Wood Handbook: Wood as an Engineering Material

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Wood as an engineering material

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Summarizes information on wood as an engineering material. Properties of wood and wood-base products of particular concern to the architect and engineer are presented, along with discussions of designing with wood and some pertinent uses of wood.

KEYWORDS: Wood structure, physical properties (wood), mechanical properties (wood), lumber, plywood, panel products, design, fastenings, wood moisture, drying, gluing, fire resistance, finishing, decay, sandwich construction, preservation, and wood-base products.
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PREFACE

Forests, distinct from all their other services and benefits, supply a basic raw material—wood—which from the earliest times has furnished mankind with necessities of existence and with comforts and conveniences beyond number.

One major use has always been in structures, particularly in housing. But despite wood's long service in structures, it has not always been used efficiently. In these days when the Nation is trying to utilize its resources more fully, better and more efficient use of the timber crop is vital.

Authorship

As an aid to more efficient use of wood as a material of construction, this handbook was prepared by the Forest Products Laboratory, a unit of the research organization of the Forest Service, U.S. Department of Agriculture. The Laboratory, established in 1910, is maintained at Madison, Wis., in cooperation with the University of Wisconsin. It was the first institution in the world to conduct general research on wood and its utilization. The vast accumulation of information that has resulted from its engineering and allied investigations of wood and wood products over six decades—along with knowledge of everyday construction practices and problems—is the chief basis for this handbook.

Purpose

This handbook provides engineers, architects, and others with a source of information on the physical and mechanical properties of wood, and how these properties are affected by variations in the wood itself. Practical knowledge of wood has, over the years, resulted in strong and beautiful structures, even though exact engineering data were not always available. Continuing research and evaluation techniques promise to permit wider and more efficient utilization of wood and to encourage even more advanced industrial, structural, and decorative uses.

Organization

Individual chapters describe not only the wood itself, but wood-based products, and the principles of how wood is dried, fastened, finished, and preserved from degradation in today's world. Each chapter is climaxed with a bibliography of allied information. A glossary of terms is presented at the end of the handbook.

The problem of adequately presenting information for the architect, engineer, and builder is complicated by the vast number of tree species he may encounter in wood form. To prevent confusion, the common and botanical names for different species mentioned in this volume conform to the official nomenclature of the Forest Service.

ACKNOWLEDGMENT

The Forest Products Laboratory appreciates the cooperation of other elements of the Forest Service, and representatives of many universities and segments of industry, in preparing this document. The number of such examples of assistance prevent the mentioning of individual contributions, but their assistance is gratefully acknowledged.

A special "thank you" is due to the organizations that provided illustrations. These include the Acoustical and Insulating Materials Association, American Hardboard Association, American Institute of Timber Construction, J. H. Baxter Wood Treating Company, Bell Lumber and Pole Company, California Redwood Association, Forest Products Division of Koppers Co., Inc., National Forest Products Association, and National Particleboard Association.

Chapters

Mention of a chemical in this handbook does not constitute a recommendation; only those chemicals registered by the U.S. Environmental Protection Agency may be recommended, and then only for uses as prescribed in the registration—and in the manner and at the concentration prescribed. The list of registered chemicals varies from time to time; prospective users, therefore, should get current information on registration status from Pesticides Regulation Division, Environmental Protection Agency, Washington, D.C. 20460.

Illustration Requests

Requests for copies of illustrations contained in this handbook should be directed to the Forest Products Laboratory, USDA Forest Service, P.O. Box 5130, Madison, Wis. 53705.

Chapter 1

CHARACTERISTICS AND AVAILABILITY OF WOODS COMMERCIALLY IMPORTANT TO THE UNITED STATES

CHARACTERISTICS AND AVAILABILITY OF WOODS COMMERCIALLY IMPORTANT IN THE UNITED STATES

Through the ages the unique characteristics and comparative abundance of wood have made it a natural material for homes and other structures, furniture, tools, vehicles, and decorative objects. Today, for the same reasons, wood is prized for a multitude of uses.

All wood is composed of cellulose, lignin, ash-forming minerals, and extractives formed in a cellular structure. Variations in the characteristics and volume of the four components and differences in cellular structure result in some woods being heavy and some light, some stiff and some flexible, some hard and some soft. For a single species, the properties are relatively constant within limits; therefore, selection of wood by species alone may sometimes be adequate. However, to use wood to its best advantage and most effectively in engineering applications, the effect of specific characteristics or physical properties must be considered.

Historically, some woods have filled many purposes, while others which were not so readily available or so desirable qualitatively might serve only one or two needs. The tough, strong, and durable white oak, for example, was a highly prized wood for shipbuilding, bridges, cooperage, barn timbers, farm implements, railroad crossties, fenceposts, flooring, paneling, and other products. On the other hand, woods such as black walnut and cherry became primarily cabinet woods. Hickory was manufactured into tough, hard resilient striking-tool handles. Black locust was prized for barn timbers and treenails. What the early builder or craftsman learned by trial and error became the basis for the decision as to which species to use for a given purpose, and what characteristics to look for in selecting a tree for a given use. It was commonly accepted that wood from trees gown in certain locations under certain conditions was stronger, more durable, and more easily worked with tools, or finer grained than wood from trees in some other locations. Modern wood quality research has substantiated that location and growth conditions do significantly affect wood properties.

The gradual utilization of the virgin forests in the United States has reduced the available supply of large clear logs for lumber and veneer However, the importance of high quality logs has diminished as new concepts of wood use have been introduced. Second-growth timber (fig. 1-1), the balance of the old-growth forests, and imports continue to fill the needs for wood in the qualitv required. Wood is as valuable an engineering material as it ever was, and in many cases technological advances have made it even more useful.

The inherent factors which keep wood in the forefront of raw materials are many and varied, but one of the chief attributes is its availability in many species, sizes, shapes, and conditions to suit almost every demand. It has a high ratio of strength to weight and a remarkable record for durability and performance as a structural material. Dry wood has good insulating properties against heat, sound, and electricity. It tends to absorb and dissipate vibrations under some conditions of use, yet is an incomparable material for such musical instruments as violins. Because of grain patterns and colors, wood is inherently an esthetically pleasing material, and its appearance may be easily enhanced by stains, varnishes, lacquers, and other finishes. It is easily shaped with tools and fastened with adhesives, nails, screws, bolts, and dowels. When wood is damaged it is easily repaired, and wood structures are easily remodeled or altered. In addition, wood resists oxidation, acid, salt water, and other corrosive agents; has a high salvage value; has good shock resistance; takes treatments with preservatives and fire retardants; and combines with almost any other material for both functional and esthetic uses.

TIMBER RESOURCES AND WOOD USES

In the United States more than 100 woods are available to the prospective user, but it is very unlikely that all are available in any one locality. Commercially, there are about 60 native woods of major importance. Another 30 woods are commonly imported in the form of logs, cants, lumber, and veneer for industrial uses, the building trades, and the craftsman.

A continuing program of timber inventory is in effect in the United States through cooperation of Federal agencies and the States. As new information regarding timber resources becomes available it appears in State and Federal

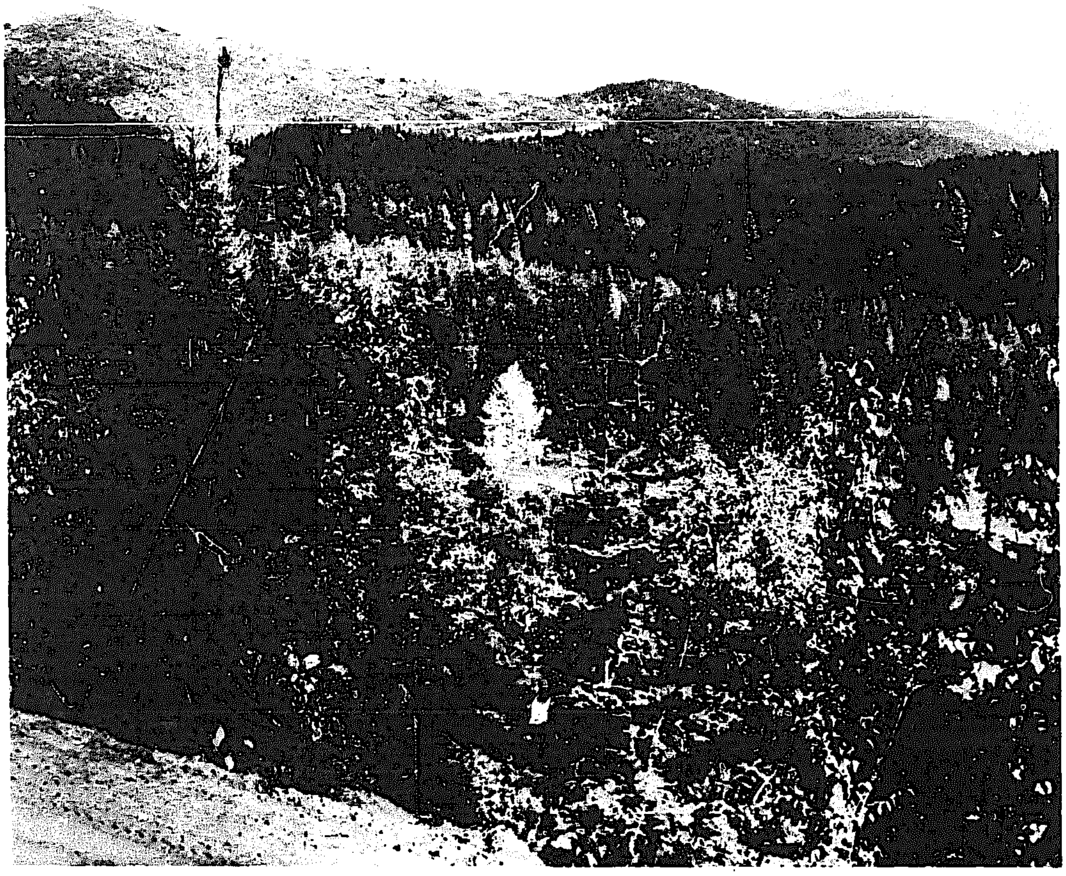

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Figure 1–1.—Reforested area on the Kaniksu National Forest in Idaho. Foreground is stocked with western larch and Douglas-fir reproduced naturally. The central area, edged by mature timber, is a field-planted western white pine plantation.

publications. One of the most valuable source books is "Timber Trends in the United States," Forest Service, U.S. Department of Agriculture Forest Resource Report No. 17.

The best source of current information on timber consumption, production, imports, and the demand and price situation is published periodically in a U.S. Department of Agriculture Miscellaneous Publication, entitled "The Demand and Price Situation for Forest Products." Both publications are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

HARDWOODS AND SOFTWOODS

Trees are divided into two broad classes, usually referred to as "hardwoods" and "softwoods." Some softwoods, however, are actually harder than some of the hardwoods, and some hardwoods are softer than softwoods. For example, such softwoods as longleaf pine and Douglas-fir produce wood that is typically harder than the hardwoods basswood and aspen. Botanically, the softwoods are Gymnosperms, species that fall into a classification called conifers that have their seed exposed, usually in cones. Examples are the pines, spruces, redwoods, and junipers. The other broad classification, the Angiosperms, comprise the various orders of hardwoods. They have true flowers and broad leaves, and the seeds are enclosed in a fruit. United States softwoods have needlelike or scalelike leaves that, except for larches and baldcypress, remain on the trees throughout the year. The hardwoods, with a few exceptions, lose their leaves in fall or during the winter. Most of the imported woods, other than those from Canada, are hardwoods.

Major resources of softwood species are spread across the United States, except for the Great Plains where only small areas are forested. Species are often loosely grouped in three general producing areas:

Western softwoods

- Douglas-fir
- Ponderosa pine
- Western hemlock
- Western redcedar
- True firs
- Redwood
- Engelmann spruce
- Western larch
- Sitka spruce
- Idaho white pine
- Sugar pine
- Lodgepole pine
- Port-Orford-cedar
- Incense-cedar
- Alaska-cedar

Northern softwoods

- Eastern white pine
- Red pine
- Jack pine
- Eastern hemlock
- Balsam fir
- Tamarack
- Eastern spruces
- Eastern redcedar
- Northern white-cedar

Southern softwoods

- Southern pine
- Baldcypress
- Eastern redcedar
- Atlantic white-cedar

With some exceptions, most hardwoods occur east of the Great Plains area (fig. 1–2). The following classification is based on the principal producing region for each wood:

Southern hardwoods

- Ash
- Basswood
- American beech
- Cottonwood
- Elm
- Hackberry
- Pecan hickory
- True hickory
- American holly
- Black locust
- Magnolia
- Soft maple
- Red oak
- White oak
- Sweetgum
- American sycamore
- Tupelo
- Black walnut
- Black willow
- Yellow-poplar

Northern and Appalachian hardwoods

- Ash
- Aspen
- Basswood
- American beech
- Birch
- Black cherry
- American chestnut[1]
- Cottonwood
- Elm
- Hackberry
- True hickory
- Black locust
- Hard maple
- Soft maple
- Red oak
- White oak
- American sycamore
- Black walnut
- Yellow-poplar

Western hardwoods

- Red alder
- Oregon ash
- Aspen
- Black cottonwood
- Bigleaf maple
- Paper birch
- Tanoak

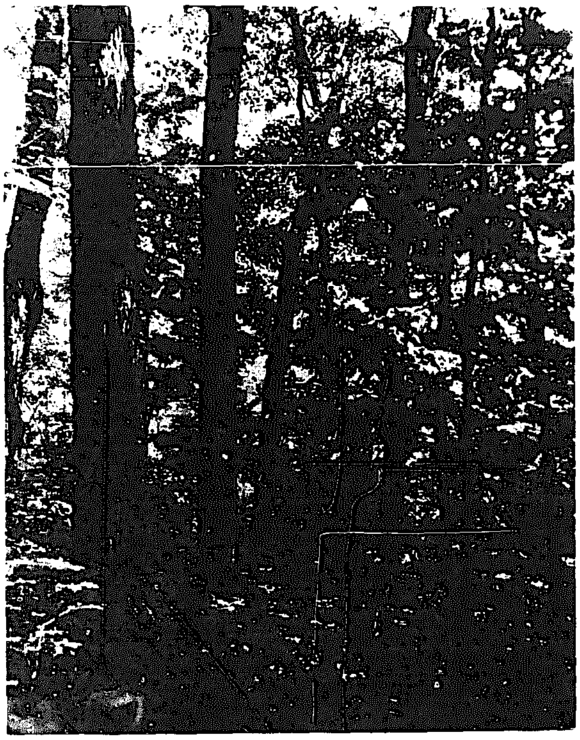

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Figure 1–2.—Mixed northern hardwoods on Ottawa National Forest in Michigan.

COMMERCIAL SOURCES OF WOOD PRODUCTS

Softwoods are available directly from the sawmill, wholesale and retail yards, or lumber brokers. Softwood lumber and plywood are used in construction for forms, scaffolding, framing, sheathing, flooring, ceiling, trim, paneling, cabinets, and many other building components. Softwoods may also appear in the form of shingles, sash, doors, and other millwork, in addition to some rough products such as round treated posts.

Hardwoods are used in construction for flooring, architectural woodwork, trim, and paneling. These items are usually available from lumberyards and building supply dealers. Most hardwood lumber and dimension are remanufactured into furniture, flooring, pallets, containers, dunnage, and blocking. Hardwood lumber and dimension are available directly from the manufacturer, through wholesalers and brokers, and in some retail yards.

Both softwood and hardwood forest products are distributed throughout the United States, although they tend to be more readily available in or near their area of origin. Local

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[1] American chestnut is no longer harvested as a living tree, but the lumber is still on the market as "wormy chestnut" and prices are quoted in the Hardwood Market Report.

preferences and the availability of certain species may influence choice; but, a wide selection of woods is generally available for building construction, industrial uses, remanufacturing, and use by home craftsmen.

USE CLASSES AND TRENDS

Some of the many use classifications for wood are growing with the overall national economy, and others are holding about the same levels of production and consumption. The wood-based industries that are growing most vigorously convert wood to thin slices (veneer), particles (chips, flakes, etc.), or fiber pulps and reassemble the elements to produce plywood, numerous types of particleboard, paper, paperboard, and fiberboard products. Another growing wood industry specializes in producing laminated timbers. Annual production by the lumber industry has continued for several years at almost the same board footage. Some of the forest products industries, such as railroad crossties, cooperage, shingles, and shakes appear to have leveled off following a period of depressed production, and in some instances to be making modest increases in production.

COMMERCIAL SPECIES IN THE UNITED STATES

The following brief discussions of the principal localities of occurrence, characteristics, and uses of the main commercial species, or groups of species, will aid in selecting woods for specific purposes. More detailed information on the properties of these and other species is given in various tables throughout this handbook.

Certain uses listed under the individual species are no longer important. They have been included to provide some information on the historical and traditional uses of the species.

The common and botanical names given for the different species conform to the Forest Service official nomenclature for trees.

Hardwoods

Alder, Red

Red alder (*Alnus rubra*) grows along the Pacific coast between Alaska and California. It is used commercially along the coasts of Oregon and Washington and is the most abundant commercial hardwood species in these States.

The wood of red alder varies from almost white to pale pinkish brown and has no visible boundary between heartwood and sapwood. It is moderately light in weight, intermediate in most strength properties, but low in shock resistance. Red alder has relatively low shrinkage.

The principal use of red alder is for furniture, but it is also used for sash, doors, panel stock, and millwork.

Ash

Important species of ash are white ash (*Fraxinus americana*), green ash (*F. pennsylvanica*), blue ash (*F. quadrangulata)*, black ash (*F. nigra*), pumpkin ash (*F. profunda*), and Oregon ash (*F. latifolia*). The first five of these species grow in the eastern half of the United States. Oregon ash grows along the Pacific coast.

Commercial white ash is a group of species that consists mostly of white ash and green ash, although blue ash is also included. Heartwood of commercial white ash is brown; the sapwood is light colored or nearly white. Second-growth trees have a large proportion of sapwood. Old-growth trees, which characteristically have little sapwood, are scarce.

Second-growth commercial white ash is particularly sought because of the inherent qualities of this wood; it is heavy, strong, hard, stiff, and has high resistance to shock. Because of these qualities such tough ash is used principally for handles, oars, vehicle parts, baseball bats, and other sporting and athletic goods. Some handle specifications call for not less than five or more than 17 growth rings per inch for handles of the best grade. The addition of a weight requirement of 43 or more pounds a cubic foot at 12 percent moisture content will assure excellent material.

Oregon ash has somewhat lower strength properties than white ash, but it is used locally for the same purposes.

Black ash is important commercially in the Lake States. The wood of black ash and pumpkin ash runs considerably lighter in weight than that of commercial white ash. Ash trees growing in southern river bottoms, especially in areas that are frequently flooded for long periods, produce buttresses that contain relatively lightweight and weak wood. Such wood is sometimes separated from tough ash when sold.

Ash wood of lighter weight, including black ash, is sold as cabinet ash, and is suitable for cooperage, furniture, and shipping containers Some ash is cut into veneer for furniture, paneling, wire-bound boxes.

Aspen

"Aspen" is a generally recognized name applied to bigtooth aspen (*Populus grandidentata*) and to quaking aspen (*P. tremuloides*). Aspen does not include balsam poplar (*P. balsamifera*) and the species of *Populus* that make up the group of cottonwoods. In lumber statistics of the U.S. Bureau of the Census, however, the term "cottonwood" includes all of the preceding species. Also, the lumber of aspens and cottonwood may be mixed in trade and sold either as poplar ("Popple") or cottonwood. The name "popple" or "poplar" should not be confused with yellow-poplar (*Liriodendron tulipifera*), also known in the trade as "poplar."

Aspen lumber is produced principally in the Northeastern and Lake States. There is some production in the Rocky Mountain States.

The heartwood of aspen is grayish white to light grayish brown. The sapwood is lighter colored and generally merges gradually into heartwood without being clearly marked. Aspen wood is usually straight grained with a fine, uniform texture. It is easily worked. Well-seasoned aspen lumber does not impart odor or flavor to foodstuffs.

The wood of aspen is lightweight and soft. It is low in strength, moderately stiff, moderately low in resistance to shock, and has a moderately high shrinkage.

Aspen is cut for lumber, pallets, boxes and crating, pulpwood, particleboard, excelsior, matches, veneer, and miscellaneous turned articles.

Basswood

American basswood (*Tilia americana*) is the most important of the several native basswood species; next in importance is white basswood (*T. heterophylla*). Other species occur only in very small quantities. Because of the similarity of the wood of the different species, no attempt is made to distinguish between them in lumber form. Other common names of basswood are linden, linn, and beetree.

Basswood grows in the eastern half of the United States from the Canadian provinces southward. Most basswood lumber comes from the Lake, Middle Atlantic, and Central States. In commercial usage, "white basswood" is used to specify white wood or sapwood of either species.

The heartwood of basswood is pale yellowish brown with occasional darker streaks. Basswood has wide, creamy-white or pale brown sapwood that merges gradually into the heartwood. When dry, the wood is without odor or taste. It is soft and light in weight, has fine, even texture, and is straight grained and easy to work with tools. Shrinkage in width and thickness during drying is rated as large; however, basswood seldom warps in use.

Basswood lumber is used mainly in venetian blinds, sash and door frames, molding, apiary supplies, woodenware, and boxes. Some basswood is cut for veneer, cooperage, excelsior, and pulpwood.

Beech, American

Only one species of beech, American beech (*Fagus grandifolia*), is native to the United States. It grows in the eastern one-third of the United States and adjacent Canadian provinces. Greatest production of beech lumber is in the Central and Middle Atlantic States.

Beechwood varies in color from nearly white sapwood to reddish-brown heartwood in some trees. Sometimes there is no clear line of demarcation between heartwood and sapwood. Sapwood may be 3 to 5 inches thick. The wood has little figure and is of close, uniform texture. It has no characteristic taste or odor.

The wood of beech is classed as heavy, hard, strong, high in resistance to shock, and highly adaptable for steam bending. Beech has large shrinkage and requires careful drying. It machines smoothly, is an excellent wood for turning, wears well, and is rather easily treated with preservatives.

Largest amounts of beech go into flooring, furniture, brush blocks, handles, veneer wooden-ware, containers, cooperage, and laundry appliances. When treated, it is suitable for railway ties.

Birch

The important species of birch are yellow birch (*Betula alleghaniensis*), sweet birch (*B. lenta*), and paper birch (*B. papyrifera*). Other birches of some commercial importance are river birch (*B. nigra*), gray birch (*B. populifolia*), and western paper birch (*B. papyrifera* var. *commutata*).

Yellow birch, sweet birch, and paper birch grow principally in the Northeastern and Lake States. Yellow and sweet birch also grow along the Appalachian Mountains to northern Georgia. They are the source of most birch lumber and veneer.

Yellow birch has white sapwood and light reddish-brown heartwood. Sweet birch has light-colored sapwood and dark brown heartwood tinged with red. Wood of yellow birch and sweet birch is heavy, hard, strong, and has good shock-resisting ability. The wood is fine and uniform in texture. Paper birch is lower in weight, softer, and lower in strength than yellow and sweet birch. Birch shrinks considerably during drying.

Yellow and sweet birch lumber and veneer go principally into the manufacture of furniture, boxes, baskets, crates, woodenware, cooperage, interior finish, and doors. Birch veneer goes into plywood used for flush doors, furniture, paneling, radio and television cabinets, aircraft, and other specialty uses. Paper birch is used for turned products, including spools, bobbins, small handles, and toys.

Buckeye

Buckeye consists of two species, yellow buckeye (*Aesculus octandra*) and Ohio buckeye (*A. glabra*). They range from the Appalachians of Pennsylvania, Virginia, and North Carolina westward to Kansas, Oklahoma, and Texas. Buckeye is not customarily separated from other species when manufactured into lumber and can be utilized for the same purposes as aspen, basswood, and sap yellow-poplar.

The white sapwood of buckeye merges gradually into the creamy or yellowish white of the heartwood. The wood is uniform in texture, generally straight-grained, light in weight, weak when used as a beam, soft, and low in shock resistance. It is rated low on machineability such as shaping, mortising, steam bending, boring, and turning.

Buckeye is suitable for pulping for paper and in lumber form has been used principally for furniture, boxes, and crates, food containers, woodenware, novelties, and planing mill products.

Butternut

Butternut (*Juglans cinerea*) is also called white walnut, American white walnut, and oilnut. It grows from southern New Brunswick and Maine, west to Minnesota. Its southern range extends into northeastern Arkansas and eastward to western North Carolina.

The narrow sapwood is nearly white, and the heartwood is a light brown, frequently modified by pinkish tones or darker brown streaks. The wood is moderately light in weight—about the same as eastern white pine—rather coarse-textured, moderately weak in bending and endwise compression, relatively low in stiffness, moderately soft, and moderately high in shock resistance. Butternut machines easily and finishes well. In many ways it resembles black walnut, but it does not have the strength or hardness. Principal uses are for lumber and veneer, which are further manufactured into furniture, cabinets, paneling, trim, and miscellaneous rough items.

