipment and tooling. In some instances, the process can be implemented without equipment, as in "hand-deburring." The hierarchal relationships shown in Fig. 31.23 between the process, equipment, and tooling provide a natural linkage for generative process planning. Once the required processes have been identified for reproducing a given geometric shape and its associated form features and special treatments, the selection of equipment and tooling is quite straightforward.

Rationale

Two major functions of an equipment classification system are for process planning and tool design. These functions are performed each time a new product or piecepart is manufactured. Consequently, the relationships between processes, equipment, and tooling have been selected as primary in development of the equipment classification system.

The equipment taxonomy parallels the process taxonomy as far as possible. Primary levels of classification include those processes whose intent is to change the form of the material—for example, shaping processes and those processes whose intent is to modify or enhance the material properties. These nonshaping processes include heat treatments and coating processes, along with attendant cleaning and deburring.

As each branch of a process tree is traversed, it soon becomes apparent that there is a point at which an equipment branch must be grafted in. It is at this juncture that the basis for equipment classification must be carefully considered. There are a number of possible bases for classification of equipment, including

1. Form change (shaping, nonshaping)
2. Mass change (reduction, consolidation, joining)
3. Basic process (machine, cast, forge)
4. Basic subprocess (deep hole drill, precision drill)
5. Machine type (gang drill, radial drill)
6. Energy source (chemical, electrical, mechanical)

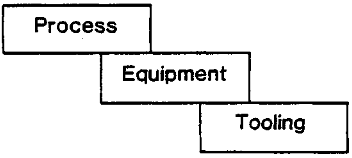


Fig. 31.23 Relationships between process, equipment, and tooling.

7. Energy transfer mechanism (mechanical, hydraulic, pneumatic)
8. Raw material form (sheet metal, forging, casting)
9. Shape produced (gear shaper, crankshaft lathe)
10. Speed of operation (high speed, low speed)
11. Machine orientation (vertical, horizontal)
12. Machine structure (open-side, two-column)
13. General purpose/special purpose (universal mill, spar mill)
14. Kinematics/motions (moving head, moving bed)
15. Control type (automatic, manual NC)
16. Feature machined (surface, internal)
17. Operating temperature (cold rolling, hot rolling)
18. Material composition (plastic molding, aluminum die casting)
19. Machine size (8-in. chucker, 12-in. chucker)
20. Machine power (600 ton, 100 ton)
21. Manufacturer (Landis, Le Blond, Gisholt)

In reviewing these bases of classification, it is apparent that some describe fundamental characteristics for dividing the equipment population into families, and others are simply attributes of a given family. For example, the features of "shaping," "consolidation," and "die casting" are useful for subdivision of the population into families (E-tree), whereas attributes such as "automatic," "cold-chamber," "aluminum," "100-ton," and "Reed-Prentice" are useful for characterizing equipment within a given family (N-tree). "Automatic" is an attribute of many machines; likewise, "100-ton" could apply to general-purpose presses, forging presses, powder-metal compacting presses, and so on. Similarly, the label "Reed-Prentice" could be applied equally well to lathes, die casting machines, or injection molders. In other words, these terms are not very useful for development of a taxonomy but are useful for characterizing a family.

Equipment Taxonomy

The first major division, paralleling the processes, is shaping or nonshaping. The second level for shaping is (1) mass-reducing, (2) mass-conserving, and (3) mass-increasing. The intent of this subdivision, as was mentioned earlier, is to classify equipment whose intent is to change the form or shape of the workpiece. The second level for nonshaping equipment includes (1) heat treating and (2) surface finishing. The intent of this subdivision is to classify equipment designed to modify or enhance material properties or appearance. The existing taxonomy identifies 257 unique families of fabrication equipment.