Cherry, Black

Black cherry (*Prunus serotina*) is sometimes known as cherry, wild black cherry, wild cherry, or chokecherry. It is the only native species of the genus *Prunus* of commercial importance for lumber production. It occurs scatteringly from southeastern Canada throughout the eastern half of the United States. Production is centered chiefly in the Middle Atlantic States.

The heartwood of black cherry varies from light to dark reddish brown and has a distinctive luster. The sapwood is narrow in old trees and nearly white. The wood has a fairly uniform texture and very satisfactory machining properties. It is moderately heavy. Black cherry is strong, stiff, moderately hard, and has high shock resistance and moderately large shrinkage. After seasoning, it is very dimensionally stable in use.

Black cherry is used principally for furniture, fine veneer panels, architectural woodwork, and for backing blocks on which electrotype plates are mounted. Other uses include burial caskets, woodenware novelties, patterns, and paneling. It has proved satisfactory for gunstocks, but has a limited market for this purpose.

Chestnut, American

American chestnut (*Castanea dentata*) is known also as sweet chestnut. Before chestnut was attacked by a blight, it grew in commercial quantities from New England to northern Georgia. Practically all standing chestnut has been killed by blight, and supplies come from dead timber. There are still quantities of standing dead chestnut in the Appalachian Mountains, which may be available for some time because of the great natural resistance to decay of its heartwood.

The heartwood of chestnut is grayish brown or brown and becomes darker with age. The sapwood is very narrow and almost white. The wood is coarse in texture, and the growth rings are made conspicuous by several rows of large, distinct pores at the beginning of each year's growth. Chestnut wood is moderately light in weight. It is moderately hard, moderately low in strength, moderately low in resistance to shock, and low in stiffness. It seasons well and is easy to work with tools.

Chestnut was used for poles, railway ties, furniture, caskets, boxes, crates, and core stock for veneer panels. It appears most frequently now as "wormy chestnut" for paneling, trim, and picture frames, while a small amount is still used in rustic fences.

Cottonwood

Cottonwood includes several species of the genus *Populus*. Most important are eastern cottonwood (*P. deltoides* and varieties), also known as Carolina poplar and whitewood; swamp cottonwood (*P. heterophylla*), also known as cottonwood, river cottonwood, and swamp poplar; and black cottonwood (*P. trichocarpa*) and balsam poplar (*P. balsamifera*).

Eastern cottonwood and swamp cottonwood grow throughout the eastern half of the United States. Greatest production of lumber is in the Southern and Central States. Black cottonwood grows in the West Coast States and in western Montana, northern Idaho, and western Nevada. Balsam poplar grows from Alaska across Canada, and in the northern Great Lake states.

The heartwood of the three cottonwoods is grayish white to light brown. The sapwood is whitish and merges gradually with the heartwood. The wood is comparatively uniform in texture, and generally straight grained. It is odorless when well seasoned.

Eastern cottonwood is moderately low in bending and compressive strength, moderately limber, moderately soft, and moderately low in ability to resist shock. Black cottonwood is slightly below eastern cottonwood in most strength properties. Both eastern and black cottonwood have moderately large shrinkage. Some cottonwood is difficult to work with tools because of fuzzy surfaces. Tension wood is largely responsible for this characteristic.

Cottonwood is used principally for lumber, veneer, pulpwood, excelsior, and fuel. The lumber and veneer go largely into boxes, crates, baskets, and pallets.

Elm

Six species of elm grow in the eastern United States: American elm (*Ulmus americana*), slippery elm (*U. rubra*), rock elm (*U. thomasii*), winged elm (*U. alata*), cedar elm (*U. crassifolia*), and September elm (*U. serotina*). American elm is also known as white elm, water elm, and gray elm; slippery elm as red elm; rock elm as cork elm or hickory elm; winged elm as wahoo; cedar elm as red elm or basket elm; and September elm as red elm.

Supply of American elm is threatened by two diseases, Dutch Elm and phloem necrosis, which have killed hundreds of thousands of trees.

The sapwood of the elms is nearly white and the heartwood light brown, often tinged with red. The elms may be divided into two general classes, hard elm and soft elm, based on the weight and strength of the wood. Hard elm includes rock elm, winged elm, cedar elm, and September elm. American elm and slippery elm are the soft elms. Soft elm is moderately heavy, has high shock resistance, and is moderately hard and stiff. Hard elm species are somewhat heavier than soft elm. Elm has excellent bending qualities.

Production of elm lumber is chiefly in the Lake, Central and Southern States.

Elm lumber is used principally in boxes, baskets, crates, and slack barrels; furniture, agricultural supplies and implements; caskets and burial boxes, and vehicles. For some uses the hard elms are preferred. Elm veneer is used for furniture, fruit, vegetable, and cheese boxes, baskets, and decorative panels.

Hackberry

Hackberry (*Celtis occidentalis*) and sugarberry (*C. laevigata*) supply the lumber known in the trade as hackberry. Hackberry grows east of the Great Plains from Alabama, Georgia, Arkansas, and Oklahoma northward, except along the Canadian boundary. Sugarberry overlaps the southern part of the range of hackberry and grows throughout the Southern and South Atlantic States.

The sapwood of both species varies from pale yellow to greenish or grayish yellow. The heartwood is commonly darker. The wood resembles elm in structure.

Hackberry lumber is moderately heavy. It is moderately strong in bending, moderately weak in compression parallel to the grain, moderately hard to hard, high in shock resistance, but low in stiffness. It has moderately large to large shrinkage but keeps its shape well during seasoning.

Most hackberry is cut into lumber, with small amounts going into dimension stock and some into veneer. Most of it is used for furniture and some for containers.

Hickory, Pecan

Species of the pecan group include bitternut hickory (*Carya cordiformis*), pecan (*C. illinoensis*), water hickory (*C. aquatica*), and nutmeg hickory (*C. myristicaeformis*). Bitternut hickory grows throughout the eastern half of the United States. Pecan hickory grows from central Texas and Louisiana to Missouri and Indiana. Water hickory grows from Texas to South Carolina. Nutmeg hickory occurs principally in Texas and Louisiana.

The wood of pecan hickory resembles that of true hickory. It has white or nearly white sapwood, which is relatively wide, and somewhat darker heartwood. The wood is heavy and sometimes has very large shrinkage.

Heavy pecan hickory finds use in tool and implement handles and flooring. The lower grades are used in pallets. Many higher grade logs are sliced to provide veneer for furniture and decorative paneling.

Hickory, True

True hickories are found throughout most of the eastern half of the United States. The species most important commercially are shagbark (*Carya ovata*), pignut (*C. glabra*), shellbark (*C. laciniosa*), and mockernut (*C. tomentosa*).

The greatest commercial production of the true hickories for all uses is in the Middle Atlantic and Central States. The Southern and South Atlantic States produce nearly half of all hickory lumber.

The sapwood of hickory is white and usually quite thick, except in old, slowly growing trees. The heartwood is reddish. From the standpoint of strength, no distinction should be made between sapwood and heartwood having the same weight.

The wood of true hickory is exceptionally tough, heavy, hard, strong, and shrinks considerably in drying. For some purposes, both rings per inch and weight are limiting factors where strength is important.

The major use for hickory is for tool handles, which require high shock resistance. It is also used for ladder rungs, athletic goods, agricultural implements, dowels, gymnasium apparatus, poles, and furniture.

A considerable quantity of lower grade hickory is not suitable, because of knottiness or other growth features and low density, for the special uses of high-quality hickory. It appears particularly useful for pallets, blocking, and similar items. Hickory sawdust and chips and some solid wood is used by the major packing companies to flavor meat by smoking.

Holly, American

American holly (*Ilex opaca*) is sometimes called white holly, evergreen holly, and boxwood. The natural range of holly extends along the Atlantic coast, gulf coast, and Mississippi Valley.

Both heartwood and sapwood are white, the heartwood with an ivory cast. The wood has a uniform and compact texture; it is moderately low in strength when used as a beam or column and low in stiffness, but it is heavy and hard, and ranks high in shock resistance. It is readily penetrable to liquids and can be satisfactorily dyed. It works well, cuts smoothly, and is used principally for scientific and musical instruments, furniture inlays, and athletic goods.

Honeylocust

The wood of honeylocust (*Gleditsia triacanthos*) possesses many desirable qualities such as attractive figure and color, hardness, and strength, but is little used because of its scarcity. Although the natural range of honeylocust has been extended by planting, it is found most commonly in the eastern United States, except for New England and the South Atlantic and Gulf Coastal Plains.

The sapwood is generally wide and yellowish in contrast to the light red to reddish brown heartwood. It is very heavy, very hard, strong in bending, stiff, resistant to shock, and is durable when in contact with the ground. When available, it is restricted primarily to local uses, such as fence posts and lumber for general construction. Occasionally it will show up with other species in lumber for pallets and crating.

Locust, Black

Black locust (*Robinia pseudoacacia*) is sometimes called yellow locust, white locust, green locust, or post locust. This species grows from Pennsylvania along the Appalachian Mountains to northern Georgia. It is also native to a small area in northwestern Arkansas. The greatest production of black locust timber is in Tennessee, Kentucky, West Virginia, and Virginia.

Locust has narrow, creamy-white sapwood. The heartwood, when freshly cut, varies from greenish yellow to dark brown. Black locust is very heavy, very hard, very high in resistance to shock, and ranks very high in strength and stiffness. It has moderately small shrinkage. The heartwood has high decay resistance.

Black locust is used extensively for round, hewed, or split mine timbers and for fenceposts, poles, railroad ties, stakes, and fuel. An important product manufactured from black locust is insulator pins, a use for which the wood is well adapted because of its strength, decay resistance, and moderate shrinkage and swelling. Other uses are for rough construction, crating, ship treenails and mine equipment.

Magnolia

Three species comprise commercial magnolia—southern magnolia (*Magnolia grandiflora*), sweetbay (*M. virginiana*), and cucumbertree (*M. acuminata*). Other names for southern magnolia are evergreen magnolia, magnolia, big laurel, bull bay, and laurel bay. Sweetbay is sometimes called swamp magnolia, or more often simply magnolia.

The natural range of sweetbay extends along the Atlantic and gulf coasts from Long Island to Texas, and that of southern magnolia from North Carolina to Texas. Cucumbertree grows from the Appalachians to the Ozarks northward to Ohio. Louisiana leads in production of magnolia lumber.

The sapwood of southern magnolia is yellowish white, and the heartwood is light to dark brown with a tinge of yellow or green. The wood, which has close, uniform texture and is generally straight grained, closely resembles yellow-poplar. It is moderately heavy, moderately low in shrinkage, moderately low in bending and compressive strength, moderately hard and stiff, and moderately high in shock resistance. Sweetbay is reported to be much like southern magnolia. The wood of cucumbertree is similar to that of yellow-poplar, and cucumbertree growing in the yellow-poplar range is not separated from that species on the market.

Magnolia lumber is used principally in the manufacture of furniture, boxes, pallets, venetian blinds, sash, doors, veneer, and millwork.

Maple

Commercial species of maple in the United States include sugar maple (*Acer saccharum*), black maple (*A. nigrum*), silver maple (*A. saccharinum*), red maple (*A. rubrum*), boxelder (*A. negundo*), and bigleaf maple (*A. macrophyllum*). Sugar maple is also known as hard maple, rock maple, sugar tree, and black maple; black maple as hard maple, black sugar maple, and sugar maple; silver maple as white maple, river maple, water maple, and swamp maple; red maple as soft maple, water maple, scarlet maple, white maple, and swamp maple; boxelder as ash-leaved maple, three-leaved maple, and cut-leaved maple; and bigleaf maple as Oregon maple.

Maple lumber comes principally from the Middle Atlantic and Lake States, which together account for about two-thirds of the production.

The wood of sugar maple and black maple is known as hard maple; that of silver maple, red maple, and boxelder as soft maple. The sapwood of the maples is commonly white with a slight reddish-brown tinge. It is from 3 to 5 or more inches thick. Heartwood is usually light reddish brown, but sometimes is considerably darker. Hard maple has a fine, uniform texture. It is heavy, strong, stiff, hard, resistant to shock, and has large shrinkage. Sugar maple is generally straight grained but also occurs as "birdseye," "curley," and "fiddleback" grain. Soft maple is not so heavy as hard maple, but has been substituted for hard maple in the better grades, particularly for furniture.

Maple is used principally for lumber, veneer, crossties, and pulpwood. A large proportion is manufactured into flooring, furniture, boxes, pallets, and crates, shoe lasts, handles, woodenware, novelties, spools, and bobbins.

Oak (Red Oak Group)

Most red oak lumber and other products come from the Southern States, the southern mountain regions, the Atlantic Coastal Plains, and the Central States. The principal species are: Northern red oak (*Quercus rubra*), scarlet oak (*Q. coccinea*), Shumard oak (*Q. shumardii*), pin oak (*Q. palustris*), Nuttall oak (*Q. nuttallii*), black oak (*Q. velutina*), southern red oak (*Q. falcata*), cherrybark oak (*Q. falcata* var. *pagodaefolia*), water oak (*Q. nigra*), laurel oak (*Q. laurifolia*), and willow oak (*Q. phellos*).

The sapwood is nearly white and usually 1 to 2 inches thick. The heartwood is brown with a tinge of red. Sawed lumber of red oak cannot be separated by species on the basis of the characteristics of the wood alone. Red oak lumber can be separated from white oak by the number of pores in summerwood and because, as a rule, it lacks the membranous growth known as tyloses in the pores. The open pores of the red oaks make these species unsuitable for tight cooperage, unless the barrels are lined with sealer or plastic. Quartersawed lumber of the oaks is distinguished by the broad and conspicuous rays, which add to its attractiveness.

Wood of the red oaks is heavy. Rapidly grown second-growth oak is generally harder and tougher than finer textured old-growth timber. The red oaks have fairly large shrinkage in drying.

The red oaks are largely cut into lumber, railroad ties, mine timbers, fenceposts, veneer, pulpwood, and fuelwood. Ties, mine timbers, and fenceposts require preservative treatment for satisfactory service. Red oak lumber is remanufactured into flooring, furniture, general millwork, boxes, pallets and crates, agricultural implements, caskets, woodenware, and handles. It is also used in railroad cars and boats.

Oak (White Oak Group)

White oak lumber comes chiefly from the South, South Atlantic, and Central States, including the southern Appalachian area.

Principal species are white oak (*Quercus alba*), chestnut oak (*Q. prinus*), post oak (*Q. stellata*), overcup oak (*Q. lyrata*), swamp chestnut oak (*Q. michauxii*), bur oak (*Q. macrocarpa*), chinkapin oak (*Q. muehlenbergii*), swamp white oak (*Q. bicolor*), and live oak (*Q. virginiana*).

The heartwood of the white oaks is generally grayish brown, and the sapwood, which is from 1 to 2 or more inches thick, is nearly white. The pores of the heartwood of white oaks are usually plugged with the membranous growth known as tyloses. These tend to make the wood impenetrable by liquids, and for this reason most white oaks are suitable for tight cooperage. Chestnut oak lacks tyloses in many of its pores.

The wood of white oak is heavy, averaging somewhat higher in weight than that of the red oaks. The heartwood has moderately good decay resistance.

White oaks are used for lumber, railroad ties, cooperage, mine timbers, fenceposts, veneer, fuelwood, and many other products. High-quality white oak is especially sought for tight cooperage. Live oak is considerably heavier and stronger than the other oaks, and was formerly used extensively for ship timbers. An important use of white oak is for planking and bent parts of ships and boats, heartwood often being specified because of its decay resistance. It is also used for flooring, pallets, agricultural implements, railroad cars, truck floors, furniture, doors, millwork, and many other items.

Sassafras

The range of sassafras (*Sassafras albidum*) covers most of the eastern half of the United States from southeastern Iowa and eastern Texas eastward.

The wood of sassafras is easily confused with black ash, which it resembles in color, grain, and texture. The sapwood is light yellow and the heartwood varies from dull grayish brown to dark brown, sometimes with a reddish tinge. The wood has an odor of sassafras on freshly cut surfaces.

Sassafras is moderately heavy, moderately hard, moderately weak in bending and endwise compression, quite high in shock resistance, and quite durable when exposed to conditions conducive to decay. It was highly prized by the Indians for dugout canoes, and some sassafras lumber is now used for small boats. Locally, it is used for fence posts and rails and general millwork, for foundation posts, and some wooden containers.

Sweetgum

Sweetgum (*Liquidambar styraciflua*) grows from southwestern Connecticut westward into Missouri and southward to the gulf. Lumber production is almost entirely from the Southern and South Atlantic States.

The lumber from sweetgum is usually divided into two classes—sap gum, the light-colored wood from the sapwood, and red gum, the reddish-brown heartwood.

Sweetgum has interlocked grain, a form of cross grain, and must be carefully dried. The interlocked grain causes a ribbon stripe, however, that is desirable for interior finish and furniture. The wood is rated as moderately heavy and hard. It is moderately strong, moderately stiff, and moderately high in shock resistance.

Sweetgum is used principally for lumber, veneer, plywood, slack cooperage, railroad ties, fuel, and pulpwood. The lumber goes principally into boxes and crates, furniture, radio and phonograph cabinets, interior trim, and millwork. Sweetgum veneer and plywood are used for boxes, pallets, crates, baskets, and interior woodwork.

Sycamore, American

American sycamore (*Platanus occidentalis*) is also known as sycamore and sometimes as buttonwood, buttonball tree, and planetree. Sycamore grows from Maine to Nebraska, southward to Texas, and eastward to Florida. In the production of sycamore lumber, the Central States rank first.

The heartwood of sycamore is reddish brown; sapwood is lighter in color and from 1½ to 3 inches thick. The wood has a fine texture and interlocked grain. It shrinks moderately in drying. Sycamore wood is moderately heavy, moderately hard, moderately stiff, moderately strong, and has good resistance to shock.

Sycamore is used principally for lumber, veneer, railroad ties, slack cooperage, fenceposts, and fuel. Sycamore lumber is used for furniture, boxes (particularly small food containers), pallets, flooring, handles, and butcher's blocks. Veneer is used for fruit and vegetable baskets, and some decorative panels and door skins.

Tanoak

In recent years tanoak (*Lithocarpus densiflorus*) has gained some importance commercially, primarily in California and Oregon. It is also known as tanbark-oak because at one time high-grade tannin in commercial quantities was obtained from the bark. This species is found in southwestern Oregon and south to Southern California, mostly near the coast but also in the Sierra Nevadas.

The sapwood of tanoak is light reddish brown when first cut and turns darker with age to become almost indistinguishable from the heartwood, which also ages to dark reddish brown. The wood is heavy, hard, and except for compression perpendicular to the grain has roughly the same strength properties as eastern white oak. Volumetric shrinkage during drying is more than for white oak, and it has a tendency to collapse during drying. It is quite susceptible to decay, but the sapwood takes preservatives easily. It has straight grain, machines and glues well, and takes staining readily.

Because of tanoak's hardness and abrasion resistance, it is an excellent wood for flooring in homes or commercial buildings. It is also suitable for industrial applications such as truck flooring. Tanoak treated with preservative has been used for railroad crossties. The wood has been manufactured into baseball bats with good results. It is also suitable for veneer, both decorative and industrial, and for high-quality furniture.

Tupelo

The tupelo group includes water tupelo (*Nyssa aquatica*), also known as tupelo gum, swamp tupelo, and gum; blacktupelo (*N. sylvatica*), also known as black gum; and sour gum; swamp tupelo (*N. sylvatica* var. *biflora*), also known as swamp blackgum, blackgum, tupelo gum, and sour gum; Ogeechee tupelo (*N. ogeche*), also known as sour tupelo, gopher plum, tupelo, and Ogeechee plum.

All except black tupelo grow principally in the southeastern United States. Black tupelo grows in the eastern United States from Maine to Texas and Missouri. About two-thirds of the production of tupelo lumber is from the Southern States.

Wood of the different tupelos is quite similar in appearance and properties. Heartwood is light brownish gray and merges gradually into the lighter colored sapwood, which is generally several inches wide. The wood has fine, uniform texture and interlocked grain. Tupelo wood is rated as moderately heavy. It is moderately strong, moderately hard and stiff, and moderately high in shock resistance. Buttresses of trees growing in swamps or flooded areas contain wood that is much lighter in weight than that from upper portions of the same trees. For some uses, as in the case of buttressed ash trees, this wood should be separated from the heavier wood to assure material of uniform strength. Because of interlocked grain, tupelo lumber requires care in drying.

Tupelo is cut principally for lumber, veneer, pulpwood, and some railroad ties and slack cooperage. Lumber goes into boxes, pallets, crates, baskets, and furniture.

Walnut, Black

Black walnut (*Juglans nigra*) is also known as American black walnut. Its natural range extends from Vermont to the Great Plains and southward into Louisiana and Texas. About three-quarters of the walnut timber is produced in the Central States.

The heartwood of black walnut varies from light to dark brown; the sapwood is nearly white and up to 3 inches wide in open-grown trees. Black walnut is normally straight grained, easily worked with tools, and stable in use. It is heavy, hard, strong, stiff, and has good resistance to shock. Black walnut wood is well suited for natural finishes.

The outstanding uses of black walnut are for furniture, architectural woodwork, and decorative panels. Other important uses are gunstocks, cabinets, and interior finish. It is used either as solid wood or as plywood.

Willow, Black

Black willow (*Salix nigra*) is the most important of the many willows that grow in the United States. It is the only one to supply lumber to the market under its own name. Black willow is most heavily produced in the Mississippi Valley from Louisiana to southern Missouri and Illinois.

The heartwood of black willow is grayish brown or light reddish brown frequently containing darker streaks. The sapwood is whitish to creamy yellow. The wood of black willow is uniform in texture, with somewhat interlocked grain. The wood is light in weight. It has exceedingly low strength as a beam or post and is moderately soft and moderately high in shock resistance. It has moderately large shrinkage.

Willow is cut principally into lumber. Small amounts are used for slack cooperage, veneer, excelsior, charcoal, pulpwood, artificial limbs, and fenceposts. Black willow lumber is remanufactured principally into boxes, pallets, crates, caskets, and furniture. Willow lumber is suitable for roof and wall sheathing, subflooring, and studding.

Yellow-Poplar

Yellow-poplar (*Liriodendron tulipifera*) is also known as poplar, tulip poplar, tulipwood, and hickory poplar. Sapwood from yellow-poplar is sometimes called white poplar or whitewood.

Yellow-poplar grows from Connecticut and New York southward to Florida and westward to Missouri. The greatest commercial production of yellow-poplar lumber is in the South.

Yellow-poplar sapwood is white and frequently several inches thick. The heartwood is yellowish brown, sometimes streaked with purple, green, black, blue, or red. These colorations do not affect the physical properties of the wood. The wood is generally straight grained and comparatively uniform in texture. Old-growth timber is moderately light in weight and is reported as being moderately low in bending strength, moderately soft, and moderately low in shock resistance. It has moderately large shrinkage when dried from a green condition but is not difficult to season and stays in place well after seasoning.

Much of the second-growth yellow-poplar is heavier, harder, and stronger than old growth. Selected trees produce wood heavy enough for gunstocks. Lumber goes mostly into furniture, interior finish, siding, core stock for plywood, radio cabinets, and musical instruments, but use for core stock is decreasing as particleboard use increases. Yellow-poplar is frequently used for crossbands in plywood. Boxes, pallets, and crates are made from lower grade stock. Yellow-poplar plywood is used for finish, furniture, piano cases, and various other special products. Yellow-poplar is used also for pulpwood, excelsior, and slack-cooperage staves.

Lumber from the cucumbertree (*Magnolia acuminata*) sometimes may be included in shipments of yellow-poplar because of its similarity.

Softwoods

Alaska-Cedar

Alaska-cedar (*Chamaecyparis nootkatensis*) grows in the Pacific coast region of North America from southeastern Alaska southward through Washington to southern Oregon.

The heartwood of Alaska-cedar is bright, clear yellow. The sapwood is narrow, white to yellowish, and hardly distinguishable from the heartwood. The wood is fine textured and generally straight grained. It is moderately heavy, moderately strong and stiff, moderately hard, and moderately high in resistance to shock. Alaska-cedar shrinks little in drying, is stable in use after seasoning, and the heartwood is ately limber, soft, and low in resistance to shock.

The eastern firs are used mainly for pulpwood, although there is some lumber produced from them, especially in New England and the Lake States.

Firs, True (Western Species)

Six commercial species make up the western true firs: Subalpine fir (*Abies lasiocarpa*), California red fir (*A. magnifica*), grand fir (*A. grandis*), noble fir (*A. procera*), Pacific silver fir (*A. amabilis*), and white fir (*A. concolor*).