Customizing

As with other taxonomies described herein, the equipment taxonomy is designed to readily accommodate new classes of machines. This may be accomplished by traversing the tree until a node point is reached where the new class or equipment must appropriately fit. The new equipment with its various subclasses may be grafted in at this point and an appropriate code number assigned. It should be noted that code numbers have been intentionally reserved for this purpose.

31.4.4 Equipment Code

The code number for fabrication equipment consists of a nine-character code. The first three digits identify the basic process, leaving the remaining six characters to identify uniquely any given piece of equipment. As can be seen in Fig. 31.24, the code consists of four fields. Each of these fields will be briefly described in the following paragraphs.

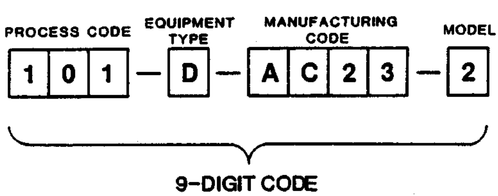


Fig. 31.24 Fabrication equipment code.

Process Code

The process code is a three-digit code that refers to one of the 222 fabrication processes currently classified. For example, code 111 = drilling and 121 = grinding. Appended to this code is a code for the specific type of equipment required to implement the given process.

Equipment Family Code

The code for equipment type consists of a one-character alphabetic code. For example, this provides for up to 26 types of turning machines, 101-A through 101-Z, 26 types of drilling machines, and so on. Immediately following the code for equipment type is a code that uniquely identifies the manufacturer.

Manufacturer Code

The manufacturer code consists of a four-digit alphanumeric code. The first character in the code is an alphabetic character (A–Z) representing the first letter in the name of the manufacturing company. The next three digits are used to identify uniquely a given manufacturing company. In-house-developed equipment would receive a code for your own company.

Model Number

The final character in the code is used to identify a particular manufacturer model number. Thus the nine-digit code is designed to provide a shorthand designation as to the basic process, type of equipment, manufacturer, and model number. The code can serve as a pointer to more detailed information, as might be contained on specification sheets, installation instructions, maintenance procedures, and so on.

31.4.5 Equipment Specification Sheets

In the preceding subsections the rationale for equipment classification was discussed, along with the type of information useful in characterizing a given piece of equipment. It has been found that this characterization information is best captured by means of a series of equipment specification sheets.

The philosophy has been that each family must have a tailored list of features or specifications to characterize it adequately. For example, the terms *swing, center-distance, rpm,* and *feed per revolution* are appropriate for a lathe family but not for forming presses, welding machines, electrical discharge machines, or vibratory deburring machines. Both common attributes and selected ones are described in the following paragraphs and shown in Figs. 31.25 and 31.26.

Equipment Family/Code

The equipment family label consists of the generic family name, subgroup name (e.g., "drill," "radial"), and the nine-digit equipment code.

Equipment Identification

Equipment name, make, model, serial number, and location provide a unique identification description for a given piece of equipment. The equipment name may be the familiar name given to the piece of equipment and may differ from the generic equipment family name.

Acquisition Data

The acquisition data include capital cost, date acquired, estimated life, and year of manufacture. This information can be used for amortization and depreciation purposes.

Facilities/Utilities

Facilities and utilities required for installing and operating the equipment include power (voltage, current, phases, frequency), and other connections, floor space, height, and weight.

Specifications

The specifications for functionality and capabilities for each family of machines must be carefully defined to be useful in selecting machines to meet needs of intended applications.

Operation Codes

A special feature of the equipment specification sheet is the section reserved for operation codes. The operation codes provide an important link between workpiece requirements and equipment capability. For example, if the workpiece is a rotational, machined part with threads, grooves, and a milled slot, and if a lathe is capable of operations for threading and grooving but not a milling slot, then it follows that either two machines are required to produce the part or a milling attachment must