The western firs are light in weight, but, with the exception of subalpine fir, have somewhat higher strength properties than balsam fir. Shrinkage of the wood is rated from small to moderately large.

The western true firs are largely cut for lumber in Washington, Oregon, California, western Montana, and northern Idaho and marketed as white fir throughout the United States. Lumber of the western true firs goes principally into building construction, boxes and crates, planing-mill products, sash, doors, and general millwork. In house construction the lumber is used for framing, subflooring, and sheathing. Some western true fir lumber goes into boxes and crates. High-grade lumber from noble fir is used mainly for interior finish, moldings, siding, and sash and door stock. Some of the best material is suitable for aircraft construction. Other special and exacting uses of noble fir are for venetian blinds and ladder rails.

Hemlock, Eastern

Eastern hemlock (*Tsuga canadensis*) grows from New England to northern Alabama and Georgia, and in the Lake States. Other names are Canadian hemlock and hemlock spruce.

The production of hemlock lumber is divided fairly evenly between the New England States, the Middle Atlantic States, and the Lake States.

The heartwood of eastern hemlock is pale brown with a reddish hue. The sapwood is not distinctly separated from the heartwood but may be lighter in color. The wood is coarse and uneven in texture (old trees tend to have considerable shake); it is moderately light in weight, moderately hard, moderately low in strength, moderately limber, and moderately low in shock resistance.

Eastern hemlock is used principally for lumber and pulpwood. The lumber is used largely in building construction for framing, sheathing, subflooring, and roof boards, and in the manufacture of boxes, pallets, and crates.

Hemlock, Western

Western hemlock (*Tsuga heterophylla*) is also known by several other names, including west coast hemlock, hemlock spruce, western hemlock spruce, western hemlock fir, Prince Albert fir, gray fir, silver fir, and Alaska pine. It grows along the Pacific coast of Oregon and Washington and in the northern Rocky Mountains, north to Canada and Alaska.

A relative, mountain hemlock, *T. mertensiana*, inhabits mountainous country from central California to Alaska. It is treated as a separate species in assigning lumber properties.

The heartwood and sapwood of western hemlock are almost white with a purplish tinge. The sapwood, which is sometimes lighter in color, is generally not more than 1 inch thick. The wood contains small, sound, black knots that are usually tight and stay in place. Dark streaks often found in the lumber and caused by hemlock bark maggots as a rule do not reduce strength.

Western hemlock is moderately light in weight and moderate in strength. It is moderate in its hardness, stiffness, and shock resistance. It has moderately large shrinkage, about the same as Douglas-fir. Green hemlock lumber contains considerably more water than Douglas-fir, and requires longer kiln drying time.

Mountain hemlock has approximately the same density as western hemlock but is somewhat lower in bending strength and stiffness.

Western hemlock is used principally for pulpwood, lumber, and plywood. The lumber goes largely into building material, such as sheathing, siding, subflooring, joists, studding, planking, and rafters. Considerable quantities are used in the manufacture of boxes, pallets, crates, and flooring, and smaller amounts for refrigerators, furniture, and ladders.

Mountain hemlock serves some of the same uses as western hemlock although the quantity available is much lower.

Incense-Cedar

Incense-cedar (*Libocedrus decurrens*) grows in California and southwestern Oregon, and a little in Nevada. Most incense-cedar lumber comes from the northern half of California and the remainder from southern Oregon.

Sapwood of incense-cedar is white or cream colored, and the heartwood is light brown, often tinged with red. The wood has a fine, uniform texture and a spicy odor. Incense-cedar is light in weight, moderately low in strength, soft, low in shock resistance, and low in stiffness. It has small shrinkage and is easy to season with little checking or warping.

Incense-cedar is used principally for lumber and fenceposts. Nearly all the high-grade lumber is used for pencils and venetian blinds. Some is used for chests and toys. Much of the incense-cedar lumber is more or less pecky; that is, it contains pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. There is no further development of peck once the lumber is seasoned. This lumber is used locally for rough construction where cheapness and decay resistance are important. Because of its resistance to decay, incense-cedar is well suited for fenceposts. Other products are railroad ties, poles, and split shingles.

Larch, Western

Western larch (*Larix occidentalis*) grows in western Montana, northern Idaho, northeastern Oregon, and on the eastern slope of the Cascade Mountains in Washington. About two-thirds of the lumber of this species is produced in Idaho and Montana and one-third in Oregon and Washington.

The heartwood of western larch is yellowish brown and the sapwood yellowish white. The sapwood is generally not more than 1 inch thick. The wood is stiff, moderately strong and hard, moderately high in shock resistance, and moderately heavy. It has moderately large shrinkage. The wood is usually straight grained, splits easily, and is subject to ring shake. Knots are common but small and tight.

Western larch is used mainly in building construction for rough dimension, small timbers, planks and boards, and for railroad ties and mine timbers. It is used also for piles, poles, and posts. Some high-grade material is manufactured into interior finish, flooring, sash, and doors.

Pine, Eastern White

Eastern white pine (*Pinus strobus*) grows from Maine to northern Georgia and in the Lake States. It is also known as white pine, northern white pine, Weymouth pine, and soft pine.

About one-half the production of eastern white pine lumber occurs in the New England States, about one-third in the Lake States, and most of the remainder in the Middle Atlantic and South Atlantic States.

The heartwood of eastern white pine is light brown, often with a reddish tinge. It turns considerably darker on exposure. The wood has comparatively uniform texture, and is straight grained. It is easily kiln-dried, has small shrinkage, and ranks high in stability. It is also easy to work and can be readily glued.

Eastern white pine is light in weight, moderately soft, moderately low in strength, and low in resistance to shock.

Practically all eastern white pine is converted into lumber, which is put to a great variety of uses. A large proportion, which is mostly second-growth knotty lumber of the lower grades, goes into container and packaging applications. High-grade lumber goes into patterns for castings. Other important uses are sash, doors, furniture, trim, knotty paneling, finish, caskets and burial boxes, shade and map rollers, toys, and dairy and poultry supplies.

Pine, Jack

Jack pine (*Pinus banksiana*), sometimes known as scrub pine, gray pine, or black pine in the United States, grows naturally in the Lake States and in a few scattered areas in New England and northern New York. In lumber, jack pine is not separated from the other pines with which it grows, including red pine and eastern white pine.

The sapwood of jack pine is nearly white, the heartwood is light brown to orange. The sapwood may make up one-half or more of the volume of a tree. The wood has a rather coarse texture and is somewhat resinous. It is moderately light in weight, moderately low in bending strength and compressive strength, moderately low in shock resistance, and low in stiffness. It also has moderately small shrinkage. Lumber from jack pine is generally knotty.

Jack pine is used for pulpwood, box lumber, pallets, and fuel. Less important uses include railroad ties, mine timber, slack cooperage, poles, and posts.

Pine, Lodgepole

Lodgepole pine (*Pinus contorta*), also known as knotty pine, black pine, spruce pine, and jack pine, grows in the Rocky Mountain and Pacific coast regions as far northward as Alaska. The cut of this species comes largely from the central Rocky Mountain States; other producing regions are Idaho, Montana, Oregon, and Washington.

The heartwood of lodgepole pine varies from light yellow to light yellow-brown. The sapwood is yellow or nearly white. The wood is generally straight grained with narrow growth rings.

The wood is moderately light in weight, fairly easy to work, and has moderately large shrinkage. Lodgepole pine rates as moderately low in strength, moderately soft, moderately stiff, and moderately low in shock resistance.

Lodgepole pine is used for lumber, mine timbers, railroad ties, and poles. Less important uses include posts and fuel. It is being used in increasing amounts for framing, siding, finish, and flooring.

Pine, Pitch

Pitch pine (*Pinus rigida*) grows from Maine along the mountains to eastern Tennessee and northern Georgia. The heartwood is brownish red and resinous; the sapwood is thick and light yellow. The wood of pitch pine is medium heavy to heavy, medium strong, medium stiff, medium hard, and medium high in shock resistance. Its shrinkage is medium small to medium large. It is used for lumber, fuel, and pulpwood. Pitch pine lumber is classified as a "minor species" along with pond pine and Virginia pine in southern pine grading rules.

Pine, Pond

Pond pine (*Pinus serotina*) grows in the coast region from New Jersey to Florida. It occurs in small groups or singly, mixed with other pines on low flats. The wood is heavy, coarse-grained, and resinous, with dark, orange-colored heartwood and thick, pale yellow sapwood. At 12 percent moisture content it weighs about 38 pounds per cubic foot. Shrinkage is moderately large. The wood is moderately strong, stiff, medium hard, and medium high in shock resistance. It is used for general construction, railway ties, posts, and poles. As noted for pitch pine, the lumber of this species is graded as a "minor species" with pitch pine and Virginia pine.

Pine, Ponderosa

Ponderosa pine (*Pinus ponderosa*) is known also as pondosa pine, western soft pine, western pine, Califorina white pine, bull pine, and black jack. Jeffrey pine (*P. jeffreyi*), which grows in close association with ponderosa pine in California and Oregon, is usually marketed with ponderosa pine and sold under that name.

Major producing areas are in Oregon, Washington, and California. Other important producing areas are in Idaho and Montana; lesser amounts come from the southern Rocky Mountain region and the Black Hills of South Dakota and Wyoming.

Botanically, ponderosa pine belongs to the yellow pine group rather than the white pine group. A considerable proportion of the wood, however, is somewhat similar to the white pines in appearance and properties. The heartwood is light reddish brown, and the wide sapwood is nearly white to pale yellow.

The wood of the outer portions of ponderosa pine of sawtimber size is generally moderately light in weight, moderately low in strength, moderately soft, moderately stiff, and moderately low in shock resistance. It is generally straight grained and has moderately small shrinkage. It is quite uniform in texture and has little tendency to warp and twist.

Ponderosa pine is used mainly for lumber and to a lesser extent for piles, poles, posts, mine timbers, veneer, and ties. The clear wood goes into sash, doors, blinds, moldings, paneling, mantels, trim, and built-in cases and cabinets. Lower grade lumber is used for boxes and crates. Much of the lumber of intermediate or lower grades goes into sheathing, subflooring, and roof boards. Knotty ponderosa pine is used for interior finish. A considerable amount now goes into particleboard and pulp chips.

Pine, Red

Red pine (*Pinus resinosa*) is frequently called Norway pine. It is occasionally known as hard pine and pitch pine. This species grows in the New England States, New York, Pennsylvania, and the Lake States. In the past, lumber from red pine has been marketed with white pine without distinction as to species.

The heartwood of red pine varies from pale red to reddish brown. The sapwood is nearly white with a yellowish tinge, and is generally from 2 to 4 inches wide. The wood resembles the lighter weight wood of southern pine. Latewood is distinct in the growth rings.

Red pine is moderately heavy, moderately strong and stiff, moderately soft and moderately high in shock resistance. It is generally straight grained, not so uniform in texture as eastern white pine, and somewhat resinous. The wood has moderately large shrinkage but is not difficult to dry and stays in place well when seasoned.

Red pine is used principally for lumber and to a lesser extent for piles, poles, cabin logs, posts, pulpwood, and fuel. The wood is used for many of the purposes for which eastern white pine is used. It goes mostly into building construction, siding, flooring, sash, doors, blinds, general millwork, and boxes, pallets, and crates.

Pine, Southern

There are a number of species included in the group marketed as southern pine lumber. The most important, and their growth range, are:

(1) Longleaf pine (*Pinus palustris*), which grows from eastern North Carolina southward into Florida and westward into eastern Texas. (2) Shortleaf pine (*P. echinata*), which grows from southeastern New York and New Jersey southward to northern Florida and westward into eastern Texas and Oklahoma. (3) Loblolly pine (*P. taeda*), which grows from Maryland southward through the Atlantic Coastal Plain and Piedmont Plateau into Florida and westward into eastern Texas. (4) Slash pine (*P. elliottii*), which grows in Florida and the southern parts of South Carolina, Georgia, Alabama, Mississippi, and Louisiana east of the Mississippi River.

Lumber from any one or from any mixture of two or more of these species is classified as southern pine by the grading standards of the industry. These standards provide also for lumber that is produced from trees of the longleaf and slash pine species to be classified as longleaf pine if conforming to the growth-ring and latewood requirements of such standards. The lumber that is classified as longleaf in the domestic trade is known also as pitch pine in the export trade. Three southern pines—pitch pine, pond pine, and Virginia pine—are designated in published grading rules as "minor species," to distinguish them from the four principal species.

Southern pine lumber comes principally from the Southern and South Atlantic States. States that lead in production are Georgia, Alabama, North Carolina, Arkansas, and Louisiana.

The wood of the various southern pines is quite similar in appearance. The sapwood is yellowish white and heartwood reddish brown. The sapwood is usually wide in second-growth stands. Heartwood begins to form when the tree is about 20 years old. In old, slow-growth trees, sapwood may be only 1 to 2 inches in width.

Longleaf and slash pine are classed as heavy, strong, stiff, hard, and moderately high in shock resistance. Shortleaf and loblolly pine are usually somewhat lighter in weight than longleaf. All the southern pines have moderately large shrinkage but are stable when properly seasoned.

To obtain heavy, strong wood of the southern pines for structural purposes, a density rule has been written that specifies certain visual characteristics for structural timbers.

Dense southern pine is used extensively in construction of factories, warehouses, bridges, trestles, and docks in the form of stringers, beams, posts, joists, and piles. Lumber of lower density and strength finds many uses for building material, such as interior finish, sheathing, subflooring, and joists, and for boxes, pallets, and crates. Southern pine is used also for tight and slack cooperage. When used for railroad ties, piles, poles, and mine timbers, it is usually treated with preservatives. The manufacture of structural grade plywood from southern pine has become a major wood-using industry.

Pine, Spruce

Spruce pine (*Pinus glabra*), also known as cedar pine, poor pine, Walter pine, and bottom white pine, is found growing most commonly on low moist lands of the coastal regions of southeastern South Carolina, Georgia, Alabama, Mississippi, and Louisiana, and northern and northwestern Florida.

Heartwood is light brown, and the wide sapwood zone is nearly white. Spruce pine wood is lower in most strength values than the major southern pines. It compares favorably with white fir in important bending properties, in crushing strength perpendicular and parallel to the grain, and in hardness. It is similar to the denser species such as coast Douglas-fir and loblolly pine in shear parallel to the grain.

Until recent years the principal uses of spruce pine were locally for lumber, and for pulpwood and fuelwood. The lumber, which is classified as one of the minor southern pine species, reportedly was used for sash, doors, and interior finish because of its lower specific gravity and less marked distinction between earlywood and latewood. In recent years it has qualified for use in plywood.

Pine, Sugar

Sugar pine (*Pinus lambertiana*) is sometimes called California sugar pine. Most of the sugar pine lumber is produced in California and the remainder in southwestern Oregon.

The heartwood of sugar pine is buff or light brown, sometimes tinged with red. The sapwood is creamy white. The wood is straight grained, fairly uniform in texture, and easy to work with tools. It has very small shrinkage, is readily seasoned without warping or checking, and stays in place well. This species is light in weight, moderately low in strength, moderately soft, low in shock resistance, and low in stiffness.

Sugar pine is used almost entirely for lumber products. The largest amounts are used in boxes and crates, sash, doors, frames, blinds, general millwork, building construction, and foundry patterns. Like eastern white pine, sugar pine is suitable for use in nearly every part of a house because of the ease with which it can be cut, its ability to stay in place, and its good nailing properties.

Pine, Virginia

Virginia pine (*Pinus virginiana*), known also as Jersey pine and scrub pine, grows from New Jersey and Virginia throughout the Appalachian region to Georgia and the Ohio Valley. The heartwood is orange and the sapwood nearly white and relatively thick. The wood is rated as moderately heavy, moderately strong, moderately hard, and moderately stiff and has moderately large shrinkage and high shock resistance. It is used for lumber, railroad ties, mine props, pulpwood, and fuel. It is one of three southern pines to be classified as a "minor species" in the grading rules.

Pine, Western White

Western white pine (*Pinus monticola*) is also known as Idaho white pine or white pine. About four-fifths of the cut comes from Idaho (fig. 1–3) with the remainder mostly from Washington; small amounts are cut in Montana and Oregon.

Heartwood of western white pine is cream colored to light reddish brown and darkens on exposure. The sapwood is yellowish white and generally from 1 to 3 inches wide. The wood is straight grained, easy to work, easily kiln-dried, and stable after seasoning.

This species is moderately light in weight, moderately low in strength, moderately soft, moderately stiff, moderately low in shock resistance, and has moderately large shrinkage.

Practically all western white pine is sawed into lumber and used mainly for building constuction, matches, boxes, patterns, and millwork products, such as sash, frames, doors, and blinds. In building construction, boards of the lower grades are used for sheathing, knotty paneling, subflooring, and roof strips. High-grade material is made into siding of various kinds, exterior and interior trim, and finish. It has practically the same uses as eastern white pine and sugar pine.

Port-Orford-Cedar

Port-Orford-cedar (*Chamaecyparis lawsoniana*) is sometimes known as Lawson cypress, Oregon cedar, and white cedar. It grows along the Pacific coast from Coos Bay, Oreg., southward to California. It does not extend more than 40 miles inland.

The heartwood of Port-Orford-cedar is light yellow to pale brown in color. Sapwood is thin and hard to distinguish. The wood has fine texture, generally straight grain, and a pleasant spicy odor. It is moderately light in weight, stiff, moderately strong and hard, and moderately resistant to shock. Port-Orford-cedar heartwood is highly resistant to decay. The wood shrinks moderately, has little tendency to warp, and is stable after seasoning.

Some high-grade Port-Orford-cedar is used in the manufacture of battery separators and venetian-blind slats. Other uses are mothproof boxes, archery supplies, sash and door construction, stadium seats, flooring, interior finish, furniture, and boatbuilding.

Redcedar, Eastern

Eastern redcedar (*Juniperus virginiana*) grows throughout the eastern half of the United States, except in Maine, Florida, and a narrow strip along the gulf coast, and at the higher elevations in the Appalachian Mountain Range. Commercial production is principally in the southern Appalachian and Cumberland Mountain regions. Another species, southern redcedar (*J. silicicola*), grows over a limited area in the South Atlantic and Gulf Coastal Plains.

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Figure 1–3.—Western white pine timber, mostly privately owned, viewed from Elk Butte in Clearwater National Forest in Idaho.

The heartwood of redcedar is bright red or dull red, and the thin sapwood is nearly white. The wood is moderately heavy, moderately low in strength, hard, and high in shock resistance, but low in stiffness. It has very small shrinkage and stays in place well after seasoning. The texture is fine and uniform. Grain is usually straight, except where deflected by knots, which are numerous. Eastern redcedar heartwood is very resistant to decay.

The greatest quantity of eastern redcedar is used for fenceposts. Lumber is manufactured into chests, wardrobes, and closet lining. Other uses include flooring, novelties, pencils, scientific instruments, and small boats. Southern redcedar is used for the same purposes.

Redcedar, Western

Western redcedar (*Thuja plicata*) grows in the Pacific Northwest and along the Pacific coast to Alaska. Western redcedar is also called canoe cedar, giant arborvitae, shinglewood, and Pacific redcedar. Western redcedar lumber is produced principally in Washington, followed by Oregon, Idaho, and Montana.

The heartwood of western redcedar is reddish or pinkish brown to dull brown and the sapwood nearly white. The sapwood is narrow, often not over 1 inch in width. The wood is generally straight grained and has a uniform but rather coarse texture. It has very small shrinkage. This species is light in weight, moderately soft, low in strength when used as a beam or posts, and low in shock resistance. Its heartwood is very resistant to decay.

Western redcedar is used principally for shingles, lumber, poles, posts, and piles. The lumber is used for exterior siding, interior finish, greenhouse construction, ship and boat building, boxes and crates, sash, doors, and millwork.

Redwood

Redwood (*Sequoia sempervirens*) is a very large tree growing on the coast of California. Another sequoia, gaint sequoia (*Sequoia gigantea*), grows in a limited area in the Sierra Nevada of California, but is used in very limited quantities. Other names for redwood are coast redwood, California redwood, and sequoia. Production of redwood lumber is limited to California, but a nationwide market exists.

The heartwood of redwood varies from a light cherry to a dark mahogany. The narrow sapwood is almost white. Typical old-growth redwood is moderately light in weight, moderately strong and stiff, and moderately hard. The wood is easy to work, generally straight grained, and shrinks and swells comparatively little. The heartwood has high decay resistance.

Most redwood lumber is used for building. It is remanufactured extensively into siding, sash, doors, blinds, finish, casket stock, and containers. Because of its durability, it is useful for cooling towers, tanks, silos, wood-stave pipe, and outdoor furniture. It is used in agriculture for buildings and equipment. Its use as timbers and large dimension in bridges and trestles is relatively minor. The wood splits readily and the manufacture of split products, such as posts and fence material, is an important business in the redwood area. Some redwood veneer is manufactured for decorative plywood.

Spruce, Eastern

The term "eastern spruce" includes three species, red (*Picea rubens*), white (*P. glauca*), and black (*P. mariana*). White spruce and black spruce grow principally in the Lake States and New England, and red spruce in New England and the Appalachian Mountains. All three species have about the same properties, and in commerce no distinction is made between them. The wood dries easily and is stable after drying, is moderately light in weight and easily worked, has moderate shrinkage, and is moderately strong, stiff, tough, and hard. The wood is light in color, and there is little difference between the heartwood and sapwood.

The largest use of eastern spruce is for pulpwood. It is also used for framing material, general millwork, boxes and crates, ladder rails, scaffold planks, and piano sounding boards.

Spruce, Engelmann

Engelmann spruce (*Picea engelmannii*) grows at high elevations in the Rocky Mountain region of the United States. This species is sometimes known by other names, such as white spruce, mountain spruce, Arizona spruce, silver spruce, and balsam. About two-thirds of the lumber is produced in the southern Rocky Mountain States. Most of the remainder comes from the northern Rocky Mountain States and Oregon.

The heartwood of Engelmann spruce is nearly white with a slight tinge of red. The sapwood varies from 3/4 inch to 2 inches in width and is often difficult to distinguish from heartwood. The wood has medium to fine texture and is without characteristic taste or odor. It is generally straight grained. Engelmann spruce is rated as light in weight. It is low in strength as a beam or post. It is limber, soft, low in shock resistance, and has moderately small shrinkage. The lumber typically contains numerous small knots.

Engelmann spruce is used principally for lumber and for mine timbers, railroad ties, and poles. It is used also in building construction in the form of dimension stock, flooring, sheathing, and studding. It has excellent properties for pulp and papermaking.

Spruce, Sitka

Sitka spruce (*Picea sitchensis*) is a tree of large size growing along the northwestern coast of North American from California to Alaska. It is generally known as Sitka spruce, although other names may be applied locally, such as yellow spruce, tideland spruce, western spruce, silver spruce, and west coast spruce. About two-thirds of the production of Sitka spruce lumber comes from Washington and one-third from Oregon.

The heartwood of Sitka spruce is a light pinkish brown. The sapwood is creamy white and shades gradually into the heartwood; it may be 3 to 6 inches wide or even wider in young trees. The wood has a comparatively fine, uniform texture, generally straight grain, and no distinct taste or odor. It is moderately light in weight, moderately low in bending and compressive strength, moderately stiff, moderately soft, and moderately low in resistance to shock. It has moderately small shrinkage. On the basis of weight, it rates high in strength properties and can be obtained in clear, straight grained pieces.

Sitka spruce is used principally for lumber, pulpwood, and cooperage. Boxes and crates account for a considerable amount of the remanufactured lumber. Other important uses are furniture, planing-mill products, sash, doors, blinds, millwork, and boats. Sitka spruce has been by far the most important wood for aircraft construction. Other specialty uses are ladder rails and sounding boards for pianos.

Tamarack

Tamarack (*Larix laricina*) is a small- to medium-sized tree with a straight, round, slightly tapered trunk. In the United States it grows from Maine to Minnesota, with the bulk of the stand in the Lake States. It was formerly used in considerable quantity for lumber, but in recent years production for that purpose has been small.

The heartwood of tamarack is yellowish brown to russet brown. The sapwood is whitish, generally less than an inch wide. The wood is coarse in texture, without odor or taste, and the transition from earlywood to latewood is abrupt. The wood is intermediate in weight and in most mechanical properties.

Tamarack is used principally for pulpwood, lumber, railroad ties, mine timbers, fuel, fenceposts, and poles. Lumber goes into framing material, tank construction, and boxes, pallets, and crates.

White-Cedar, Northern and Atlantic

Two species of white-cedar grow in the eastern part of the United States—northern white-cedar (*Thuja occidentalis*) and Atlantic white-cedar (*Chamaecyparis thyoides*). Northern white-cedar is also known as arborvitae, or simply cedar. Atlantic white-cedar is also known as juniper, southern white-cedar, swamp cedar, and boat cedar.