Equipment Family: Mill, NC, vertical	Code: 113-K
Identification:	
Name: Cintimatic, Single Spindle	Serial No.: 364
Make/Model: Cincinnati Milling Machine Co.	Location: 115 SNLB
Acquisition:	
Capital Cost: $25,000	Estimated Life: 15 yr
Date Acquired: 15 Aug. 1963	Year of Manufacture: 1963
Maintenance:	
Condition: U2	Reevaluation Date: 15 January 1981
Date: 15 Aug. 1963	
Facilities:	
Voltage: 230 volts, 3 ph, 60 Hz	Floor Space: 63 in. × 74 in.
Current: 3 hp	Height: 101 in.
Other Connections: Air, 40 psi	Weight:

Specifications:

Working surface	22 in. × 36 in.
Throat	16$\frac{1}{4}$ in.
Table top to spindle	14–24 in. (8 in. travel)
Weight capacity, max	1000 lb
Spindle:	
Axes	One axis
Range	85–3800 rpm
Rate	1–40 ipm
Table:	
Axes	Two axes
Range	15 in. × 25 in.
Rate	Feed—0–40 ipm, rapid travel 200 ipm
Motor hp:	
Drive motor	3.0 hp
Feed	Hydraulic servo motors
Coolant	Air mist spray
Spindle taper	#40 NMTB
T-slots	3 in X axis, $\frac{11}{16}$ in. wide
Accuracy	±0.001 in. in 24 in.
Control type	Accramatic Series 200 control

Fig. 31.25 Equipment specifications.

be installed on the lathe. A significant benefit of the operation code is that it can aid process planners in selecting the minimum number of machines required to produce a given workpiece. This fact must, of course, be balanced with production requirements and production rates. The main objective is to reduce transportation and waiting time and minimize cost. (See Fig. 31.26.)

Photograph or Sketch

A photograph or line drawing provides considerable data to aid in plant layout, tool design, process planning, and other production planning functions. Line drawings often provide information regarding T-slot size, spindle arbor size, limits of machine motion, and other information useful in interfacing the machine with tooling, fixtures, and the workpiece.

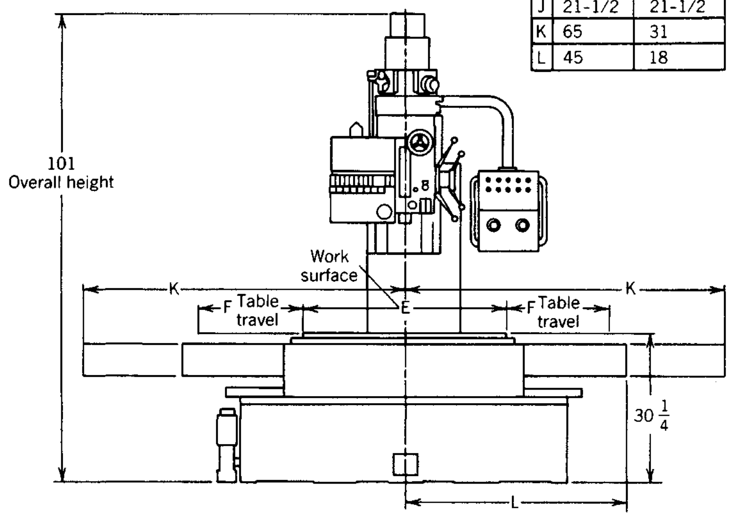
Equipment Family: Mill, N/C, vertical Code: 113-K

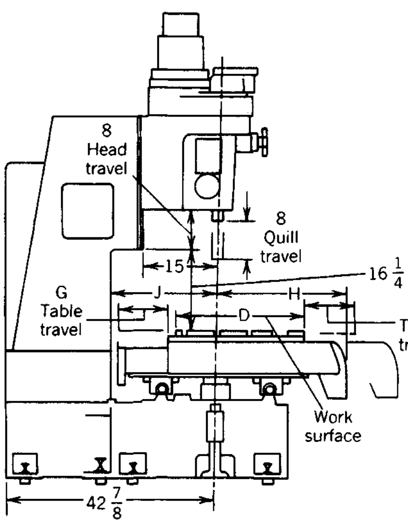
Operation Codes:

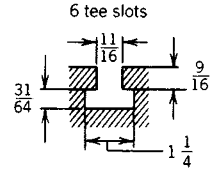
102 (boring), 104 (grooving), 111 (drilling), 112 (reaming), 113 (milling), 115 (tapping)

Photo or Sketch

	20" × 40" table	18" × 25" table
A	48	36
B	28-7/8	29-1/2
C	9-7/8	12-1/2
D	25-3/8	22
E	41	27
F	20	13
G	10	8
H	27	26-1/2
J	21-1/2	21-1/2
K	65	31
L	45	18







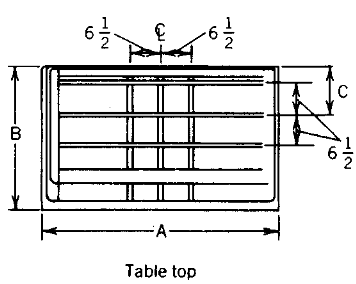


Fig. 31.26 Operation codes and machine illustration.

31.5 FABRICATION TOOL CLASSIFICATION AND CODING

31.5.1 Introduction

Because standard and special tooling represent a sizable investment, it is prudent to minimize redundant tooling, to evaluate performance of perishable tooling, and to provide good storage and retrieval practices to avoid excessive tool-float and loss of valuable tooling.

The use of a standard tool-classification system could provide many benefits for both the supplier and the user. The problem is to derive a comprehensive tool-classification system that is suitable for the extremely wide variety of tools available to industry and that is agreeable to all suppliers and users. Although no general system exists, most companies have devised their own proprietary tool-classification schemes. This has resulted in much duplicate effort. Because of the difficulty of developing general systems that are expandable to accommodate new tooling categories, many of these existing schemes for tool classification are found to be inadequate.

This section describes a new classification and coding system for fabrication tooling. Assembly, inspection, and testing tools are not included. This new system for classifying fabrication tools is a derivative of the work on classifying fabrication processes and fabrication equipment. Furthermore, special tooling categories are directly related through a unique coding system to the basic shape of the workpieces they are used to fabricate.

Investment

The investment a manufacturing company must make for standard and special tooling is usually substantial. Various manufacturing companies may carry in stock from 5,000 to 10,000 different tools and may purchase several thousand special tools, as required. As a rule of thumb, the investment in standard tooling for a new machine tool is often 20–30% of the basic cost of the machine. Special tooling costs may approach or even exceed the cost of certain machines. For instance, complex die-casting molds costing from $50,000 to $250,000 are quite commonplace.

The use of a tool classification system can aid a manufacturing enterprise by helping to get actual cost data for various tooling categories and thus begin to monitor and control tooling expenditures. The availability of good tooling is essential for economical and productive manufacturing. The intent of monitoring tooling costs should be to ensure that funds are available for such needed tooling and that these funds are wisely used. The intent should not be the miserly allocation of tooling money.

Tool Control

Tool control is a serious challenge in almost all manufacturing enterprises. Six important aspects that must be addressed in any good tool control system include*

- Tool procurement
- Tool storage
- Tool identification and marking
- Tool dispensing
- Tool performance measurement
- Tool maintenance

The availability of a standard, comprehensive tool classification and coding system can greatly aid each of these elements of tool control. For example, tool-procurement data may be easily cross-indexed with a standard tool number, thus reducing problems in communication between the user and the purchasing department.

Tool storage and retrieval may be enhanced by means of standard meaningful codes to identify tools placed in a given bin or at a given location. This problem is especially acute with molds, patterns, fixtures, and other special tooling.

Meaningful tool identification markings aid in preventing loss or misplacement of tools. Misplaced tools can quickly be identified and returned to their proper storage locations. Standard tool codes may also be incorporated into bar codes or other machine-readable coding systems if desirable.