Northern white-cedar grows from Maine along the Appalachian Mountain Range and westward through the northern part of the Lake States. Atlantic white-cedar grows near the Atlantic coast from Maine to northern Florida and westward along the gulf coast to Louisiana. It is strictly a swamp tree.

Production of northern white-cedar lumber is probably greatest in Maine and the Lake States. Commercial production of Atlantic white-cedar centers in North Carolina and along the gulf coast.

The heartwood of white-cedar is light brown, and the sapwood is white or nearly so. The sapwood is usually thin. The word is light in weight, rather soft and low in strength, and low in shock resistance. It shrinks little in drying. It is easily worked, holds paint well, and the heartwood is highly resistant to decay. The two species are used for similar purposes, mostly for poles, ties, lumber, posts, and decorative fencing. White-cedar lumber is used principally where high degree of durability is needed, as in tanks and boats, and for woodenware.

IMPORTED WOODS

This section does not purport to discuss all of the woods that have been at one time or another imported into the United States. Only those species at present considered to be of commercial importance are included. The same species may be marketed in the United States under other common names.

Text information is necessarily brief, but when used in conjunction with the shrinkage and strength tables (ch. 3 and 4), a reasonably good picture may be obtained of a particular wood. The bibliography at the end of this chapter contains information on many species not described here.

Afrormosia (See Kokrodua)

Almon (See Lauans)

Andiroba

Because of the widespread distribution of andiroba (*Carapa guianensis*) in tropical America, the wood is known under a variety of names that include cedro macho, carapa, crabwood, and tangare. These names are also applied to the related species *Carapa nicaraguensis*, whose properties are generally inferior to those of *C. guianensis*.

The heartwood color varies from reddish brown to dark reddish brown. The texture (size of pores) is like that of mahogany (*Swietenia*). The grain is usually interlocked but is rated as easy to work, paint, and glue. The wood is rated as durable to very durable with respect to decay and insects. Andiroba is heavier than mahogany and accordingly is markedly superior in all static bending properties, compression parallel to the grain, hardness, shear, and toughness.

On the basis of its properties, andiroba appears to be suited for such uses as flooring, frame construction in the tropics, furniture and cabinetwork, millwork, and utility and decorative veneer and plywood.

Angelique

Angelique (*Dicorynia guianensis*), or basra locus, comes from French Guiana and Surinam and was previously identified under the name *D. paraensis*. Because of the variability in heartwood color between different trees, two forms are commonly recognized by producers. Heartwood that is russet colored when freshly cut, and becomes superficially dull brown with a purplish cast, is referred to as "gris." Heartwood that is more distinctly reddish and frequently shows wide bands of purplish color is called angelique rouge.

The texture is somewhat coarser than that of black walnut. The grain is generally straight or slightly interlocked. In strength, angelique is superior to teak and white oak, when either green or air dry, in all properties except tension perpendicular to grain. Angelique is rated as highly resistant to decay, and resistant to marine borer attack. Machining properties vary and may be due to differences in density, moisture content, and silica content. After the wood is thoroughly air dried or kiln dried, it can be worked effectively only with carbide-tipped tools.

The strength and durability of angelique make it especially suitable for heavy construction, harbor installations, bridges, heavy planking for pier and platform decking, and railroad bridge ties. The wood is particularly suitable for ship decking, planking, boat frames, and underwater members. It is currently being used in the United States for pier and dock fenders and flooring.

Apamate

Apamate (*Tabebuia rosea*) ranges from southern Mexico through Central America to Venezuela and Ecuador. The name roble is frequently applied to this species because of some fancied resemblance of the wood to that of oak (Quercus). Another common name for for apamate in Belize is mayflower.

The sapwood becomes a pale brown upon exposure. The heartwood varies through the browns, from a golden to a dark brown. Texture is medium, and grain is closely and narrowly interlocked. Heartwood is without distinctive odor or taste. The wood weighs about 38 pounds per cubic foot at 12 percent moisture content.

Apamate has excellent working properties in all machine operations. It finishes attractively in natural color and takes finishes with good results.

Apamate averages lighter in weight than the average of the American white oaks, but is comparable with respect to bending and compression parallel to grain. The white oaks are superior with respect to side hardness and shear.

The heartwood of apamate is generally rated as durable to very durable with respect to fungus attack; the darker colored and heavier wood is regarded as more resistant than the lighter forms.

Within its region of growth, apamate is used extensively for furniture, interior trim, doors, flooring, boat building, ax handles, and general construction. The wood veneers well and produces an attractive paneling.

Apitong

Apitong is the most common structural timber of the Philippine Islands. The principal species are apitong (*Dipterocarpus grandiflorus*), panau (*D. gracilis*), and hagakhak (*D. warburgii*). All members of the genus are timber trees, and all are marketed under the name apitong. Other important species of the genus *Dipterocarpus* are marketed as keruing in Malaysia and Indonesia, yang in Thailand, and gurjun in India and Burma.

The wood is light to dark reddish brown in color, comparatively coarse to comparatively fine textured, straight grained or very nearly so, strong, hard, and heavy. The wood is characterized by the presence of resin ducts, which occur in short arcs as seen from end grain surfaces.

Although the heartwood is fairly resistant to decay and insect attack, the wood should be treated with preservatives when it is to be used in contact with the ground.

In machining research at the Forest Products Laboratory on apitong and the various species of "Philippine mahogany," apitong ranked appreciably above the average in all machining operations.

Apitong is used for heavy-duty purposes as well as for such items as mine guides, truck floors, chutes, flumes, agitators, pallets, and boardwalks.

Avodire

Avodire (*Turraeanthus africanus*) has rather extensive range from Sierra Leone westward to the Cameroons and southward to Zaire. It is a medium-sized tree of the rain forest in which it forms fairly dense but localized and discontinuous stands.

The wood is cream to pale yellow in color with a high natural luster and eventually darkens to a golden yellow. The grain is sometimes straight but more often is wavy or irregularly interlocked, which produces an unusual and attractive mottled figure when sliced or cut on the quarter.

Although its weight is only 85 percent that of English oak, avodire has almost identical strength properties except that it is lower in shock resistance and in shear. The wood works fairly easily with hand and machine tools and finishes well in most operations.

Figured material is usually converted into veneer for use in decorative work and it is this kind of material that is chiefly imported into the United States.

Bagtikan

The genus *Parashorea* consists of about seven species occurring in Southeast Asia. The principal species in the United States lumber trade is bagtikan (*P. plicata*) of the Philippines and Borneo. White seraya (*P. malaanonan*) from Sabah is also important. In the United States, bagtikan may be encountered under its usual common name or more frequently with the species comprising the light-red group of lauans. The heartwood is gray to straw colored or very pale brown and sometimes has a pinkish cast. It is not always clearly demarcated from the sapwood. The wood weighs about 34 pounds per cubic foot at 12 percent moisture content. The texture is similar to that of the light-red group of Philippine lauans. The grain is interlocked and shows a rather widely spaced stripe pattern on quartered surfaces.

With respect to strength, Philippine bagtikan exceeds the lauans in all properties. Its natural durability is very low and it is resistant or extremely resistant to preservative treatment.

The wood works fairly easily with hand and machine tools and has little blunting effect on tool cutting edges.

Bagtikan is used for many of the same purposes as the Philippine lauans, but in the solid form and in thin stock it is best utilized in the quartersawn condition to prevent excessive movement with changes in moisture conditions of service. It is perhaps most useful as a veneer for plywood purposes. In Britain it is best known as a decking timber which has been specially selected for this use in vessels.

Balsa

Balsa (*Ochroma pyramidale*) is widely distributed throughout tropical America from southern Mexico to southern Brazil and Bolivia, but Ecuador has been the principal area of growth since the wood gained commercial importance.

Balsa possesses several characteristics that make possible a wide variety of uses. It is the lightest and softest of all woods on the market. The lumber selected for use in the United States when dry weighs on the average of about 11 pounds per cubic foot and often as little as 6 pounds. Because of its light weight and exceedingly porous composition, balsa is highly efficient in uses where buoyancy, insulation against heat and cold, or absorption of sound and vibration are important considerations.

The wood is readily recognized by its light weight, white to very pale gray color, and its unique "velvety" feel.

The principal uses of balsa are in life-saving equipment, floats, rafts, core stock, insulation, cushioning, sound modifiers, models, and novelties. Balsa is imported in larger volume than most of the foreign woods entering the United States.

Banak

More than 40 species of *Virola* occur in tropical America, but only three species supply the bulk of the timber known as banak. These are: *V. koschnyi* of Central America, and *V. surinamensis* and *V. sebifera* of northern South America.

The heartwood is usually pinkish brown or grayish brown in color and is not differentiated from the sapwood. The wood is straight grained and is of a medium to coarse texture.

The various species are nonresistant to decay and insect attack but can be readily treated with preservatives. Their machining properties are very good, but fuzzing and grain tearing are to be expected when zones of tension wood are present. The wood finishes readily and is easily glued. It is rated as a first-class veneer species. Its strength properties are similar to yellow-poplar.

Banak is considered as a general utility wood in both lumber and plywood form.

Basra Locus (See Angelique)

Benge

Although benge (*Guibourtia arnoldiana*) and ehie (*G. ehie*) belong to the same botanical genus, they differ rather markedly with respect to their color. The heartwood of benge is a yellow-brown to medium brown with gray to almost black striping. Ehie heartwood tends to be a more golden brown and is striped as in benge. Ehie appears to be the more attractive of the two species.

The technical aspects of these species have not been investigated, but both are moderately hard and heavy. Benge is fine textured and in this respect similar to birch; the texture of ehie is somewhat coarser. Both are straight grained or have slightly interlocked grain.

These woods are as yet little known in the United States, but would provide both veneer and lumber for decorative purposes and furniture manufacture.

Capirona

A genus of about five species found throughout most of Latin America. The species best known in the United States and particularly in the archery field is degame (*Calycophyllum candidissimum*), which was imported in the past in some quantities from Cuba. Capirona (*C. spruceanum*) of the Amazon Basin is a much larger tree and occurs in considerably greater abundance than degame.

The heartwood of degame ranges from a light brown to gray, while that of capirona has a distinct yellowish cast. The texture is fine and uniform. The grain is usually straight or infrequently shows a shallow interlocking, which may produce a narrow and indistinct strip on quartered faces. The luster is medium and the wood is without odor and taste. The wood weighs about 50 pounds per cubic foot.

Natural durability is low when the wood is used under conditions favorable to stain, decay, and insect attack.

In strength, degame is above the average for woods of similar density. Tests show degame superior to persimmon (*Diospyros virginiana*) in all respects but hardness. Limited tests on hardness of capirona from Peru gave higher values of side hardness than those of degame or persimmon.

Degame is moderately difficult to machine because of its density and hardness, although it produces no appreciable dulling effect on cutting tools. Machined surfaces are very smooth.

Degame and capirona are little used in the United States at the present time, but the characteristics of the wood should make it particularly adaptable for shuttles, picker sticks, and other textile industry items in which resilience and strength are required. It should find application for many of the same purposes as hard maple and yellow birch.

Carapa (See Andiroba)

Cativo

Cativo (*Prioria copaifera*) is one of the few tropical American species that occur in abundance and often in nearly pure stands. Commercial stands are found in Nicaragua, Costa Rica, Panama, and Colombia. The sapwood is usually thick, and in trees up to 30 inches in diameter the heartwood may be only 7 inches in diameter. The sapwood that is utilized commercially may be a very pale pinkish color or may be distinctly reddish. The grain is straight and the texture of the wood is uniform, comparable to that of mahogany. Figure on flatsawn surfaces is rather subdued and results from the exposure of the narrow bands of parenchyma tissue. Odor and taste are not distinctive, and the luster is low.

The wood can be seasoned rapidly and easily with very little degrade. The dimensional stability of the wood is very good; it is practically equal to that of mahogany. Cativo is classed as a nondurable wood with respect to decay and insects. Cativo may contain appreciable quantities of gum, which may interfere with finishes. In wood that has been properly seasoned, however, the gum presents no difficulties.

The tendency of the wood to bleed resinous material in use and in warping of narrow cuttings kept this species in disfavor for many years. Improved drying and finishing techniques have materially reduced the prominence of these inherent characteristics, and the uses for this wood are rapidly increasing. Considerable quantities are used for interior trim, and resin-stabilized veneer has become an important pattern material, particularly in the automotive industry. Cativo is widely used for furniture and cabinet parts, lumber core for plywood, picture frames, edge banding for doors, and bases for piano keyboards.

Cedro (See Spanish-Cedar)

Cedro Macho (See Andiroba)

Cocal (See Sande)

Courbaril

The genus *Hymenaea* consists of about 30 species occurring in the West Indies and from southern Mexico, through Central America, into the Amazon Basin of South America. The best known and most important species is *H. courbaril*, which occurs throughout the range of the genus.

Courbaril sapwood is gray-white and usually quite wide. The heartwood is sharply differentiated and varies through shades of brown to an occasional purplish cast. The texture is medium. Grain is interlocked, and luster is fairly high. The heartwood is without distinctive odor or taste. The wood weighs about 50 pounds per cubic foot at 12 percent moisture content.

The strength properties of courbaril are quite high but very similar to those of shagbark hickory, species of lower specific gravity.

In decay resistance, courbaril is rated as very durable to durable.

Courbaril can be finished smoothly, and it turns and glues well. It compares favorably with white oak in steam-bending behavior.

Courbaril has been little utilized in the United States, but should find application for a number of uses. Its high shock resistance recommends it for certain types of sporting equipment, or as a substitute for ash in handle stock. It promises to be a suitable substitute for white oak in steam-bent boat parts. It makes an attractive veneer and should also find application in the solid form for furniture. The thick sapwood would provide a excellent source of blond wood.

Crabwood (See Andiroba)

Cuangare (See Virola)

Degame (See Capirona)

Ehie (See Benge)

Encino (See Oak)

Freijo (See Laurel)

Gola

Gola (*Tetraberlinia tubmaniana*) is known presently only from Liberia. The names "African pine" and "Liberian pine" have been applied to this species, but because it is a hardwood and not a pine, these names are most inappropriate and very misleading.

The heartwood is light reddish brown and is distinct from the lighter colored sapwood, which may be up to 2 inches thick. The wood is moderately coarse textured. Luster is medium. Grain is interlocked, showing a narrow stripe pattern on quartered surfaces. The wood weighs about 39 pounds per cubic foot at 12 percent moisture content.

Tests made at the Forest Products Laboratory indicate no potential difficulties in the machining of gola. It also peels and slices very well.

Gola is a very recent newcomer to the timber market and its potential has yet to be developed. Its workability and relatively light color should permit utilization in both the solid and veneer form for both utility and decorative purposes.

Goncalo Alves

The major and early imports of goncalo alves (*Astronium graveolens & fraxinifolium*) have been from Brazil. These species range from southern Mexico, through Central America into the Amazon Basin.

The heartwood ranges from various shades of brown to red with narrow to wide, irregular stripes of dark brown or nearly black. The sapwood is grayish white and sharply demarcated from the heartwood. The texture is medium and uniform. Grain is variable from straight to interlocked and wavy. The wood is very heavy and averages about 63 pounds per cubic foot at 12 percent moisture content.

It turns readily, finishes very smoothly, and takes a high natural polish. The heartwood is highly resistant to moisture absorption and the pigmented areas, because of their high density, may present some difficulties in gluing.

The heartwood is rated as very durable with respect to fungus attack.

The high density of the wood is accompanied by equally high strength values, which are considerably higher in most respects than those of any well known U.S. species. It is not expected, however, that goncalo alves will be imported for purposes where strength is an important criterion.

In the United States the greatest value of goncalo alves is in its use for specialty items such as archery bows, billiard cue butts, brush backs, cutlery handles, and for fine and attractive products of turnery or carving.

Greenheart

Greenheart (*Ocotea rodiaei*) is essentially a Guyana tree although small stands also occur in Surinam. The heartwood varies in color from light to dark olive-green or nearly black. The texture is fine and uniform.

Greenheart is stronger and stiffer than white oak and generally more difficult to work with tools because of its high density. The heartwood is rated as very resistant to decay and termites. It also is very resistant to marine borers in temperate waters but much less so in warm tropical waters.

Greenheart is used principally where strength and resistance to wear are required. Uses include ship and dock building, lock gates, wharves, piers, jetties, engine bearers, planking, flooring, bridges, and trestles.

Curjun (See Apitong)

Ilomba

Ilomba (*Pycnanthus angolensis*) is a tree of the rain forest and ranges from Guinea and Sierra Leone through west tropical Africa to Uganda and Angola. This species is also referred to in the literature under the synonymous name *Pycnanthus kombo*.

The wood is a grayish white to pinkish brown and in some trees may be a uniform light brown. There is generally no distinction between heartwood and sapwood. The texture is moderately coarse and even. Luster is low. Grain is generally straight. The wood weighs about 32 pounds per cubic foot at 12 percent moisture content. This species is generally similar to banak (*Virola*), but is somewhat coarser textured.

The wood is rated as perishable, but permeable to preservative treatment. The general characteristics of ilomba would suggest similarity to banak in working properties, seasoning, finishing, and utilization.

This species has been utilized in the United States only in the form of plywood for general utility purposes.

Ipe (See Lapacho)

Jacaranda (See Rosewood, Brazilian)

Jarrah

Jarrah (*Eucalyptus marginata*) is native to the coastal belt of southwestern Australia and one of the principal timbers of the sawmill industry.

The heartwood is a uniform pinkish to dark red, often a rich, dark red mahogany hue, turning to a deep brownish red with age and exposure to light. The sapwood is pale in color and usually very narrow in old trees. The texture is even and moderately coarse. The grain, though usually straight, is frequently interlocked or wavy. The wood weighs about 44 pounds per cubic foot at 12 percent moisture content. The common defects of jarrah include gum veins or pockets which, in extreme instances, separate the log into concentric shells.

Jarrah is a heavy, hard timber possessing correspondingly high strength properties. It is resistant to attack by termites and rated as very durable with respect to fungus attack. The heartwood is rated as extremely resistant to preservative treatment.

Jarrah is fairly hard to work in machines and difficult to cut with hand tools.

Jarrah is used for decking and underframing of piers, jetties, and bridges, and also for piling and fenders in dock and harbor installations. As a flooring timber it has a high resistance, but is inclined to splinter under heavy traffic.

Jelutong

Jelutong (*Dyera costulata*) is an important species in Malaya where it is best known for its latex production rather than its timber.

The wood is white or straw-colored and there is no differentiation between heartwood and sapwood. The texture is moderately fine and even. The grain is straight, and luster is low. The wood weighs about 29 pounds per cubic foot at 12 percent moisture content.

The wood is reported to be very easy to season with little tendency to split or warp, but staining may cause trouble.

It is easy to work in all operations, finishes well, and can be glued satisfactorily.

The wood is rated as nondurable, but readily permeable to preservatives.

Jelutong would make an excellent core stock if it were economically feasible to fill the latex channels which radiate outward in the stem at the branch whorls. Because of its low density and ease of working, it is well suited for sculpture and pattern. Jelutong is essentially a "short-cutting" species, because the wood between the channels is remarkably free of other defects.

Kapur

The genus *Dryobalanops* comprises some nine species distributed over parts of Malaya, Sumatra, and Borneo, including North Borneo and Sarawak. For the export trade, however, the species are combined under the name kapur.

The heartwood is light reddish brown, clearly demarcated from the pale colored sapwood. The wood is fairly coarse textured but uniform. In general appearance the wood resembles that of apitong and keruing, but on the whole it is straighter grained and not quite so coarse in texture. The Malayan timber averages about 48 pounds per cubic foot at 12 percent moisture content.

Strength property values available for *D. lanceolata* show it to be on a par with apitong or keruing of similar specific gravity.

The heartwood is rated as very durable and extremely resistant to preservative treatment.

The wood works with moderate ease in most hand and machine operations. A good surface is obtainable from the various machining operations, but there is a tendency toward "raised grain" if dull cutters are used. It takes nails and screws satisfactorily.

The wood provides good and very durable construction timbers and is suitable for all the purposes for which apitong and keruing are used in the United States.

Karri

Karri (*Eucalyptus diversicolor*) is a very large tree limited to Western Australia, occurring in the southwestern portion of the state.

Karri resembles jarrah (*E. marginata*) in structure and general appearance. It is usually paler in color, and, on the average, slightly heavier (57 lb. per cu. ft. at 12 pct. m.c.).

The heartwood is rated as moderately durable and extremely resistant to preservative treatment.

Karri is a heavy hardwood possessing mechanical properties of a correspondingly high order.

The wood is fairly hard to work in machines and difficult to cut with hand tools. It is generally more resistant to cutting than jarrah and has slightly more dulling effect on tool edges.

It is inferior to jarrah for underground use and waterworks, but where flexural strength is required, such as in bridges, floors, rafters, and beams, it is an excellent timber. Karri is popular in the heavy construction field because of its strength and availability in large sizes and long lengths that are free of defects.

Keruing (See Apitong)

Khaya

The bulk of the khaya or "African Mahogany" [2] shipped from west central Africa is *Khaya ivorensis*, which is the most widely distributed and most plentiful species of the genus found in the coastal belt of the so-called closed or high forest. The closely allied species, *Khaya anthotheca*, has a more restricted range and is found farther inland in regions of lower rainfall but well within the area now being worked for the export trade.

The heartwood varies from a pale pink to a dark reddish brown. The grain is interlocked, and the texture is equal to that of mahogany (*Swietenia*). The wood is very well known in the United States and large quantities are imported annually. The wood is easy to season, machines and finishes well. In decay resistance, it is generally rated below American mahogany.

Principal uses include furniture, interior finish, boat construction, and veneer.

Kokrodua

Kokrodua (*Pericopsis elata*) is the vernacular name used in Ghana. It is also known as afrormosia, its former generic name.

This large West African tree shows promise of becoming a substitute for teak (*Tectona grandis*). The heartwood is fine textured, with straight to interlocked grain. The wood is brownish yellow with darker streaks, moderately hard and heavy, weighing about 44 pounds per cubic foot at 15 percent moisture content. The wood strongly resembles teak in appearance but lacks the oily nature of teak and is finer textured.

The wood seasons readily with little degrade and has good dimensional stability. It is somewhat heavier than teak and stronger. The heartwood appears to be highly resistant to decay and should prove extremely durable under adverse conditions. The wood can undoubtedly be used for the same purposes as teak, such as boat construction, interior trim, and decorative veneer.

Korina (See Limba)

Krabak (See Mersawa)

Lapacho

The lapacho group or series of the genus *Tabebuia* consists of about 20 species of trees and occurs in practically every Latin American country except Chile. Another commonly used name is ipe.

The sapwood is relatively thick, yellowish gray or gray brown and sharply differentiated from the heartwood, which is a light to dark

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[2] Forest Service nomenclature restricts the name mahogany to the species belonging to the botanical genus *Swietenia*.

olive brown. The texture is fine. Grain is closely and narrowly interlocked. Luster is medium. The wood is very heavy and averages about 64 pounds per cubic foot at 12 percent moisture content. Thoroughly air-dried specimens of heartwood generally sink in water.

Lapacho is moderately difficult to machine because of its high density and hardness. Glassy smooth surfaces can be readily produced.

Being a very heavy wood, lapacho is also very strong in all properties and in the air-dry condition is comparable to greenheart.

Lapacho is highly resistant to decay and insects, including both subterranean and drywood termites. It is, however, susceptible to marine borer attack. The heartwood is impermeable, but the sapwood can be readily treated with preservatives.

Lapacho is used almost exclusively for heavy duty and durable construction. Because of its hardness (two to three times that of oak or apitong) and very good dimensional stability, it would be particularly well suited for heavy duty flooring in trucks and box cars.

Lauans

The term "lauan" or "Philippine mahogany" is applied commercially to Philippine woods belonging to three genera—*Shorea*, *Parashorea*, and *Pentacme*. These woods are usually grouped by the United States trade into "dark red Philippine mahogany" and "light red Philippine mahogany." The species found in these two groups and their heartwood color are:

"Dark red Philippine mahogany"

Red lauan, *Shorea negrosensis*	Dark reddish-brown to brick red
Tanguile, *Shorea polysperma*	Red to reddish-brown
Tianong, *Shorea agsaboensis*	Light red to light reddish-brown

"Light red Philippine mahogany"

Almon, *Shorea almon*	Light red to pinkish
Bagtikan, *Parashorea plicata*	Grayish-brown
Mayapis, *Shorea squamata*	Light red to reddish-brown
White lauan, *Pentacme contorta*	Grayish to very light red

The species within each group are shipped interchangeably when purchased in the form of lumber. Mayapis of the light red group is quite variable with respect to color and frequently shows exudations of resin. For this reason, some purchasers of "Philippine mahogany'" specify that mayapis be excluded from their shipments.

"Philippine mahoganies" as a whole have a coarser texture than mahogany or the "African mahoganies" and do not have the dark colored deposits in the pores. Forest Products Laboratory studies showed that the average decay resistance was greater for mahogany than for either the "African mahoganies" or the "Philippine mahoganies." The resistance of "African mahogany" was of the moderate type and seemed no greater than that of some of the "Philippine mahoganies." Among the Philippine species, the woods classified as "dark red Philippine mahogany" usually were more resistant than the woods belonging to the light red group.

In machining trials made at the Laboratory, the Philippine species appeared to be about equal with the better of the hardwoods found in the United States. Tanguile was consistently better than average in all or most of the tests. Mayapis, almon, and white lauan were consistently below average in all or most of the trials. Red lauan and bagtikan were intermediate. All of the species showed interlocked grain.

The shrinkage and swelling characteristics of the Philippine species are comparable to those found in the oaks and maples of the United States.

Principal uses include interior trim, paneling, flush doors, plywood, cabinets, furniture, siding, and boat construction. The use of the woods of the dark red group for boatbuilding in the United States exceeds in quantity that of any foreign wood.

Laurel

The genus *Cordia* contains numerous species, but only a relatively small number are trees of commercial size. The three most important species are *Cordia alliodora* (laurel) with the most extensive range from the West Indies and Mexico southward to northern Bolivia and eastern Peru; *C. goeldiana* (freijo) of the Amazon Basin; and *C. trichotoma* (peterebi) of southeastern Brazil, northern Argentina, and adjacent Paraguay.

The heartwood is light to medium brown, plain or frequently with a pigment figure outlining the growth ring pattern. Sapwood is generally distinct and of a yellowish or very light brown color. Grain is generally straight or shallowly interlocked. Texture is medium and uniform. The wood is variable in weight, but in the same density range as mahogany and cedro.

The wood saws and machines easily with good to excellent results in all operations. It is reported to glue readily and holds its place well when manufactured.

The *Cordia* woods are rated as moderately durable to durable when used in contact with the ground, and are rated slightly above mahogany with respect to resistance against drywood termites. The darker colored wood is reputed to be more durable with respect to decay and have better termite resistance than the lighter colored material.

The strength properties of these *Cordias* are generally on a par with those of mahogany and cedro.

Because of their ease of working, good durability, low shrinkage, and attractiveness, the woods are used extensively within their areas of growth for furniture, cabinetwork, general construction, boat construction and many other uses. The characteristics of the wood should qualify it for use in the United States for many of the same purposes as mahogany and cedro.

Lignum Vitae

Lignum vitae (*Guaiacum offinale*) native to the West Indies, northern Venezuela, northern Colombia, and Panama, was for a great many years the only species used on a large scale. With the near exhaustion of commercial-size timbers of *G. officinale* the principal species of commerce is now *G. sanctum.* The latter species occupies the same range as *G. officinale*, but is more extensive and includes the Pacific side of Central America as well as southern Mexico and southern Florida.

Lignum vitae is one of the heaviest and hardest woods on the market. The wood is characterized by its unique green color and oily or waxy feel. The wood has a fine, uniform texture and closely interlocked grain. Its resin content may constitute up to about one-fourth of the air-dry weight of the heartwood.

Lignum vitae wood is used chiefly for bearing or bushing blocks for the lining of stern tubes of steamship propeller shafts. The great strength and tenacity of lignum vitae, combined with the self-lubricating properties that are due to the high resin content, make it especially adaptable for underwater use. It is also used for such articles as mallets, pulley sheaves, caster wheels, stencil and chisel block, various turned articles, and brush backs.

Vera or verawood (*Bulnesia arborea*) of Colombia and Venezuela is sometimes substituted for lignum vitae; however, vera is not suitable for underwater bearings.

Limba

Abundant supplies of limba (*Terminalia superba*) occur in west central Africa and the Congo region.

The wood varies in color from a gray-white to creamy brown and may contain dark streaks, which are valued for special purposes. The light colored wood is considered an important asset for the manufacture of blond furniture. The wood is generally straight grained and of uniform but coarse texture.

The wood is easy to season and the shrinkage is reported to be rather small. Limba is not resistant to decay, insects, or termites. It is easy to work with all types of tools and is veneered without difficulty.

Principal uses include interior trim, paneling, and furniture. Selected limba plywood is sold in the United States under the copyrighted name, "korina."

Lupuna

Lupuna (*Ceiba samauma*) is a very large tree found in the Amazon Basin. In the Peruvian-Amazon region it is known as lupuna. In its Brazilian range it is known as samauma. The wood is white or grayish to very pale reddish, very soft and light, weighing about 25 pounds per cubic foot air dry. The wood is coarse textured and has a dull luster. It is nondurable with respect to decay and insect attack. Some of the veneer used for plywood cores has been known to give off highly objectionable odor when subjected to high humidity.

The wood is available in large sizes, and its low density combined with a rather high degree of dimensional stability make it ideally suited for pattern and core stock.

The mechanical properties have not been investigated.

Mahogany

Mahogany (*Swietenia macrophylla*) ranges from southern Mexico through Central America into South America as far south as Bolivia. Mexico, Belize, and Nicaragua furnish about 70 percent of the mahogany imported into the United States.

The heartwood varies from a pale to a dark reddish brown. The grain is generally straighter than that of "African mahogany;" however, a wide variety of grain patterns are obtained from this species.

Among the properties that mahogany possesses to a high degree are dimensional stability, fine finishing qualities, and ease of working with tools. The wood is without odor or taste. It weighs about 32 pounds per cubic foot at 12 percent moisture content.

The principal uses for mahogany are furniture, models and patterns, boat construction, radio and television cabinets, caskets, interior trim, paneling, precision instruments, and many other uses where an attractive and dimensionally stable wood is required.

Mahogany, African (See Khaya)

Mahogany, Philippine (See Lauans)

Mayapis (See Lauans)

Mayflower (See Apamate)

Meranti

The trade name meranti covers a number of closely related species of *Shorea* from which light or only moderately heavy timber is produced. This timber is imported from Malaysia and Indonesia. On the Malay Peninsula this timber is commonly classified for export either as light red or dark red meranti. Each of these color varieties is the product of several species of *Shorea*. Meranti exported from Sarawak and various parts of Indonesia is generally similar to the Malayan timber. Meranti corresponds roughly to seraya from North Borneo and lauan from the Philippines, which are names used for the lighter types of *Shorea* and allied genera.

Meranti shows considerable variation in color, weight, texture, and related properties, according to the species. The grain tends to be slightly interlocked so that quartered stock shows a broad stripe figure. The texture is moderately coarse but even. Resin ducts with or without white contents occur in long tangential lines on the end surfaces of the wood, but the wood is not resinous like some of the keruing species. Wood from near the center of the log is apt to be weak and brittle.

Light red meranti is classed as a lightweight utility hardwood and comprises those species yielding a red or reddish but not a dark red timber. The actual color of the heartwood varies from pale pink to light reddish brown. The weight of the wood may vary over a rather wide range from 25 to 44 pounds per cubic foot in the seasoned condition.

Dark red meranti is darker in color than ordinary red meranti and appreciably heavier, weighing on the average about 43 pounds per cubic foot seasoned. This color variation is the product of a more limited number of species and consequently tends to be more uniform in character than light red meranti. Because of the number of species contributing to the production of meranti, appreciable variation may be encountered with respect to mechanical and physical properties, durability, and working characteristics.

The wood is used in both plywood and solid form for much the same purposes as the Philippine lauans.

Mersawa

Mersawa is one of the *Anisoptera*, a genus of about 15 species distributed from the Philippine Islands and Malaysia to East Pakistan. Names applied to the timber vary with the source and three names are generally encountered in the lumber trade: *krabak* (Thailand), *mersawa* (Malaysia), and *palosapis* (Philippines).

The *Anisoptera* species produce wood of light color and moderately coarse texture. The heartwood when freshly sawn is pale yellow or yellowish brown and darkens on exposure. Some timber may show a pinkish cast or pink streaks, but these eventually disappear on exposure. The wood weighs about 39 pounds per cubic foot in the seasoned condition at 12 percent moisture content and about 59 pounds when green.

The sapwood is susceptible to attack by powderpost beetles and the heartwood is not resistant to termites. With respect to fungus resistance, the heartwood is rated as moderately resistant and should not be used under conditions favoring decay. The heartwood does not absorb preservative solutions readily.

The wood machines readily, but because of the presence of silica, the dulling effect on the cutting edges of ordinary tools is severe and is very troublesome with saws.

It appears probable that the major volume of these timbers will be used in the form of plywood, because conversion in this form presents considerably less difficulty than lumber production.

Nogal, Tropical Walnut

Nogal or tropical walnut includes two species, *Juglans neotropica* of the eastern slope of the Andes and *J. olanchana* of northern Central America. There is widespread interest in walnut from sources where lumber costs are decidedly lower than in the United States, but unfortunately little technical information is available regarding these species.

The wood of the tropical species is generally darker than that of typical American black walnut, and the texture (pore size) is somewhat coarser. From the limited number of specimens available for examination, nogal also appears to be somewhat lighter in weight than U.S. black walnut. Logs frequently show streaks of lighter color in the heartwood and this characteristic has caused some concern about the potential utility of the tropical wood. Other features that are mentioned whenever tropical walnut is under discussion are the extreme slowness with which the wood dries and the dull yellowish-green coloring of the inner portion of some boards that occurs during drying. It has been stated that lumber to 5/4-inch thickness can be dried at the same rate as American black walnut, but thicker stock takes an appreciably longer period of time, and in the thicker stock the wood is prone to collapse and honeycomb.

Tropical walnut peels and slices readily, but the veneer is said to dry more slowly than American black walnut. Tension wood and compression failures have been observed in a number of specimens, and these invariably came from the central core of the tree.

It appears that these species require rather intensive study, particularly with respect to seasoning and machining, in order to ascertain their true potential.

Oak

The oaks (*Quercus* spp.) are abundantly represented in Mexico and Central America with about 150 species, which are nearly equally divided between red and white oak groups. Mexico is represented with over 100 species and Guatemala with about 25; the numbers diminish southward to Colombia, which has two species. The usual Spanish name applied is encino or roble and no distinction is made in the use of these names.

The wood of the various species is in most cases heavier than the species of the United States.

Strength data are available for only four species and the values obtained fall between those of white oak and the southern live oak or are equal to those of the latter. The average specific gravity for these species is 0.72 based on volume when green and weight ovendry, with an observed maximum average for one species from Guatemala of 0.86.

Utilization of the tropical oaks is very limited at present due to difficulties encountered in the drying of the wood. The major volume is used in the form of charcoal.

Obeche

Obeche (*Triplochiton scleroxylon*) trees of west central Africa reach heights of 150 feet or more and diameters of up to 5 feet. The trunk is usually free of branches for considerable heights so that clear lumber of considerable size is obtainable.

The wood is creamy white to pale yellow with little or no difference between the sapwood and heartwood. It is fairly soft, of uniform texture, and the grain is straight or more often interlocked. The wood weighs about 24 pounds per cubic foot in the air-dry condition.

The wood seasons readily with little degrade. It is not resistant to decay, and the sapwood blue stains readily unless appropriate precautions are taken after the trees are felled as well as after they have been converted into lumber.

The wood is easy to work and machine, veneers and glues well, and takes nails and screws without splitting.

The characteristics of this species make it especially suitable for veneer and core stock.

This species is also called samba and wawa.

Okoume

The natural distribution of okoume (*Aucoumea klaineana*) is rather restricted and is found only in west central Africa and Guinea. This species has been popular in European markets for many years, but its extensive use in the United States is rather recent. When first introduced in volume in the plywood and door fields, its acceptance was phenomenal because it provided attractive appearance at moderate cost. The wood has a salmon-pink color with a uniform texture and high luster. The texture is slightly coarser than that of birch. Okoume offers unusual flexibility in both working and finishing because the color, which is of medium intensity, permits toning to either lighter or darker shades.

In this country it is used for decorative plywood paneling, general utility plywood, and for doors. Its use as solid lumber has been hampered because special saws and planer knives are required to effectively machine this species because of the silica content of the wood.

Palosapis (See Mersawa)

"Parana Pine"

The wood that is commonly called "Parana pine" (Araucaria angustifolia) is not a true pine. It is a softwood that comes from southeastern Brazil and adjacent areas of Paraguay and Argentina.

"Parana pine" has many desirable characteristics. It is available in large sizes of clear boards with uniform texture. The small pinhead knots (leaf traces) that appear on flat-sawn surfaces and the light brown or reddish-brown heartwood, which is frequently streaked with red, provide desirable figured effects for matching in paneling and interior finishes. The growth rings are fairly distinct and more nearly like those of white pine (*Pinus strobus*) rather than those of the yellow pines. The wood has relatively straight grain, takes paint well, glues easily, and is free from resin ducts, pitch pockets, and streaks.

The strength values of this species compare favorably with those softwood species of similar density found in the United States and, in some cases, approach the strength values of species with greater specific gravity. It is especially good in shearing strength, hardness, and nail-holding ability, but notably deficient in strength in compression across the grain.

Some tendency towards splitting of kiln-dried "Parana pine" and warping of seasoned and ripped lumber is caused by the presence of compression wood, an abnormal type of wood structure with intrinsically large shrinkage along the grain. Boards containing compression wood should be excluded from exacting uses. The principal uses of "Parana pine" include framing lumber, interior trim, sash and door stock, furniture, case goods, and veneer.

This species is known in Brazil as pinheiro do Parana or pinho do Parana.

Pau Marfim

The growing range of Pau marfim (*Balfourodendron riedelianum*) is rather limited, extending from the State of Sao Paulo, Brazil, into Paraguay and the provinces of Corrientes and Missiones of northern Argentina. In Brazil it is generally known as pau marfim and in Argentina and Paraguay as guatambu.

In color and general appearance the wood is very similar to birch or hard maple sapwood. Although growth rings are present, they do not show as distinctly as in birch and maple. The wood is straight grained, easy to work and finish but is not considered to be resistant to decay. There is no apparent difference in color between heartwood and sapwood.

The average specific gravity of pau marfim is about 0.63 based on the volume when green and weight when ovendry. On the basis of its specific gravity, its strength values would be above those of hard maple which has an average specific gravity of 0.56.

In the areas of growth it is used for much the same purposes as our native hard maple and birch. Pau marfim was introduced to the U.S. market in the late 1960's and has been very well received and is especially esteemed for turned items.

Peroba de Campos

Peroba de campos (*Paratecoma peroba*) occurs in the coastal forests of eastern Brazil ranging from Bahia to Rio de Janeiro. It is the only species in the genus.

The heartwood is variable in color, but generally is in shades of brown with tendencies toward casts of olive and reddish color. The sapwood is a yellowish gray, clearly defined from the heartwood. The texture is relatively fine and approximates that of birch. The wood averages about 47 pounds per cubic foot at 12 percent moisture content.

The wood machines easily, but when smooth surfaces are required particular care must be taken in planing to prevent excessive grain tearing of quartered surfaces because of the presence of interlocked or irregular grain. There is some evidence that the fine dust arising from machining operations may produce allergic responses in certain individuals.

Peroba de campos is heavier than teak or white oak and is proportionately stronger than either of these species.

The heartwood is rated as very durable with respect to fungus attack and is rated as resistant to preservative treatment.

In Brazil, the wood is used in the manufacture of fine furniture, flooring, and decorative paneling. The principal use in the United Sates is in shipbuilding, where it serves as an alternate for white oak for all purposes except bent members. The wood is classified as a poor "bender."

Peterebi (See Laurel)

Pine, Caribbean

Caribbean pine (*Pinus caribaea*) occurs along the Caribbean side of Central America from Belize to northeastern Nicaragua. It is also native to the Bahamas and Cuba. It is primarily a tree of the lower elevations.

The heartwood is a golden brown to red brown and distinct from the sapwood which is 1 to 2 inches in thickness and a light yellow. The wood has a strong resinous odor and a greasy feel. The wood averages about 51 pounds per cubic foot at 12 percent moisture content.

The lumber can be kiln dried satisfactorily using the same schedule as that for ocote pine.

Caribbean pine is easy to work in all machining operations but the high resin content may necessitate occasional stoppages to permit removal of accumulated resin from the equipment.

Caribbean pine is an appreciably heavier wood than slash pine (*P. elliottii*), but the mechanical properties of these two species are rather similar.

Caribbean pine is used for the same purposes as the southern pines of the United States.

Pine, Ocote

Ocote pine (*Pinus oocarpa*) is a species of the higher elevations and occurs from northwestern Mexico southward through Guatemala into Nicaragua. The largest and most extensive stands occur in northern Nicaragua and Honduras.

The sapwood is a pale yellowish brown and generally up to 3 inches in thickness. The heartwood is a light reddish brown. Grain is straight. Luster is medium. The wood has a resinous odor, and weighs about 41 pounds per cubic foot at 12 percent moisture content.

The strength properties of ocote pine are comparable in most respects with those of longleaf pine (*P. palustris*).

Decay resistance studies show ocote pine heartwood to be very durable with respect to attack by a white-rot fungus and moderately durable with respect to brown rot.

Ocote pine is comparable to the southern pines in workability and machining characteristics.

Ocote pine is a general construction timber and is suited for the same uses as the southern pines.

Primavera

The natural distribution of primavera (*Cybistax donnell-smithii*) is restricted to southwestern Mexico, the Pacific coast of Guatemala and El Salvador, and north central Honduras.

Primavera is regarded as one of the primary light-colored woods, but its use was limited because of its rather restricted range and the relative scarcity of wild trees within its natural growing area.

Plantations now coming into production have increased the availability of this species and provided a more constant source of supply. The quality of the plantation-grown wood is equal in all respects to that obtained from wild trees.

The heartwood is whitish to straw-yellow and in some logs may be tinted with pale brown or pinkish streaks. The wood has a very high luster.

Primavera produces a wide variety of figure patterns.

The shrinkage properties are very good, and the wood shows a high degree of dimensional stability. Although the wood has considerable grain variation, it machines remarkably well. With respect to decay resistance it is rated as durable to very durable.

The dimensional stability, ease of working, and pleasing appearance recommend primavera for solid furniture, paneling, interior trim, and special exterior uses.

Ramin

Ramin (*Gonystylus bancanus*) is one of the very few moderately heavy woods that are classified as a "blond" wood. This species is native to southeast Asia from the Malay Peninsula to Sumatra and Borneo.

The wood is a uniform pale straw or yellowish to whitish in color. The grain is straight or shallowly interlocked. The texture is moderately fine, similar to that of mahogany (*Swietenia*), and even. The wood is without figure or luster. Ramin is moderately hard and heavy, weighing about 42 pounds per cubic foot in the air-dry condition. The wood is easy to work, finishes well, and glues satisfactorily.

With respect to natural durability ramin is rated as perishable, but it is permeable with regard to preservative treatment.

Ramin has been used in the United States in the form of plywood for doors and in the solid form for interior trim.

Red lauan (See Lauans)

Roble (See Oak)

Rosewood, Brazilian

Brazilian rosewood or jacaranda (*Dalbergia nigra*) occurs in the eastern forests of the State of Bahia to Rio de Janeiro. Having been exploited for a long period of time it is, at present, nowhere abundant.

The wood of commerce is very variable with respect to color, ranging through shades of brown, red, and violet and is irregularly and conspicuously streaked with black. Many kinds are distinguished locally on the basis of prevailing color. The texture is coarse, and the grain is generally straight. Heartwood has an oily or waxy appearance and feel. The odor is fragrant and distinctive. The wood is hard and heavy; thoroughly air-dried wood is just barely floatable in water.

The strength properties have not been determined, but for the purposes for which Brazilian rosewood is utilized they are more than adequate. In hardness, for example, it exceeds by far any of the native hardwood species used in the furniture and veneer field.

The wood machines and veneers well. It can be glued satisfactorily, providing the necessary precautions are taken to ensure good glue bonds as with other woods in this density class.

Brazilian rosewood has an excellent reputation for durability with respect to fungus and insect attack, including termites, although the wood is not used for purposes where these would present a problem.

Brazilian rosewood is used primarily in the form of veneer for decorative plywood. Limited quantities are used in the solid form for specialty items such as cutlery handles, brush backs, billiard cue butts, and fancy articles of turnery.

Rosewood, Indian

Indian rosewood (*Dalbergia latifolia*) is native to most provinces of India except in the northwest.

The heartwood is a dark purplish brown with denser blackish streaks terminating the growth zones and giving rise to an attractive figure on flat-sawn surfaces. The average weight is about 53 pounds per cubic foot at 12 percent moisture content. The texture is uniform and moderately coarse. The wood of this species is quite similar in appearance to that of the Brazilian and Honduras rosewood. The timber is said to kiln dry well, but rather slowly, and the color is said to improve during drying.

Indian rosewood is a heavy timber with high strength properties and is particularly hard for its weight after being thoroughly seasoned.

The wood is moderately hard to work with handtools and offers a fair resistance in machine operations. Lumber containing calcareous deposits tends to blunt tools rapidly. The wood turns well and has high screw-holding properties. Filling of the pores is desirable if a very smooth surface is required for certain purposes.

Indian rosewood is essentially a decorative wood for high-class furniture and cabinetwork. In the United States it is used primarily in the form of veneer.

Samauma (See Lupuna)

Samba (See Obeche)

Sande

Practically all of the exportation of sande (*Brosimum* spp.-utile group) is from Pacific Ecuador and Colombia. It is also known as cocal.

The sapwood and heartwood show no distinction, being a uniform yellowish white to yellowish brown or light brown. The pores are moderately coarse and evenly distributed. The grain is straight to widely and shallowly interlocked. In many respects, sande has much the same appearance as white seraya (*Parashorea malaanonan*) from Sabah. The wood averages about 33 pounds per cubic foot at 12 percent moisture content.

The wood is nondurable with respect to stain, decay, and insect attack and care must be exercised to prevent degrade from these agents.

Strength data for sande are too limited to permit comparison with woods of similar density such as banak, although it is suspected that they would be rather similar.

Normal wood of sande machines easily, takes stains, and finishes readily, and presents no gluing problems. Sande should find utilization for many of the same purposes as banak, and with the current demand for molding species, it should assist in relieving the ever-increasing wood demand of this industry.

Santa Maria

Santa Maria (*Calophyllum brasiliense*) ranges from the West Indies to southern Mexico and southward through Central America into northern South America.

The heartwood is pinkish to brick red or rich reddish brown and marked by a fine and slightly darker striping on flat-sawn surfaces. The sapwood is lighter in color and generally distinct from the heartwood. Texture is medium and fairly uniform. Luster is medium. The heartwood is rather similar in appearance to the red lauan of the Philippines. The wood averages about 38 pounds per cubic foot at 12 percent moisture content.

The wood is moderately easy to work and good surfaces can be obtained when attention is paid to machining operations.

Santa Maria is in the density class of hard maple and its strength properties are generally similar, with the exception of hardness, in which property hard maple is superior to Santa Maria.

The heartwood is generally rated as moderately durable to very durable in contact with the ground, but apparently has little resistance against termites and marine borers.

The inherent natural durability, color, and figure on the quarter suggest utilization as face veneer for plywood in boat construction. It also offers possibilities for use in flooring, furniture, cabinetwork, millwork, and decorative plywood.

Sapele

Sapele (*Entandrophragma cylindricum*) is a large African rain forest tree ranging from Sierra Leone to Angola and eastward through the Congo to Uganda.

The heartwood ranges in color from that of mahogany to a dark reddish or purplish brown. The lighter colored and distinct sapwood may be up to 4 inches thick. Texture is finer than that of mahogany. Grain is interlocked and produces a narrow and uniform stripe pattern on quartered surfaces. The wood averages about 39 pounds per cubic foot at 12 percent moisture content.

Sapele has the same average density as white oak, and its mechanical properties are in general higher than those of white oak.

The wood works fairly easily with machine tools, although interlocked grain offers difficulties in planing and molding. Sapele finishes and glues well.

The heartwood is rated as moderately durable and as resistant to preservative treatment.

Sapele is used extensively, primarily in the form of veneer for decorative plywood.

Spanish-Cedar

Spanish-cedar or cedro (*Cedrela* spp.) comprises a group of about seven species that are widely distributed in tropical America from southern Mexico to northern Argentina. The wood is more or less distinctly ring porous, and the heartwood varies from light reddish brown to dark reddish brown. The heartwood is characterized by its distinctive cedarlike odor.

The wood seasons readily. It is not high in strength but is roughly rated to be similar to Central American mahogany in most properties except in hardness and compression perpendicular to the grain where mahogany is definitely superior. It is considered decay resistant and works and glues well.

Spanish-cedar is used locally for all purposes where an easily worked, light but strong, straight grained, and durable wood is required. Spanish-cedar and mahogany are the classic timbers of Latin America.