The development of an illustrated tooling manual can be a great asset to both the user and to the tool crib personnel in identifying and dispensing tools. The use of a cross-referenced standard tool code can provide an ideal index to such a manual.

Tool-performance measures require the use of some sort of coding system for each type of tool to be evaluated. Comparison of tools within a given tool family may be facilitated by means of

*"Small Tools Planning and Control," in *Tool Engineers Handbook*, McGraw-Hill, New York, 1959, Section 3.

expanded codes describing the specific application and the various types of failures. Such extended codes may be easily tied to the standard tool family code.

Tool-maintenance and repair costs can be best summarized when they are referenced to a standard tool family code. Maintenance and acquisition costs could be easily reduced to obtain realistic life-cycle costs for tools of a given family or type.

In summary, tool control in general may be enhanced with a comprehensive, meaningful tool classification and coding system.

31.5.2 Standard and Special Tooling

Although tooling may be classified in many ways, such as "durable or perishable tooling," "fabrication or assembly tooling," and "company-owned or customer-owned tooling," the fabrication tooling system described below basically classifies tooling as "standard tooling" or "special tooling."

Definition of Terms

STANDARD TOOLING. Standard tooling is defined as that which is basically off the shelf and may be used by different users or a variety of products. Standard tooling is usually produced in quantity, and the cost is relatively low.

SPECIAL TOOLING. Special tooling is that which is designed and built for a specific application, such as a specific product or family of products. Delivery on such tooling may be several weeks, and tooling costs are relatively high.

Examples

Examples of standard tooling are shown in Fig. 31.27. Standard tooling usually includes cutting tools, die components, nozzles, certain types of electrodes, rollers, brushes, tool holders, laps, chucks, mandrels, collets, centers, adapters, arbors, vises, step-blocks, parallels, angle-plates, and the like.

Examples of special tooling are shown in Fig. 31.28. This usually includes dies, molds, patterns, jigs, fixtures, cams, templates, N/C programs, and the like. Some standard tooling may be modified to perform a special function. When this modification is performed in accordance with a specified design, then the tooling is classified as special tooling.

31.5.3 Tooling Taxonomy

The tooling taxonomy is based on the same general classification system used for fabrication processes and for fabrication equipment. The first-level divisions are "shaping" and "nonshaping." The second-level divisions for shaping are "mass reduction," "mass conserving," and "mass increasing" (joining, laminating, etc.). Second-level divisions for nonshaping are "heat treatment'" and "surface finishing." Third-level subdivisions are more variable but include "mechanical," "chemical," and "thermal," among other criteria for subdivisions.

Rationale

The basic philosophy has been to create a tooling classification system that is related to fabrication processes, to fabrication equipment, and to fabrication products insofar as possible. The statement "Without the process, there is no product" has aided in clarifying the importance of a process classification to all phases of manufacturing. It was recognized early that "process" is really a concept and that only through the application of "equipment and tooling" could a process ever be implemented. Thus, this process taxonomy was used as the basis of both equipment classification and this tooling classification. Most tooling is used in conjunction with given families of equipment and in that way is related to the equipment taxonomy. Special tooling is also related to the workpiece geometry through a special coding system that will be explained later. Standard tooling may be applied to a number of product families and may be used on a variety of different machine tools.

31.5.4 Tool Coding

The tool code is a shorthand notation used for identification and communication purposes. It has been designed to provide the maximum amount of information in a short, flexible code. Complete tool information may be held in a computer database or charts and tables. The code provides a pointer to this information.