Tangare (See Andiroba)

Tanguile (See Lauans)

Teak

Teak (*Tectona grandis*) occurs in commercial quantities in India, Burma, Thailand, Laos, Cambodia, North and South Vietnam, and the East Indies. Numerous plantations have been developed within its natural range and tropical areas of Latin America and Africa, and many of these are now producing timber.

The heartwood varies from a yellow-brown to a rich brown. It has a coarse texture, is usually straight grained, and has a distinctly oily feel. The heartwood has excellent dimensional stability and possesses a very high degree of natural durability.

Although not generally used in the United States where strength is of prime importance, the values for teak are generally on a par with those of our native oaks.

Teak generally works with moderate ease with hand and machine tools. Because of the presence of silica, its dulling effect on tools is sometimes considerable. Finishing and gluing are satisfactory although pretreatment may be necessary to ensure good bonding of finishes and glues.

Intrinsically, teak is one of the most valuable of all woods, but its use is limited by scarcity and high cost. Teak is unique in that it does not cause rust or corrosion when in contact with metal: hence, it is extremely useful in the shipbuilding industry. It is currently used in the construction of expensive boats, furniture, flooring, decorative objects, and veneer for decorative plywood.

Tianong (See Lauans)

Verawood (See Lignum Vitae)

Virola

Virola is the common name being currently applied to the wood of two or more species of *Dialyanthera* originating in the Pacific forests of Colombia and Ecuador. The local name for this wood is cuangare, and would be preferred for common usage because the common name "virola" is frequently confused with the botanical genus *Virola*.

The wood is a pale pinkish brown with a high luster. There is no sharp demarcation between heartwood and sapwood. The wood is generally straight grained, easy to work, holds nails well, and finishes smoothly. The texture is quite similar to that of okoume.

Virola is a relatively low-density wood. On the dry-weight basis, it is equal to that of alder, aspen, and basswood. Shrinkage properties of virola are about the same as those of sugar maple. The wood is rated very low with respect to natural durability; hence it is best suited for use under interior conditions.

Currently the wood is being used for paneling, interior trim, and core stock.

The mechanical properties have not been investigated.

Walnut, European

Although generally referred to as European walnut or by its country of origin, walnut (*Juglans regia*) is a native of western and central Asia, extending to China and northern India. Trees are grown in commercial quantities mainly in Turkey, Italy, France, and Yugoslavia.

Walnut is variable in color, with a grayish-brown background, marked with irregular dark-colored streaks. The figure, which is due to the infiltration of coloring matter, is sometimes accentuated by the naturally wavy grain. The highly figured veneers used in cabinetmaking and decorative paneling are obtained from the stumps, burls, and crotches of a relatively small percentage of the trees. The wood weighs about 40 pounds per cubic foot in the air-dry condition.

The product of any one locality may vary considerably in color, figure, and texture, but the selected export timber generally shows certain typical characteristics. French walnut is typically paler and grayer than English walnut, while the Italian wood is characterized by its elaborate figure and dark, streaky coloration. Because of the ease of machining, finishing, and gluing, walnut is used extensively in veneer form as well as in the solid form for furniture, paneling, and decorative objects. It and American black walnut are the classic woods for rifle stocks.

Walnut, tropical (See Nogal)

Wawa (See Obeche)

White lauan (See Lauans)

White seraya (See Bagtikan)

Yang (See Apitong)

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Chapter 2

STRUCTURE OF WOOD

STRUCTURE OF WOOD

The fibrous nature of wood strongly influences how it is used. Specifically, wood is composed mostly of hollow, elongate, spindle-shaped cells that are arranged parallel to each other along the trunk of a tree. When lumber is cut from the tree, the characteristics of these fibrous cells and their arrangement affects such properties as strength and shrinkage, as well as grain pattern of the wood.

A brief description of some elements of anatomical structure are given in this chapter.

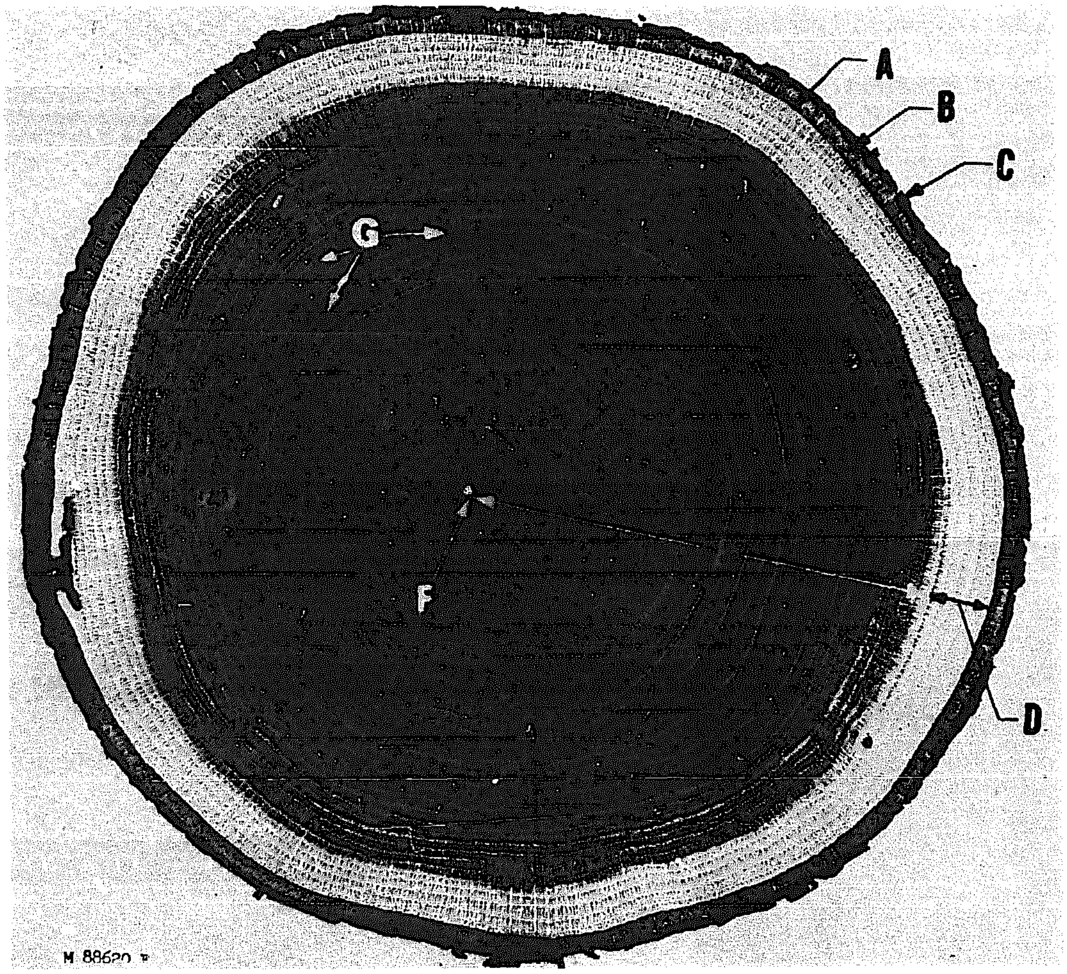

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Figure 2–1.—Cross section of a white oak tree trunk: A, Cambium layer (microscopic) is inside inner bark and forms wood and bark cells. B, Inner bark is moist, soft, and contains living tissue. Carries prepared food from leaves to all growing parts of tree. C, Outer bark containing corky layers is composed of dry dead tissue. Gives general protection against external injuries. Inner and outer bark are separated by a bark cambium. D, Sapwood, which contains both living and dead tissues, is the light-colored wood beneath the bark. Carries sap from roots to leaves. E, Heartwood (inactive) is formed by a gradual change in the sapwood. F, Pith is the soft tissue about which the first wood growth takes place in the newly formed twigs. G, Wood rays connect the various layers from pith to bark for storage and transfer of food.

BARK, WOOD, AND PITH

A cross section of a tree (fig. 2–1) shows the following well-defined features in succession from the outside to the center: (1) Bark, which may be divided into the outer, corky, dead part that varies greatly in thickness with different species and with age of trees, and the thin, inner living part; (2) wood, which in merchantable trees of most species is clearly differentiated into sapwood and heartwood; and (3) the pith, indicated by a small central core, often darker in color, which represents primary growth formed when woody stems or branches elongate.

Most branches originate at the pith, and their bases are intergrown with the wood of the trunk as long as they are alive. These living branch bases constitute intergrown knots. After the branches die, their bases continue to be surrounded by the wood of the growing trunk. Such enclosed portions of dead branches constitute the loose or encased knots. After the dead branches drop off, the dead stubs become overgrown and, subsequently, clear wood is formed. In a tree, the part containing intergrown knots comprises a cylinder, extending the entire length of the tree; the part containing loose knots forms a hollow cylinder, extending from the ground to the base of the green crown. Clear wood constitutes an outer cylinder covering overgrown branch ends. In second-growth trees, the clear zone and even the zone of loose knots may be absent.

GROWTH RINGS

Between the bark and the wood is a layer of thin-walled living cells called the cambium, invisible without a microscope, in which most growth in thickness of bark and wood arises by cell division. No growth in either diameter or length takes place in wood already formed; new growth is purely the addition of new cells, not the further development of old ones. New wood cells are formed on the inside and new bark cells on the outside of the cambium. As the diameter of the woody trunk increases, the bark is pushed outward, and the outer bark layers become stretched, cracked, and ridged in patterns often characteristic of a species. A bark cambium forms from living cells and this tissue separates the outer bark from the inner bark.

With most species in temperate climates, there is sufficient difference between the wood formed early and that formed late in a growing season to produce well-marked annual growth rings. The age of a tree at the stump or the age at any cross section of the trunk may be determined by counting these rings (fig. 2–2). If the growth of trees in diameter is interrupted by drought or defoliation by insects, more than one ring may be formed in the same season. In such an event, the inner rings usually do not have sharply defined boundaries and are termed false rings. Trees that have only very small crowns or that have accidentally lost most of their foliage may form only an incomplete growth layer, sometimes called a discontinuous ring, until the crown is restored.

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Figure 2–2.—Cross section of a ponderosa pine log showing growth rings: Light bands are earlywood, dark bands are latewood. An annual ring is composed of the earlywood ring and the latewood ring outside it.

Growth rings are most readily seen in species with sharp contrast between earlywood and latewood, such as the native ring-porous hardwoods as ash and oak, and most softwoods except the soft pines. In some other species, such as water tupelo, sweetgum, and soft maple, differentiation of early and late growth is slight, and the annual growth rings are difficult to recognize. In some tropical regions, growth may be practically continuous throughout the year, and no well-defined annual rings are formed.

EARLYWOOD AND LATEWOOD

The inner part of the growth ring formed first in the growing season is called earlywood or springwood, and the outer part formed later in the growing season, latewood or summerwood. Actual time of formation of these two parts of a ring may vary with environmental and weather conditions. Earlywood is characterized by cells having relatively large cavities and thin walls. Latewood cells have smaller cavities and thicker walls. The transition from earlywood to latewood may be gradual or abrupt, depending on the kind of wood and the growing conditions at the time it was formed. In some species, such as the maples, gums, and yellow-poplar, there is little difference in the appearance of the earlywood and latewood parts of a growth ring.

When growth rings are prominent, as in most softwoods and the ring-porous hardwoods, earlywood differs markedly from latewood in physical properties. Earlywood is lighter in weight, softer, and weaker than latewood; it shrinks less across and more lengthwise along the grain of the wood. Because of the greater density of latewood, the proportion of latewood is sometimes used to judge the quality or strength of wood. This method is useful with such species as the southern pines, Douglas-fir, and the ring-porous hardwoods—ash, hickory, and oak.

SAPWOOD AND HEARTWOOD

Sapwood is located next to the cambium. It contains only a few living cells and functions primarily in the storage of food and the mechanical transport of sap.

The sapwood layer may vary in thickness and in the number of growth rings contained in it. Sapwood commonly ranges from 1½ to 2 inches in radial thickness. In certain species, such as catalpa and black locust, the sapwood contains very few growth rings and sometimes does not exceed one-half inch in thickness. The maples, hickories, ashes, some of the southern pines, and ponderosa pine may have sapwood 3 to 6 inches or more in thickness, especially in second-growth trees. As a rule, the more vigorously growing trees of a species have wider sapwood layers. Many second-growth trees of merchantable size consist mostly of sapwood.

Heartwood consists of inactive cells that have been slightly changed, both chemically and physically, from the cells of the inner sapwood rings. In this condition these cells cease to conduct sap.

The cell cavities of heartwood also may contain deposits of various materials which frequently give much darker color to the heartwood. All heartwood, however, is not dark colored. Species in which heartwood does not darken to a great extent include the spruces (except Sitka spruce), hemlock, the true firs, Port-Orford-cedar, basswood, cottonwood, and buckeye. The infiltrations or materials deposited in the cells of heartwood usually make the wood more durable when used in exposed situations. Unless treated, all sapwood is nondurable when exposed to conditions that favor decay.

In some species, such as the ashes, hickories, and certain oaks, the pores become plugged to a greater or lesser degree with ingrowths, known as tyloses, before the change to heartwood is completed. Heartwood having pores tightly plugged by tyloses, as in white oak, is suitable for tight cooperage.

Heartwood has a higher extractives content than sapwood, and because of this, exhibits a higher specific gravity. For most species the difference is so small as to be quite unimportant. The weight and strength of wood are influenced more by growth conditions of the trees at the time the wood is formed than they are by the change from sapwood to heartwood. In some instances, as in redwood, western redcedar, and black locust, considerable amounts of infiltrated material may somewhat increase the weight of the wood and its resistance to crushing.

WOOD CELLS

Wood cells that make up the structural elements of wood are of various sizes and shapes and are quite firmly grown together. Dry wood cells may be empty or partly filled with deposits, such as gums and resins, or with tyloses. A majority of cells are considerably elongated and pointed at the ends; they are customarily called fibers or tracheids. The length of wood fibers is highly variable within a tree and among species. Hardwood fibers average about one twenty-fifth of an inch in length (1 mm.); softwood fibers (called tracheids) range from one-eighth to one-third of an inch in length (3 to 8 mm.).

In addition to their fibers, hardwoods have cells of relatively large diameter known as vessels. These form the main arteries in the movement of sap. Softwoods do not contain special vessels for conducting sap longitudinally in the tree; this function is performed by the tracheids.

Both hardwoods and softwoods have cells (usually grouped into structures) that are oriented horizontally in the direction from the pith toward the bark. These structures conduct sap radially across the grain and are called rays or wood rays. The rays are most easily seen on quartersawed surfaces. They vary greatly in size in different species. In oaks and sycamores, the rays are conspicuous and add to the decorative features of the wood.

Wood also has other cells, known as longitudinal, or axial, parenchyma cells, that function mainly for the storage of food.

CHEMICAL COMPOSITION OF WOOD

Dry wood is made up chiefly of the following substances, listed in decreasing order of amounts present: Cellulose, lignin, hemicelluloses, extractives, and ash-forming minerals.

Cellulose, the major constituent, comprises approximately 50 percent of wood substance by weight. It is a high-molecular weight linear polymer that, on chemical degradation by mineral acids, yields the simple sugar glucose as the sole product. During growth of the tree, the linear cellulose molecules are arranged into highly ordered strands called fibrils, which in turn are organized into the larger structural elements comprising the cell wall of wood fibers. The intimate physical, and perhaps partially chemical, association of cellulose with lignin and the hemicelluloses imparts to wood its useful physical properties. Delignified wood fibers have great commercial value when reconstituted into paper. Moreover, they may be chemically altered to form synthetic textiles, films, lacquers, and explosives.

Lignin comprises 23 to 33 percent of softwoods, but only 16 to 25 percent of hardwoods. It occurs in the wood largely as an intercellular material. Like cellulose, it has a macromolecular chemical structure, but its three-dimensional network is far more complex and not yet completely worked out. As a chemical, lignin is an intractable, insoluble material, probably bonded at least loosely to the cellulose. To remove it from the wood on a commercial scale requires vigorous reagents, high temperatures, and high pressures. Such conditions greatly modify the lignin molecule, producing a complex mixture of high-molecular-weight phenolic compounds.

To the paper industry, lignin is difficult to solubilize and is a sometimes troublesome byproduct. Theoretically, it might be converted to a variety of chemical products but, practically, a large percentage of the lignin removed from wood during pulping operations is burned for heat and recovery of pulping chemicals. One sizable commercial use for lignin is in the formulation of drilling muds, used in the drilling of oil wells, where its dispersant and metal-combining properties are valuable. It has found use also in rubber compounding and as an air-entraining agent in concrete mixes. Lesser amounts are processed to yield vanillin for flavoring purposes and to product solvents such as dimethyl sulfide and dimethyl sulfoxide.

The hemicelluloses are intimately associated with cellulose in nature and, like cellulose, are polymeric units built up from simple sugar moleclues. Unlike cellulose, however, the hemicelluloses yield more than one type of sugar on acid cleavage. Also, the relative amounts of these sugars vary markedly with species. Hardwoods contain an average of 20 to 30 percent hemicelluloses with xylose as the major sugar. Lesser amounts of arabinose, mannose, and a sugar acid are also attached to the main polymer chain. Softwoods contain an average of 15 to 20 percent hemicelluloses, with mannose as the main sugar unit. Xylose, arabinose, and the sugar acid are again present at lower levels. The hemicelluloses play an important role in fiber-to-fiber bonding in the papermaking process. The component sugars of hemicellulose are of potential interest for conversion into chemical products.

Unlike the major constituents just discussed. the extractives are not part of the wood structure. However, they do contribute to such properties of wood as color, odor, taste, decay resistance, strength, density, hygroscopicity, and flammability. They include tannins and other poly-phenolics, coloring matters, essential oils, fats, resins, waxes, gums, starch, and simple metabolic intermediates. They can be removed from wood by extraction with such inert neutral solvents as water, alcohol, acetone, benzene, and ether. In quantity, the extractives may range from roughly 5 to 30 percent, depending on such factors as species, growth conditions, and time of year the tree is cut.

Ash-forming minerals comprise from 0.1 to 3 percent of wood substance, although considerably higher values are occasionally reported. Calcium, potassium, phosphate, and silica are common constituents. Due to the uniform distribution of these inorganic materials throughout the wood, ash often retains the microstructural pattern of wood.

A significant dollar value of nonfibrous products is produced from wood including naval stores, pulp byproducts, vanillin, ethyl alcohol, charcoal, extractives, and bark products.

IDENTIFICATION

Many species of wood have unique physical, mechanical, or chemical properties. Efficient utilization dictates that species should be matched to use requirements through an understanding of properties. This requires identification of the species in wood form, independent of bark, foliage, and other characteristics of the tree.

Field identification can often be made on the basis of readily visible characteristics such as color, presence of pitch, or grain pattern. Sometimes odor, density, or splitting tendency is helpful. Where more positive identification is required, a laboratory investigation of the microscopic anatomy of the wood can be made. Detailed descriptions of identifying characteristics are given in texts such as "Textbook of Wood Technology" by Panshin and de Zeeuw.

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Chapter 3

PHYSICAL PROPERTIES OF WOOD

PHYSICAL PROPERTIES OF WOOD

The versatility of wood is demonstrated by a wide variety of products. This variety is a result of a spectrum of desirable physical characteristics or properties that is available among the many species of wood. Often more than one property of wood is important to an end product. For example, to select a species for a product, the value of appearance-type properties such as texture, grain pattern, or color may be evaluated against the influence of characteristics such as machinability, stability, or decay resistance. This chapter discusses the physical properties most often of interest in the design of wood products.

Some physical properties discussed and tabulated are influenced by species as well as variables like moisture content; other properties tend to be more independent of species. The thoroughness of sampling and the degree of variability influences the confidence with which species-dependent properties are known. In this chapter an effort is made to indicate either the general or specific nature of the properties tabulated.

APPEARANCE

Grain and Texture

The terms "grain" and "texture" are commonly used rather loosely in connection with wood. Grain is often used in reference to annual rings, as in fine grain and coarse grain, but it is also employed to indicate the direction of fibers, as in straight grain, spiral grain, and curly grain. Grain, as a synonym for fiber direction, is discussed in more detail relative to mechanical properties in chapter 4. Wood finishers refer to woods as open grained and close grained as terms reflecting the relative size of the pores, which determines whether the surface needs a filler. Texture is often used synonymously with grain, but usually it refers to the finer structure of wood rather than to annual rings. When the words "grain" or "texture" are used in connection with wood, the meaning intended should be made perfectly clear (see glossary).

Plainsawed and Quartersawed Lumber

Lumber can be cut from a log in two distinct ways: Tangent to the annual rings, producing "plainsawed" lumber in hardwoods and "flat-grained" or "slash-grained" lumber in softwoods; and radially to the rings or parallel to the rays, producing "quartersawed" lumber in hardwoods and "edge-grained" or "vertical-grained" lumber in softwoods (fig. 3-1). Usually quartersawed or edge-grained lumber is not cut strictly parallel with the rays; and often in plainsawed boards the surfaces next to the edges are far from being tangent to the rings. In commercial practice, lumber with rings at angles of 45° to 90° with the wide surface is called quartersawed, and lumber with rings at angles of 0° to 45° with the wide surface is called plainsawed. Hardwood lumber in which annual rings make angles of 30° to 60° with the wide faces is sometimes called "bastard sawn."

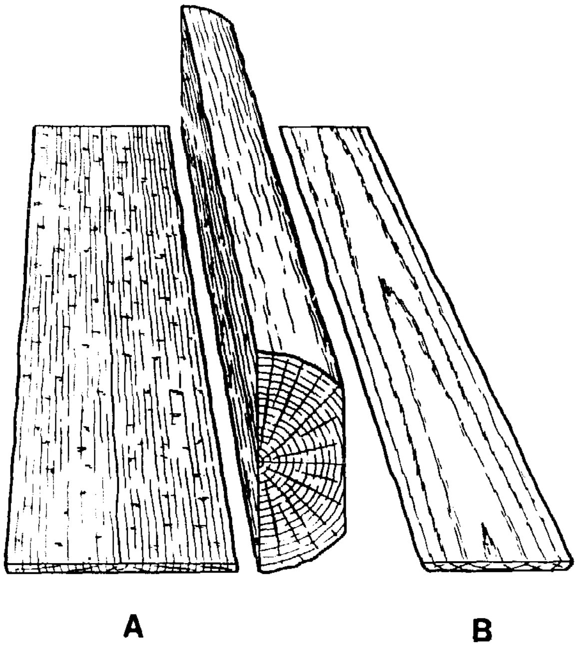

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Figure 3-1.—Quartersawed *A* and plainsawed *B* boards cut from a log.

For many purposes either plainsawed or quartersawed lumber is satisfactory. Each type has certain advantages, however, that may by important in a particular use. Some of the advantages are given in table 3-1.

Table 3–1—*Some advantages of plainsawed and quartersawed lumber*

Plainsawed	Quartersawed
Figure patterns resulting from the annual rings and some other types of figure are brought out more conspicuously by plainsawing.	Quartersawed lumber shrinks and swells less in width.
Round or oval knots that may occur in plainsawed boards affect the surface appearance less than spike knots that may occur in quartersawed boards. Also, a board with a round or oval knot is not as weak as a board with a spike knot.	It twists and cups less.
Shakes and pitch pockets, when present, extend through fewer boards.	It surface-checks and splits less in seasoning and in use.
It is less susceptible to collapse in drying.	Raised grain caused by separation in the annual rings does not become so pronounced.
It shrinks and swells less in thickness.	It wears more evenly.
It may cost less because it is easier to obtain.	Types of figure due to pronounced rays, interlocked grain, and wavy grain are brought out more conspicuously.
	It does not allow liquids to pass into or through it so readily in some species.
	It holds paint better in some species.
	The sapwood appearing in boards is at the edges and its width is limited according to the width of the sapwood in the log.

Decorative Features of Common Woods

The decorative value of wood depends upon its color, figure, luster, and the way in which it bleaches or takes fillers, stains, and transparent finishes. Because of the combinations of color and the multiplicity of shades found in wood, it is impossible to give detailed descriptions of colors of the various kinds. Sapwood of most species, however, is light in color, and in some species it is practically white. White sapwood of certain species, such as maple, may be preferred to the heartwood for specific uses. In some species, such as hemlock, spruce, the true firs, basswood, cottonwood, and beech, there is typically little or no difference in color between sapwood and heartwood, but in most species heartwood is darker and fairly uniform in color. Table 3–2 describes in a general way the color of heartwood of the more common kinds of woods.

In plainsawed boards and rotary-cut veneer, the annual growth rings frequently form ellipses and parabolas that make striking figures, especially when the rings are irregular in width and outline on the cut surface. On quartersawed surfaces, these rings form stripes, which are not especially ornamental unless they are irregular in width and direction. The relatively large rays, sometimes referred to as flecks, form a conspicuous figure in quartersawed oak and sycamore. With interlocked grain, which slopes in alternate directions in successive layers from the center of the tree outward, quartersawed surfaces show a ribbon effect, either because of the difference in reflection of light from successive layers when the wood has a natural luster or because cross grain of varying degree absorbs stains unevenly. Much of this type of figure is lost in plainsawed lumber.

In open-grained hardwoods, the appearance of both plainsawed and quartersawed lumber can be varied greatly by the use of fillers of different colors. In softwoods, the annual growth layers can be made to stand out more by applying a stain.

Knots, pin wormholes, bird pecks, decay in isolated pockets, birdseye, mineral streaks, swirls in grain, and ingrown bark are decorative in some species when the wood is carefully selected for a particular architectural treatment.

MOISTURE CONTENT

Moisture content of wood is defined as the weight of water in wood expressed as a fraction, usually as a percentage, of the weight of ovendry wood. Weight, shrinkage, strength, and other properties depend upon moisture content of wood.

In trees, moisture content may range from about 30 percent to more than 200 percent of the weight of wood substance. Moisture content of the sapwood portion is usually high. Heartwood moisture content may be much less than sapwood moisture content in some species, greater in others. Table 3–3 gives some moisture content values for heartwood and sapwood of some domestic species. These values are considered typical, but there is considerable variation within and between trees. Variability of moisture content exists even within individual boards cut from the same tree. Information on heartwood and sapwood moisture content is not available for imported species.

Table 3-2—*Color and figure of common kinds of domestic wood*

Species	Color of dry heartwood[1]	Type of figure in—	
		Plainsawed lumber or rotary-cut veneer	Quartersawed lumber or quarter-sliced veneer
		HARDWOODS	
Alder, red	Pale pinkish brown	Faint growth ring	Scattered large flakes, sometimes entirely absent.
Ash:			
Black	Moderately dark grayish brown	Conspicuous growth ring; occasional burl.	Distinct, not conspicuous growth-ring stripe; occasional burl.
Oregon	Grayish brown, sometimes with reddish tinge.	do	Do.
White	do	do	Do.
Aspen	Light brown	Faint growth ring	None.
Basswood	Creamy white to creamy brown, sometimes reddish.	do	Do.
Beech, American	White with reddish tinge to reddish brown.	do	Numerous small flakes up to ⅛ inch in height.
Birch:			
Paper	Light brown	do	None.
Sweet	Dark reddish brown	Distinct, not conspicuous growth ring; occasionally wavy.	Occasionally wavy.
Yellow	Reddish brown	do	Do.
Butternut	Light chestnut brown with occasional reddish tinge or streaks.	Faint growth ring	None.
Cherry, black	Light to dark reddish brown	Faint growth ring; occasional burl	Occasional burl.
Chestnut, American	Grayish brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Cottonwood	Grayish white to light grayish brown	Faint growth ring	None.
Elm:			
American and rock	Light grayish brown, usually with reddish tinge.	Distinct, not conspicuous with fine wavy pattern within each growth ring.	Faint growth-ring stripe.
Slippery	Dark brown with shades of red	Conspicuous growth ring with fine pattern within each growth ring.	Distinct, not conspicuous growth-ring stripe.
Hackberry	Light yellowish or greenish gray	Conspicuous growth ring	Do.
Hickory	Reddish brown	Distinct, not conspicuous growth ring	Faint growth-ring stripe.
Honeylocust	Cherry red	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Locust, black	Golden brown, sometimes with tinge of green.	do	Do.
Magnolia	Light to dark yellowish brown with greenish or purplish tinge.	Faint growth ring	None.
Maple:			
Black, bigleaf, red, silver, and sugar.	Light reddish brown	Faint growth ring, occasionally birdseye, curly, and wavy.	Occasionally curly and wavy.
Oak:			
All red oaks	Grayish brown usually with fleshy tinge.	Conspicuous growth ring	Pronounced flake; distinct, not conspicuous growth-ring stripe.
All white oaks	Grayish brown, rarely with fleshy tinge.	do	Do.
Sweetgum	Reddish brown	Faint growth ring; occasional irregular streaks.	Distinct, not pronounced ribbon; occasional streak.

Sycamore	Flesh brown	Faint growth ring	Numerous pronounced flakes up to ¼ inch in height.
Tupelo:			
Black and water	Pale to moderately dark brownish gray.	do	Distinct, not pronounced ribbon.
Walnut, black	Chocolate brown occasionally with darker, sometimes purplish streaks.	Distinct, not conspicuous growth ring; occasionally wavy, curly, burl, and other types.	Distinct, not conspicuous growth-ring stripe; occasionally wavy, curly, burl, crotch, and other types.
Yellow-poplar	Light to dark yellowish brown with greenish or purplish tinge.	Faint growth ring	None.
		SOFTWOODS	
Baldcypress	Light yellowish brown to reddish brown.	Conspicuous irregular growth ring	Distinct, not conspicuous growth-ring stripe.
Cedar:			
Alaska-	Yellow	Faint growth ring	None.
Atlantic white-	Light brown with reddish tinge	Distinct, not conspicuous growth ring	Do.
Eastern redcedar	Brick red to deep reddish brown	Occasionally streaks of white sapwood alternating with heartwood.	Occasionally streaks of white sapwood alternating with heartwood.
Incense-	Reddish brown	Faint growth ring	Faint growth-ring stripe.
Northern white-	Light to dark brown	do	Do.
Port-Orford-	Light yellow to pale brown	do	None.
Western redcedar	Reddish brown	Distinct, not conspicuous growth ring	Faint growth-ring stripe.
Douglas-fir	Orange red to red; sometimes yellow	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Fir:			
Balsam	Nearly white	Distinct, not conspicuous growth ring	Faint growth-ring stripe.
White	Nearly white to pale reddish brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Hemlock:			
Eastern	Light reddish brown	Distinct, not conspicuous growth ring	Faint growth-ring stripe.
Western	do	do	Do.
Larch, western	Russet to reddish brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Pine:			
Eastern white	Cream to light reddish brown	Faint growth ring	None.
Lodgepole	Light reddish brown	Distinct, not conspicuous growth ring; faint "pocked" appearance.	None.
Ponderosa	Orange to reddish brown	Distinct, not conspicuous growth ring	Faint growth-ring stripe.
Red	do	do	Do.
Southern: Longleaf, loblolly, shortleaf, and slash	do	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Sugar	Light creamy brown	Faint growth ring	None.
Western white	Cream to light reddish brown	do	None.
Redwood	Cherry to deep reddish brown	Distinct, not conspicuous growth ring; occasionally wavy and burl.	Faint growth-ring stripe; occasionally wavy and burl.
Spruce:			
Black, Engelmann, red, white.	Nearly white	Faint growth ring	None.
Sitka	Light reddish brown	Distinct, not conspicuous growth ring	Faint growth-ring stripe.
Tamarack	Russet brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.

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[1] The sapwood of all species is light in color or virtually white unless discolored by fungus or chemical stains.

Table 3–3.—*Average moisture content of green wood, by species*

Species	Moisture content[1]	
	Heart-wood *Pct.*	Sap-wood *Pct.*
HARDWOODS		
Alder, red	...	97
Apple	81	74
Ash:		
Black	95	...
Green		58
White	46	44
Aspen	95	113
Basswood, American	81	133
Beech, American	55	72
Birch:		
Paper	89	72
Sweet	75	70
Yellow	74	72
Cherry, black	58	
Chestnut, American	120	
Cottonwood, black	162	146
Elm:		
American	95	92
Cedar	66	61
Rock	44	57
Hackberry	61	65
Hickory, pecan:		
Bitternut	80	54
Water	97	62
Hickory, true:		
Mockernut	70	52
Pignut	71	49
Red	69	52
Sand	68	50
Magnolia	80	104
Maple:		
Silver	58	97
Sugar	65	72
Oak:		
California black	76	75
Northern red	80	69
Southern red	83	75
Water	81	81
White	64	78
Willow	82	74
Sweetgum	79	137
Sycamore, American	114	130
Tupelo:		
Black	87	115
Swamp	101	108
Water	150	116
Walnut, black	90	73
Yellow-poplar	83	106

Species	Moisture content[1]	
	Heart-wood *Pct.*	Sap-wood *Pct.*
SOFTWOODS		
Baldcypress	121	171
Cedar:		
Alaska-	32	166
Eastern redcedar	33	...
Incense-	40	213
Port Orford-	50	98
Western redcedar	58	249
Douglas-fir:		
Coast type	37	115
Fir:		
Grand	91	136
Noble	34	115
Pacific silver	55	164
White	98	160
Hemlock:		
Eastern	97	119
Western	85	170
Larch, western	54	110
Pine:		
Loblolly	33	110
Lodgepole	41	120
Longleaf	31	106
Ponderosa	40	148
Red	32	134
Shortleaf	32	122
Sugar	98	219
Western white	62	148
Redwood, old-growth	86	210
Spruce:		
Eastern	34	128
Engelmann	51	173
Sitka	41	142
Tamarack	49	

[1] Based on weight when ovendry.

Green Wood and Fiber Saturation Point

Moisture can exist in wood as water or water vapor in cell lumens (cavities) and as water "bound" chemically within cell walls. Green wood often is defined as wood in which the cell walls are completely saturated with water; however, green wood usually contains additional water in the lumens. The moisture content at which cell walls are completely saturated (all "bound" water) but no water exists in cell cavities is called the "fiber saturation point." The fiber saturation point of wood averages about 30 percent moisture content, but individual species and individual pieces of wood may vary by several percentage points from that value.

The fiber saturation point often also is considered as that moisture content below which the physical and mechanical properties of wood begin to change as a function of moisture content.

Equilibrium Moisture Content

The moisture content of wood below the fiber saturation point or "green" condition is a function of both relative humidity and temperature of the surrounding air. The equilibrium moisture content is defined as that moisture content at which the wood is neither gaining nor losing moisture; an equilibrium condition has been reached. The relationship between equilibrium moisture content, relative humidity, and temperature is shown in table 3–4. This table illustrates that below the fiber saturation point wood will attain a moisture content in equilibrium with widely differing atmospheric conditions. For most practical purposes the values in table 3–4 may be applied to wood of any species.

Wood in service usually is exposed to both long-term (seasonal) and short-term (such as daily) changes in the relative humidity and temperature of the surrounding air. Thus, wood virtually always is undergoing at least slight changes in moisture content. These changes usually are gradual and short-term fluctuations tend to influence only the wood surface. Moisture content changes may be retarded by protective coatings, such as varnish, lacquer, or paint. The practical objective of all wood seasoning, handling, and storing methods should be to minimize moisture content changes in wood in service. Favored procedures are those that bring the wood to a moisture content corresponding to the average atmospheric conditions to which it will be exposed (see ch. 14 and 16).

SHRINKAGE

Wood is dimensionally stable when the moisture content is above the fiber saturation point. Wood changes dimension as it gains or loses moisture below that point. It shrinks when losing moisture from the cell walls and swells when gaining moisture in the cell walls. This shrinking and swelling may result in warping, checking, splitting, or performance problems that detract from its usefulness. It is therefore important that these phenomena be understood and considered when they may affect a product in which wood is used.

Wood is an anisotropic material in shrinkage characteristics. It shrinks most in the direction of the annual growth rings (tangentially), about one-half as much across the rings (radially), and only slightly along the grain (longitudinally). The combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings. Figure 3–2 illustrates the major types of distortion due to these effects.

Transverse and Volumetric Shrinkage

Data have been collected to represent the average radial, tangential, and volumetric shrinkage of numerous domestic species by methods described in ASTM Designation D143. These shrinkage values, expressed as a percentage of the green dimension, are summarized in table 3–5. Shrinkage values collected from the world literature for selected imported species are summarized in table 3–6.

The shrinkage of wood is affected by a number of variables. In general, greater shrinkage is associated with greater density. The size and shape of a piece of wood may also affect shrinkage, as may the temperature and rate of drying for some species. Transverse and volumetric shrinkage variability can be expressed by a coefficient of variation of approximately 15 percent, based on a study in which 50 species were represented.

Longitudinal Shrinkage

Longitudinal shrinkage of wood (shrinkage parallel to the grain) is generally quite small. Average values for green to ovendry shrinkage are between 0.1 and 0.2 percent for most species of wood. Certain atypical types of wood, however, exhibit excessive longitudinal shrinkage, and these should be avoided in uses where longitudinal stability is important. Reaction wood, whether compression wood in softwoods or tension wood in hardwoods, tends to shrink excessively along the grain. Wood from near the center of trees (juvenile wood) of some species also shrinks excessively lengthwise. Wood with cross grain exhibits increased shrinkage along the longitudinal axis of the piece.

Reaction wood exhibiting excessive longitudinal shrinkage may occur in the same board with normal wood. The presence of this type of wood, as well as cross grain, can cause serious warping such as bow, crook, or twist, and cross breaks may develop in the zones of high shrinkage.

Table 3-4—*Moisture content of wood in equilibrium with stated dry-bulb temperature and relative humidity*

Temperature dry-bulb, °F.	Relative humidity, percent																			
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	98
30	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3	26.9
40	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3	26.9
50	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3	26.9
60	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1	26.8
70	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9	26.6
80	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6	26.3
90	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3	26.0
100	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9	25.6
110	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4	25.2
120	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0	24.7
130	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5	24.2
140	.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0	23.7
150	.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4	23.1
160	.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9	22.5
170	.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3	21.9
180	.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7	21.3
190	.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1	20.7
200	.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5	20.0
210	.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9	19.3

Table 3–5.—*Shrinkage values of domestic woods*

Species	Shrinkage from green to ovendry moisture content[1]		
	Radial	Tangential	Volumetric
	Pct.	*Pct.*	*Pct.*
HARDWOODS			
Alder, red	4.4	7.3	12.6
Ash:			
Black	5.0	7.8	15.2
Blue	3.9	6.5	11.7
Green	4.6	7.1	12.5
Oregon	4.1	8.1	13.2
Pumpkin	3.7	6.3	12.0
White	4.9	7.8	13.3
Aspen:			
Bigtooth	3.3	7.9	11.8
Quaking	3.5	6.7	11.5
Basswood, American	6.6	9.3	15.8
Beech, American	5.5	11.9	17.2
Birch:			
Alaska paper	6.5	9.9	16.7
Gray	5.2		14.7
Paper	6.3	8.6	16.2
River	4.7	9.2	13.5
Sweet	6.5	9.0	15.6
Yellow	7.3	9.5	16.8
Buckeye, yellow	3.6	8.1	12.5
Butternut	3.4	6.4	10.6
Cherry, black	3.7	7.1	11.5
Chestnut, American	3.4	6.7	11.6
Cottonwood:			
Balsam poplar	3.0	7.1	10.5
Black	3.6	8.6	12.4
Eastern	3.9	9.2	13.9
Elm:			
American	4.2	9.5	14.6
Cedar	4.7	10.2	15.4
Rock	4.8	8.1	14.9
Slippery	4.9	8.9	13.8
Winged	5.3	11.6	17.7
Hackberry	4.8	8.9	13.8
Hickory, Pecan	4.9	8.9	13.6
Hickory, True:			
Mockernut	7.7	11.0	17.8
Pignut	7.2	11.5	17.9
Shagbark	7.0	10.5	16.7
Shellbark	7.6	12.6	19.2
Holly, American	4.8	9.9	16.9
Honeylocust	4.2	6.6	10.8
Locust, black	4.6	7.2	10.2
Madrone, Pacific	5.6	12.4	18.1
Magnolia:			
Cucumbertree	5.2	8.8	13.6
Southern	5.4	6.6	12.3
Sweetbay	4.7	8.3	12.9
Maple:			
Bigleaf	3.7	7.1	11.6
Black	4.8	9.3	14.0
Red	4.0	8.2	12.6
Silver	3.0	7.2	12.0
Striped	3.2	8.6	12.3
Sugar	4.8	9.9	14.7
Oak, red:			
Black	4.4	11.1	15.1
Laurel	4.0	9.9	19.0
Northern red	4.0	8.6	13.7
Pin	4.3	9.5	14.5
Scarlet	4.4	10.8	14.7
Southern red	4.7	11.3	16.1
Water	4.4	9.8	16.1
Willow	5.0	9.6	18.9
Oak, white:			
Bur	4.4	8.8	12.7
Chestnut	5.3	10.8	16.4
Live	6.6	9.5	14.7
Overcup	5.3	12.7	16.0
Post	5.4	9.8	16.2
Swamp chestnut	5.2	10.8	16.4
White	5.6	10.5	16.3
Persimmon, common	7.9	11.2	19.1
Sassafras	4.0	6.2	10.3
Sweetgum	5.3	10.2	15.8
Sycamore, American	5.0	8.4	14.1
Tanoak	4.9	11.7	17.3
Tupelo:			
Black	5.1	8.7	14.4
Water	4.2	7.6	12.5
Walnut, black	5.5	7.8	12.8
Willow, black	3.3	8.7	13.9
Yellow-poplar	4.6	8.2	12.7
SOFTWOODS			
Baldcypress	3.8	6.2	10.5
Cedar:			
Alaska-	2.8	6.0	9.2
Atlantic white-	2.9	5.4	8.8
Eastern redcedar	3.1	4.7	7.8
Incense-	3.3	5.2	7.7
Northern white-	2.2	4.9	7.2
Port-Orford-	4.6	6.9	10.1
Western redcedar	2.4	5.0	6.8
Douglas-fir:[2]			
Coast	4.8	7.6	12.4
Interior north	3.8	6.9	10.7
Interior west	4.8	7.5	11.8
Fir:			
Balsam	2.9	6.9	11.2
California red	4.5	7.9	11.4
Grand	3.4	7.5	11.0
Noble	4.3	8.3	12.4
Pacific silver	4.4	9.2	13.0
Subalpine	2.6	7.4	9.4
White	3.3	7.0	9.8
Hemlock:			
Eastern	3.0	6.8	9.7
Mountain	4.4	7.1	11.1
Western	4.2	7.8	12.4
Larch, western	4.5	9.1	14.0
Pine:			
Eastern white	2.1	6.1	8.2
Jack	3.7	6.6	10.3

Table 3-5.—*Shrinkage values of domestic woods*—continued

Species	Shrinkage from green to ovendry moisture content[1]		
	Radial	Tangential	Volumetric
	Pct.	*Pct.*	*Pct.*
	SOFTWOODS—Continued		
Pine (cont.)			
Loblolly	4.8	7.4	12.3
Lodgepole	4.3	6.7	11.1
Longleaf	5.1	7.5	12.2
Pitch	4.0	7.1	10.9
Pond	5.1	7.1	11.2
Ponderosa	3.9	6.2	9.7
Red	3.8	7.2	11.3
Shortleaf	4.6	7.7	12.3
Slash	5.4	7.6	12.1
Sugar	2.9	5.6	7.9
Virginia	4.2	7.2	11.9
Western white	4.1	7.4	11.8
Redwood:			
Old-growth	2.6	4.4	6.8
Young-growth	2.2	4.9	7.0
Spruce:			
Black	4.1	6.8	11.3
Engelmann	3.8	7.1	11.0
Red	3.8	7.8	11.8
Sitka	4.3	7.5	11.5
Tamarack	3.7	7.4	13.6

[1] Expressed as a percentage of the green dimension.

[2] Coast Douglas-fir is defined as Douglas-fir growing in the States of Oregon and Washington west of the summit of the Cascade Mountains. Interior West includes the State of California and all counties in Oregon and Washington east of but adjacent to the Cascade summit. Interior North includes the remainder of Oregon and Washington and the States of Idaho, Montana, and Wyoming.

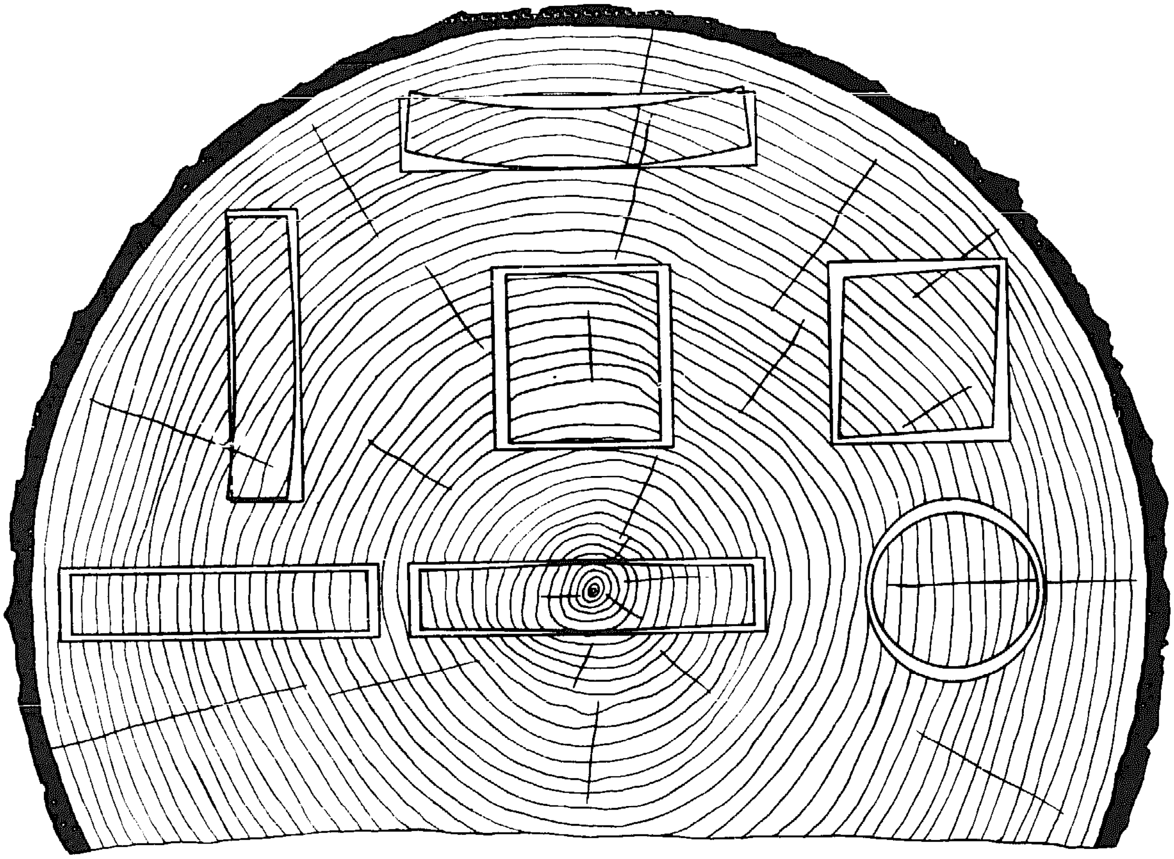

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Figure 3-2.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial.

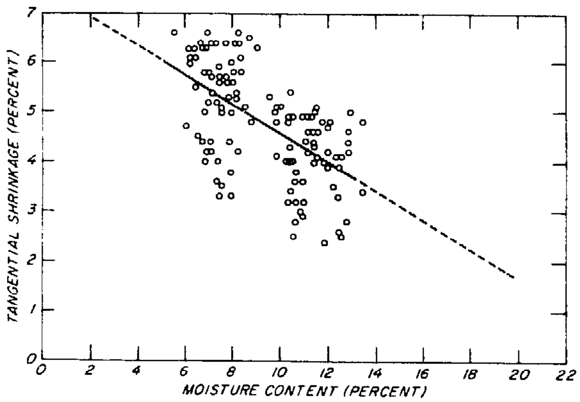

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Figure 3–3.—An illustration of variation in individual tangential shrinkage values of several boards of Douglas-fir from one locality, dried from green condition.

Moisture-Shrinkage Relationship

The shrinkage of a small piece of wood normally begins at about the fiber saturation point and continues in a fairly linear manner until the wood is completely dry. However, in the normal drying of lumber or other large pieces of wood the surface of the wood dries first. When the surface gets below the fiber saturation point, it begins to shrink. Meanwhile, the interior may still be quite wet. The exact form of the moisture content-shrinkage curve depends on several variables, principally size and shape of the piece, species of wood, and drying conditions employed.

Considerable variation in shrinkage occurs for any species. Figure 3–3 is a plot of shrinkage data for boards, ⅞ by 5½ inches in cross section, of Douglas-fir from one locality when dried under mild conditions from green to near equilibrium at 65° F. and 30 percent relative humidity. The figure shows that it is impossible to predict accurately the shrinkage of an individual piece of wood; the average shrinkage of a quantity of pieces is more predictable.