Tool Code Format

The format used for the tool code is shown in Fig. 31.29. The code consists of three basic fields of information. The first field contains a three-digit process code that identifies the process for which the tooling is to be used. The second field consists of a one-digit code that indicates the tool type. Tool types are explained in the next subsection. The last field consists of either a three-digit numeral code for standard tooling or a three-digit alphanumeric code for special tooling. Standard tool codes have been designed to accommodate further subdivision of tool families if so desired. For example, the tool code for single-point turning inserts is 101-1-020. The last three digits could be amplified

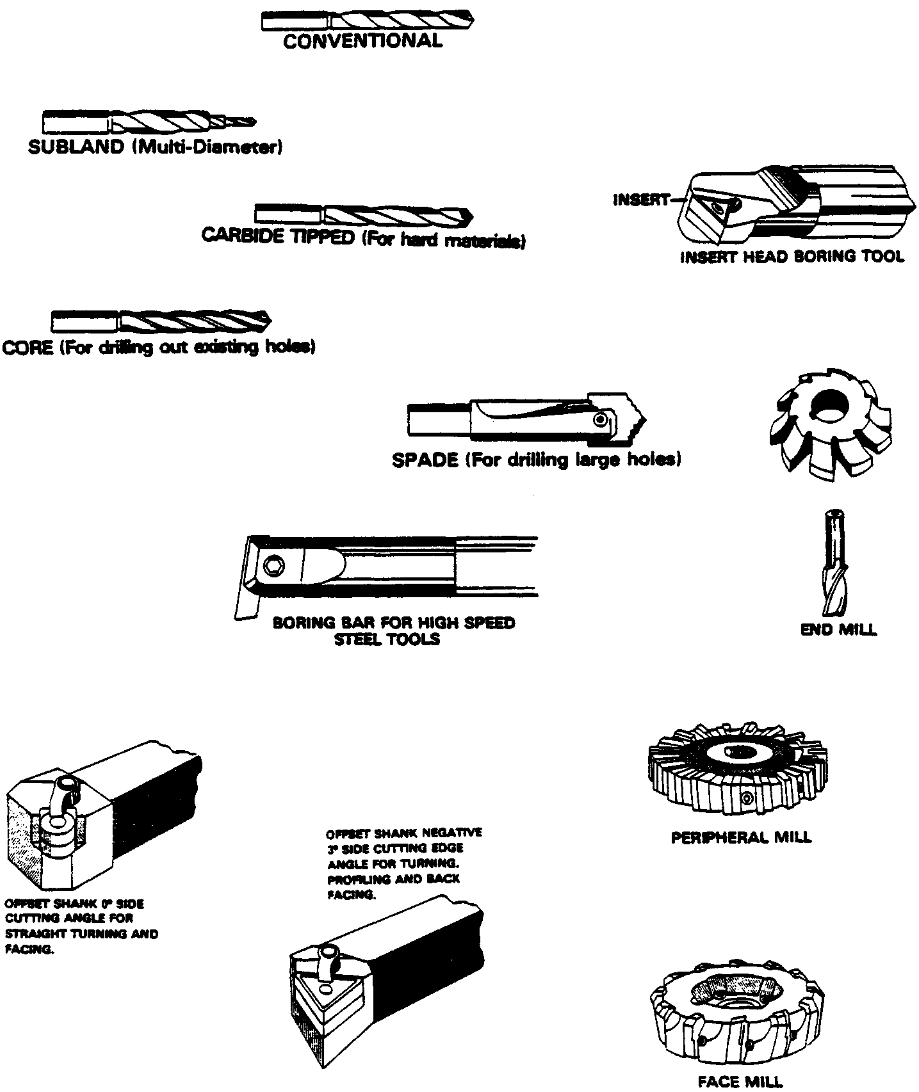


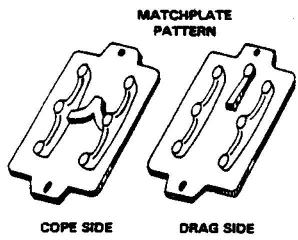
Fig. 31.27 Standard tooling.

for given insert geometry (e.g., triangular, −021; square, −022; round, −023). A dash number may further be appended to these codes to uniquely identify a given tool, as shown on the tool specification sheets.

Special tool codes are identified in the charts by a box containing three small squares. It is intended that the first three digits of this part family code will be inserted in this box, thus indicating the basic shape family for which the tool is designed. This way it will be possible to identify tool families and benefit from the application of group technology principles.

Tool Types

A single-digit alphanumeric code is used to represent the tool type. A code type of −1, for example, indicates that the tool actually contacts the workpiece, while a −2 indicates that the tool is used indirectly in shaping the workpiece. A foundry patten is an example of this: the pattern creates this mold cavity into which molten metal is introduced. The various tool type codes are shown in Fig. 31.30.



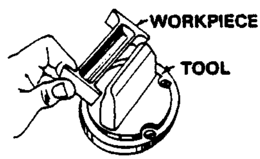


Fig. 31.28 Special tooling.

31.5.5 Tool Specification Sheets

The tool classification system is used to identify the family to which a tool belongs. The tool specification sheet is used to describe the attributes of a tool within the family. Figure 31.31 shows a sample tool specification sheet for a standard tool. Special tooling is best described with tool drawings and will not be discussed further.

Tool Identification

Tool identification consists of the tool name and the tool code number. The general tool family name is written first, followed by a specific qualifying label if applicable (e.g., "drill, subland, straight-shank"). The tool code consists of the seven-digit code described previously.

Acquisition Information

Information contained in this acquisition section may contain identifying codes for approved suppliers. This section may also contain information relating to the standard quantity per package, if applicable, special finish requirements, or other pertinent information.

Tool Sketches

Tool sketches are a valuable feature of the tool specification sheet. Prominent geometric relationships and parameters are shown in the sketch. Information relative to interfacing this tool to other devices or adapters should also be shown. This may include type and size or shape, key slot size, and tool capacity.

Tool Parameters

Tool parameters are included on the tool specification sheet to aid selection of the most appropriate tools. Because it is expensive to stock all possible tools, the usual practice is to identify preferred

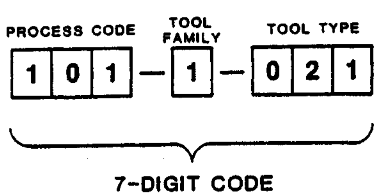


Fig. 31.29 Fabrication tool code format.

TOOL FAMILY	
-1-	TOOL/DIE (CONTACTS WORKPIECE)
-2-	MOLDS, PATTERNS, NEGATIVES
-3-	TIPS, NOZZLES
-4-	ELECTRODES
-5-	OTHER TOOLS
-6-	RESERVED
-7-	TOOL HOLDERS
-8-	WORK HOLDERS
-9-	RESERVED
-A-	N/C PROGRAMS
-B-	CAMS
-C-	TRACING TEMPLATES (2-D)
-D-	TRACING PATTERNS (3-D)

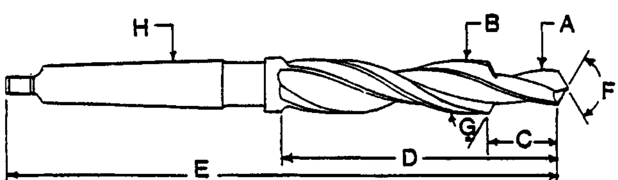
Fig. 31.30 Tool types.

TOOL FAMILY: DRILL, SUBLAND | CODE NO. 111-1-080

ACQUISITION INFORMATION:

Supplier Codes: A23, C13, 055

Std. Qty. per Pkg: N/A



DASH NO.	A	B	C	D	E	F	G	H	

Fig. 31.31 Sample tool specification sheet.

tools and to store these. Preferred tools may be so indicated by a special symbol such as an asterisk (*) in the dash-number column.

Tool parameters must be selected that are appropriate for each tool family and that match product requirements. Tool parameters must also be identified that will aid in interfacing tools with fabrication equipment, as was explained earlier. Typical tool parameters for a subland drill are shown in Fig. 31.31.