If the shrinkage-moisture content relationship is not known for a particular product and drying condition, the data in tables 3–5 and 3–6 can be used to estimate shrinkage from the green condition to any moisture content:

$$S_m = S_o \left(\frac{30-m}{30} \right)$$

where S_m is shrinkage (in percent) from the green condition to moisture content m (below 30 pct.) and S_o is total shrinkage (in percent) from table 3–5 or 3–6. If the moisture content at which shrinkage from the green condition begins is known to vary from 30 percent for a species, the shrinkage estimate can be improved by replacing 30 in the equation with the appropriate moisture content.

TABLE 3–6.—*Shrinkage for some woods imported into the United States*[1]

Species	Shrinkage from green to ovendry moisture content[2]	
	Radial	Tangential
	Pct.	*Pct.*
Andiroba (*Carapa guianensis*)	4.0	7.8
Angelique (*Dicorynia guianensis*)	5.2	8.8
Apitong (*Dipterocarpus* spp.)	5.2	10.9
Avodire (*Turraeanthus africanus*)	3.7	6.5
Balsa (*Ochroma pyramidale*)	3.0	7.6
Banak (*Virola surinamensis*)	4.6	8.8
Cativo (*Prioria copaifera*)	2.3	5.3
Greenheart (*Ocotea rodiaei*)	8.2	9.0
Ishpingo (*Amburana acreana*)	2.7	4.4
Khaya (*Khaya* spp.)	4.1	5.8
Kokrodua (*Pericopsis elata*)	3.2	6.3
Lauan (*Shorea* spp.)	3.8	8.0
Limba (*Terminalia superba*)	4.4	5.4
Lupuna (*Ceiba samauma*)	3.5	6.3
Mahogany (*Swietenia macrophylla*)	3.7	5.1
Nogal (*Juglans* spp.)	2.8	5.5
Obeche (*Triplochiton scleroxylon*)	3.1	5.3
Okoume (*Aucoumea klaineana*)	5.6	6.1
Parana pine (*Araucaria angustifolia*)	4.0	7.9
Primavera (*Cybistax donnell-smithii*)	3.1	5.2
Ramin (*Gonystylus* spp.)	3.9	8.7
Santa Maria (*Calophyllum brasiliense*)	5.4	7.9
Spanish-cedar (*Cedrela* spp.)	4.1	6.3
Teak (*Tectona grandis*)	2.2	4.0
Virola (*Dialyanthera* spp.)	5.3	9.6
Walnut, European (*Juglans regia*)	4.3	6.4

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[1] Shrinkage values in this table were obtained from world literature and may not represent a true species average.

[2] Expressed as a percentage of the green dimension.

S_o may be an appropriate value of radial, tangential, or volumetric shrinkage. Tangential values should be used for estimating width shrinkage of flat-sawed material; radial values for quartersawed material. For mixed or unknown ring orientations, the tangential values are suggested. Individual pieces will vary from predicted shrinkage values. As noted previously, shrinkage variability is characterized by a coefficient of variation of approximately 15 percent. Chapter 14 contains further discussion of shrinkage-moisture content relations.

DENSITY–SPECIFIC GRAVITY–WEIGHT

Two primary sources of variation affect the weight of wood products. One is the density of the basic wood structure; the other is the variable moisture content. A third source, minerals and extractable substances, has a marked effect only on a limited number of species. The density of wood, exclusive of water, varies greatly both within and between species. While the density of most species falls between about 20 and 45 pounds-mass per cubic foot, the range of densities actually extends from about 10 pounds-mass per cubic foot for balsa to over 65 pounds-mass per cubic foot for some other imported woods. A coefficient of variation of about 10 percent is considered suitable for describing the variability of density within common domestic species.

Wood is used in a wide range of conditions and thus has a wide range of moisture contents in use. Since moisture makes up part of the weight of each product in use, the density must reflect this fact. This has resulted in the density of wood often being determined and reported on a moisture content-in-use condition.

The calculated density of wood, including the water contained in it, is usually based on average species characteristics. This value should always be considered an approximation because of the natural variation in anatomy, moisture content, and the ratio of heartwood to sapwood that occurs. Nevertheless, this determination of density usually is sufficiently accurate to permit proper utilization of wood products where weight is important. Such applications range from estimation of structural loads to the calculating of approximate shipping weights.

To standardize comparisons of species or products and estimations of product weights, specific gravity is used as a standard reference basis, rather than density. The traditional definition of specific gravity is the ratio of the density of the wood to the density of water at a specified reference temperature (often 4° C. where the density of water is 1.0000 g. per cc.). To reduce any confusion introduced by the variable moisture content the specific gravity of wood usually is based on the ovendry weight and the volume at some specified moisture content. A coefficient of variation of about 10 percent describes the variability inherent in many common domestic species.

In research activities specific gravity may be reported on the basis of both weight and volume ovendry. For engineering work, the basis commonly is ovendry weight and volume at the moisture content of test or use. Often the moisture content of use is taken as 12 percent. Some specific gravity data are reported in table 4–2, chapter 4, on this basis.

If the specific gravity of wood is known, based on ovendry weight and volume at a specified moisture content, the specific gravity at any other moisture content between 0 and 30 percent can be approximated from figure 3–4. This figure adjusts for average shrinkage and swelling that affects the volume of the wood. The specific gravity of wood based on ovendry weight does not change at moisture contents above approximately 30 percent (the approximate fiber saturation point). To use figure 3–4 locate the point corresponding to the known specific gravity on the vertical axis and the specified moisture content on the horizontal axis. From this point, move left or right parallel to the inclined lines until vertically above the target moisture content. Then read the new specific gravity corresponding to this point at the left-hand side of the graph.

With a knowledge of the specific gravity at the moisture content of interest, the density of wood including water at that moisture content can be read directly from table 3–7.[1] For example, to estimate the density of white ash at 12 percent moisture content, consult table 4–2 in chapter 4. The average green specific gravity for the species is 0.55. Using figure 3–4, the 0.55 green specific gravity curve is found to intersect with the vertical 12 percent moisture content line at a point corresponding

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[1] Table 3–7 is repeated as A–3–7 in metric (SI) units at the end of this chapter.

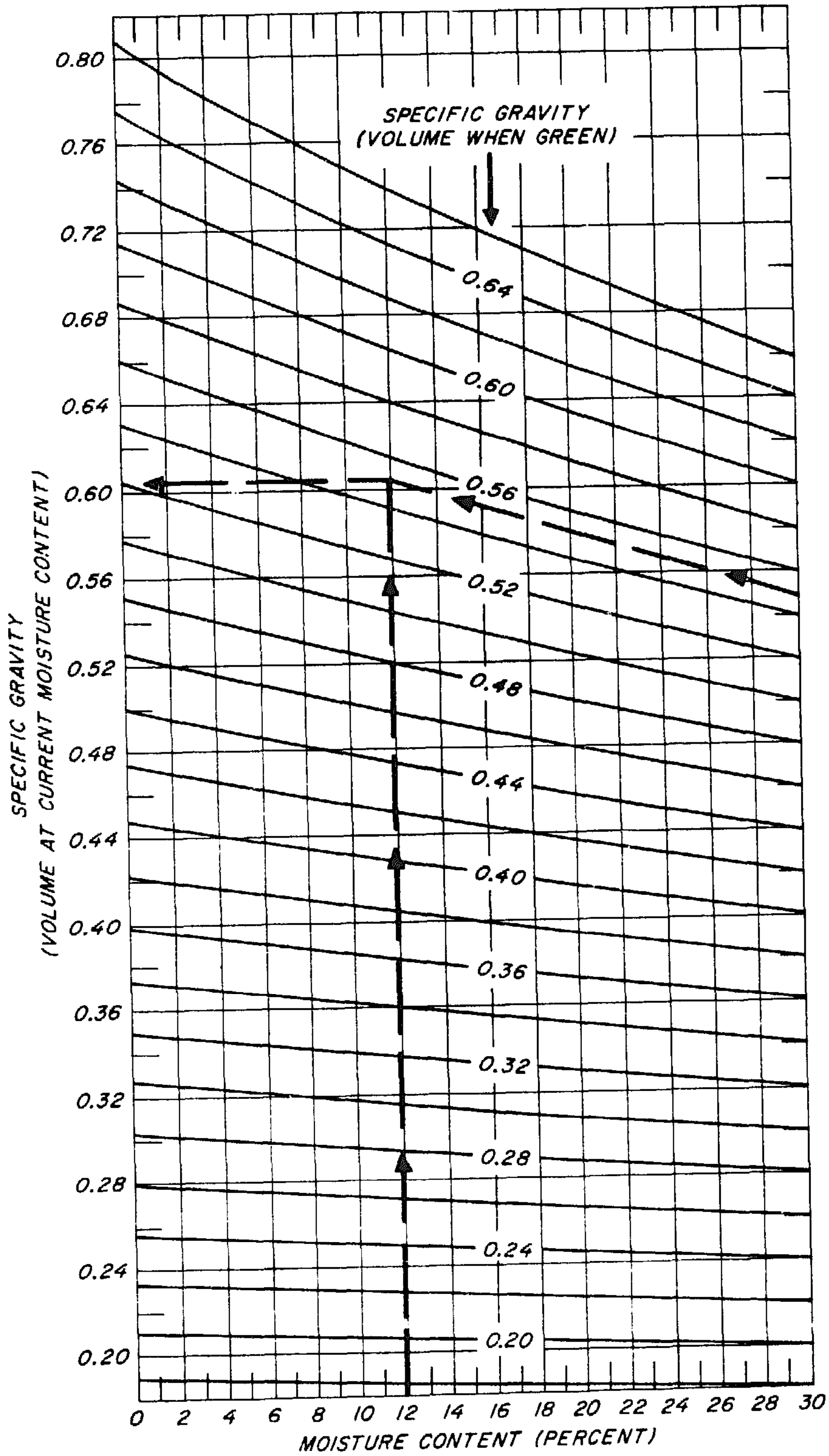

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Figure 2–4.—Relation of specific gravity and moisture content.

Table 3-7.—*Density of wood as a function of specific gravity and moisture content*

Moisture content of wood (%)	Density in pounds-mass per cubic foot when the specific gravity[1] is—																				
	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70
0	18.7	20.0	21.2	22.5	23.7	25.0	26.2	27.5	28.7	30.0	31.2	32.4	33.7	34.9	36.2	37.4	38.7	39.9	41.2	42.4	43.7
4	19.5	20.8	22.1	23.4	24.7	26.0	27.2	28.6	29.8	31.2	32.4	33.7	35.0	36.3	37.6	38.9	40.2	41.5	42.8	44.1	45.4
8	20.2	21.6	22.9	24.3	25.6	27.0	28.3	29.6	31.0	32.3	33.7	35.0	36.4	37.7	39.1	40.4	41.8	43.1	44.5	45.8	47.2
12	21.0	22.4	23.8	25.2	26.6	28.0	29.4	30.8	32.2	33.5	34.9	36.3	37.7	39.1	40.5	41.9	43.3	44.7	46.1	47.5	48.9
16	21.7	23.2	24.6	26.0	27.5	29.0	30.4	31.8	33.3	34.7	36.2	37.6	39.1	40.5	42.0	43.4	44.9	46.3	47.8	49.2	50.7
20	22.5	24.0	25.5	27.0	28.4	30.0	31.4	32.9	34.4	35.9	37.4	38.9	40.4	41.9	43.4	44.9	46.4	47.9	49.4	50.9	52.4
24	23.2	24.8	26.3	27.8	29.4	31.0	32.5	34.0	35.6	37.1	38.7	40.2	41.8	43.3	44.9	46.4	48.0	49.5	51.1	52.6	54.2
28	24.0	25.6	27.2	28.8	30.4	31.9	33.5	35.1	36.7	38.3	39.9	41.5	43.1	44.7	46.3	47.9	49.5	51.1	52.7	54.3	55.9
32	24.7	26.4	28.0	29.7	31.3	32.9	34.6	36.2	37.9	39.5	41.2	42.8	44.5	46.1	47.8	49.4	51.1	52.7	54.4	56.0	57.7
36	25.5	27.2	28.9	30.6	32.2	33.9	35.6	37.3	39.0	40.7	42.4	44.1	45.8	47.5	49.2	50.9	52.6	54.3	56.0	57.7	59.4
40	26.2	28.0	29.7	31.4	33.2	34.9	36.7	38.4	40.2	41.9	43.7	45.4	47.2	48.9	50.7	52.4	54.2	55.9	57.7	59.4	61.2
44	27.0	28.8	30.6	32.3	34.1	35.9	37.7	39.5	41.3	43.1	44.9	46.7	48.5	50.3	52.1	53.9	55.7	57.5	59.3	61.1	62.9
48	27.7	29.6	31.4	33.2	35.1	36.9	38.8	40.6	42.5	44.3	46.2	48.0	49.9	51.7	53.6	55.4	57.3	59.1	61.0	62.8	64.6
52	28.5	30.4	32.2	34.1	36.0	37.9	39.8	41.7	43.6	45.5	47.4	49.3	51.2	53.1	55.0	56.9	58.8	60.7	62.6	64.5	66.4
56	29.2	31.2	33.1	35.0	37.0	38.9	40.9	42.8	44.8	46.7	48.7	50.6	52.6	54.5	56.5	58.4	60.4	62.3	64.2	66.2	68.1
60	30.0	31.9	33.9	35.9	37.9	39.9	41.9	43.9	45.9	47.9	49.9	51.9	53.9	55.9	57.9	59.9	61.9	63.9	65.9	67.9	69.9
64	30.7	32.7	34.8	36.8	38.9	40.9	43.0	45.0	47.1	49.1	51.2	53.2	55.3	57.3	59.4	61.4	63.4	65.5	67.5	69.6	71.6
68	31.4	33.5	35.6	37.7	39.8	41.9	44.0	46.1	48.2	50.3	52.4	54.5	56.6	58.7	60.8	62.9	65.0	67.1	69.2	71.3	73.4
72	32.2	34.3	36.5	38.6	40.8	42.9	45.1	47.2	49.4	51.5	53.7	55.8	58.0	60.1	62.3	64.4	66.5	68.7	70.8	73.0	75.1
76	32.9	35.1	37.3	39.5	41.7	43.9	46.1	48.3	50.5	52.7	54.9	57.1	59.3	61.5	63.7	65.9	68.1	70.3	72.5	74.7	76.9
80	33.7	35.9	38.2	40.4	42.7	44.9	47.2	49.4	51.7	53.9	56.2	58.4	60.7	62.9	65.1	67.4	69.6	71.9	74.1	76.4	78.6
84	34.4	36.7	39.0	41.3	43.6	45.9	48.2	50.5	52.8	55.1	57.4	59.7	62.0	64.3	66.6	68.9	71.2	73.5	75.8	78.1	80.4
88	35.2	37.5	39.9	42.2	44.6	46.9	49.3	51.6	54.0	56.3	58.7	61.0	63.3	65.7	68.0	70.4	72.7	75.1	77.4	79.8	82.1
92	35.9	38.3	40.7	43.1	45.5	47.9	50.3	52.7	55.1	57.5	59.9	62.3	64.7	67.1	69.5	71.9	74.3	76.7	79.1	81.5	83.9
96	36.7	39.1	41.6	44.0	46.5	48.9	51.4	53.8	56.3	58.7	61.2	63.6	66.0	68.5	70.9	73.4	75.8	78.3	80.7	83.2	85.6
100	37.4	39.9	42.4	44.9	47.4	49.9	52.4	54.9	57.4	59.9	62.4	64.9	67.4	69.9	72.4	74.9	77.4	79.9	82.4	84.9	87.4
110	39.3	41.9	44.6	47.2	49.8	52.4	55.0	57.7	60.3	62.9	65.5	68.1	70.8	73.4	76.0	78.6	81.2	83.9	86.5	89.1	91.7
120	41.2	43.9	46.7	49.4	52.2	54.9	57.7	60.4	63.1	65.9	68.6	71.4	74.1	76.9	79.6	82.4	85.1	87.9	90.6	93.4	96.1
130	43.1	45.9	48.8	51.7	54.5	57.4	60.3	63.1	66.0	68.9	71.8	74.6	77.5	80.4	83.2	86.1	89.0	91.9	94.7	97.6	100.5
140	44.9	47.9	50.9	53.9	56.9	59.9	62.9	65.9	68.9	71.9	74.9	77.9	80.9	83.9	86.9	89.9	92.9	95.8	98.8	101.8	104.8
150	46.8	49.9	53.0	56.2	59.3	62.4	65.5	68.6	71.8	74.9	78.0	81.1	84.2	87.4	90.5	93.6	96.7	99.8	103.0	106.1	109.2

[1] Based on mass when ovendry and volume at tabulated moisture content.

to a specific gravity of 0.605 based on ovendry weight and volume at 12 percent moisture content (see dashed lines in fig. 3–4). Table 3–7 then can be used to convert the specific gravity of 0.605 to a density of 42 pounds-mass per cubic foot.

WORKING QUALITIES

The ease of working wood with hand tools generally varies directly with the specific gravity of the wood. The lower the specific gravity, the easier it is to cut the wood with a sharp tool. Tables 4–2 and 4–3 list the specific gravity values for various native and imported species. These specific gravity figures can be used as a general guide to the ease of working with hand tools.

A wood species that is easy to cut does not necessarily develop a smooth surface when it is machined. Consequently, tests have been made with many United States hardwoods to evaluate them for machining properties. Results of these evaluations are given in table 3–8.

Machining evaluations are not available for many imported woods. However, it is known that three major factors other than density may affect production of smooth surfaces during wood machining. These factors are: Interlocked and variable grain; hard mineral deposits; and reaction wood, particularly tension wood in hardwoods. Interlocked grain is characteristic of the majority of tropical species and presents difficulty in planing quartered surfaces unless attention is paid to feed rate, cutting angles, and sharpness of knives. Hard deposits such as calcium carbonate and silica may have a pronounced dulling effect on all cutting edges. This dulling effect becomes more pronounced as the wood is dried to the usual inservice requirements. Tension wood may cause fibrous and fuzzy surfaces. It can be very troublesome in species of lower density. Reaction wood may also be responsible for the pinching effect on saws due to stress relief. The pinching may result in burning and dulling of the sawteeth. Table 3–9 lists some of the imported species that have irregular grain, hard deposits, or tension wood.

Table 3–8.—*Some machining and related properties of selected domestic hardwoods*

Kind of wood [1]	Planing—perfect pieces	Shaping—good to excellent pieces	Turning—fair to excellent pieces	Boring—good to excellent pieces	Mortising—fair to excellent pieces	Sanding—good to excellent pieces	Steam bending—unbroken pieces	Nail splitting—pieces free from complete splits	Screw splitting—pieces free from complete splits
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Alder, red	61	20	88	64	52				
Ash	75	55	79	94	58	75	67	65	71
Aspen	26	7	65	78	60				
Basswood	64	10	68	76	51	17	2	79	68
Beech	83	24	90	99	92	49	75	42	58
Birch	63	57	80	97	97	34	72	32	48
Birch, paper	47	22							
Cherry, black	80	80	88	100	100				
Chestnut	74	28	87	91	70	64	56	66	60
Cottonwood	21	3	70	70	52	19	44	82	78
Elm, soft	33	13	65	94	75	66	74	80	74
Hackberry	74	10	77	99	72		94	63	63
Hickory	76	20	84	100	98	80	76	35	63
Magnolia	65	27	79	71	32	37	85	73	76
Maple, bigleaf	52	56	80	100	80				
Maple, hard	54	72	82	99	95	38	57	27	52
Maple, soft	41	25	76	80	34	37	59	58	61
Oak, red	91	28	84	99	95	81	86	66	78
Oak, white	87	35	85	95	99	83	91	69	74
Pecan	88	40	89	100	98		78	47	69
Sweetgum	51	28	86	92	58	23	67	69	69
Sycamore	22	12	85	98	96	21	29	79	74
Tanoak	80	39	81	100	100				
Tupelo, water	55	52	79	62	33	34	46	64	63
Tupelo, black	48	32	75	82	24	21	42	65	63
Walnut, black	62	34	91	100	98		78	50	59
Willow	52	5	58	71	24	24	73	89	62
Yellow-poplar	70	13	81	87	63	19	58	77	67

[1] Commercial lumber nomenclature.

Table 3-9.—*Some characteristics of imported woods that may effect machining.*

Irregular and interlocked grain	Hard mineral deposits (silica or calcium carbonate)	Reaction wood (tension wood)
Apamate	Angelique	Andiroba
Apitong	Apitong	Banak
Avodire	Kapur	Cativo
Capirona	Okoume	Khaya
Courbaril	Palosapis	Lupuna
Gola	Rosewood, Indian	Mahogany
Goncalo alves	Teak	Nogal
Ishpingo		Sande
Jarrah		Spanish-cedar
Kapur		
Karri		
Khaya		
Kokrodua		
Lapacho		
Laurel		
Lignum vitae		
Limba		
Meranti		
Obeche		
Okoume		
Palosapis		
Peroba de campos		
Primavera		
Rosewood, Indian		
Santa Maria		
Sapele		

WEATHERING

Without protective treatment, freshly cut wood exposed to the weather changes materially in color. Other changes due to weathering include warping, loss of some surface fibers, and surface roughening and checking. The effects of weathering on wood may be desirable or undesirable, depending on the requirements for the particular wood product. The time required to reach the fully weathered appearance depends on the severity of the exposure to sun and rain. Once weathered, wood remains nearly unaltered in appearance.

The color of wood is affected very soon on exposure to weather. With continued exposure all woods turn gray; however, only the wood at or near the exposed surfaces is noticeably affected. This very thin gray layer is composed chiefly of partially degraded cellulose fibers and micro-organisms. Further weathering causes fibers to be lost from the surface but the process is so slow that only about $1/4$ inch is lost in a century.

In the weathering process, chemical degradation is influenced greatly by the wavelength of light. The most severe effects are produced by exposure to ultraviolet light. As cycles of wetting and drying take place, most woods develop physical changes such as checks or cracks that are easily visible. Moderate to low density woods acquire fewer checks than do high density woods. Vertical-grain boards check less than flat-grain boards.

As a result of weathering, boards tend to warp (particularly cup) and pull out their fastenings. The cupping tendency varies with the density, width, and thickness of a board. The greater the density and the greater the width in proportion to the thickness, the greater is the tendency to cup. Warping also is more pronounced in flat-grain boards than in vertical-grain boards. For best cup resistance, the width of a board should not exceed eight times its thickness.

Biological attack of a wood surface by micro-organisms is recognized as a contributing factor to color changes. When weathered wood has an unsightly dark gray and blotchy appearance, it is due to dark-colored fungal spores and mycelium on the wood surface. The formation of a clean, light gray, silvery sheen on weathered wood occurs most frequently where micro-organism growth is inhibited by a hot, arid climate or a salt atmosphere in coastal regions.

The contact of fasteners and other metallic products with the weathering wood surface is a source of color, often undesirable if a natural color is desired. Chapter 16 discusses this effect in more detail.

Details of treatments to preserve the natural color, retard biological attack, or impart additional color to the wood, are covered in chapters 16, 17, and 18.

DECAY RESISTANCE

Wood kept constantly dry does not decay. Further, if it is kept continuously submerged in water even for long periods of time, it is not decayed significantly by the common decay fungi regardless of the wood species or the presence of sapwood. Bacteria and certain soft-rot fungi can attack ,submerged wood but the resulting deterioration is very slow. A large proportion of wood in use is kept so dry at all times that it lasts indefinitely. Moisture and temperature, which vary greatly with local conditions, are the principal factors affecting rate of decay. When exposed to conditions that favor decay, wood deteriorates more rapidly in warm, humid areas than in cool or dry areas. High altitudes, as a rule, are less favorable to decay than low altitudes because the average temperatures are lower and the growing seasons for fungi, which cause decay, are shorter.

The heartwoods of some common native species of wood have varying degrees of natural decay resistance. Untreated sapwood of substantially all species has low resistance to decay and usually has a short service life under decay-producing conditions. The decay resistance of heartwood is greatly affected by differences in the preservative qualities of the wood extractives, the attacking fungus, and the conditions of exposure. Considerable difference in service life may be obtained from pieces of wood cut from the same species, or even from the same tree, and used under apparently similar conditions. There are further complications because, in a few species, such as the spruces and the true firs (not Douglas-fir), heartwood and sapwood are so similar in color that they cannot be easily distinguished. Marketable sizes of some species such as southern pine and baldcypress are becoming largely second growth and contain a high percentage of sapwood.

Table 3–10.—*Grouping of some domestic woods according to heartwood decay*

Resistant or very resistant	Moderately resistant	Slightly or nonresistant
Baldcypress (old growth)[1]	Baldcypress (young growth)[1]	Alder
Catalpa	Douglas-fir	Ashes
Cedars	Honeylocust	Aspens
Cherry, black	Larch, western	Basswood
Chestnut	Oak, swamp chestnut	Beech
Cypress, Arizona	Pine, eastern white[1]	Birches
Junipers	Southern pine:	Buckeye
Locust, black[2]	Longleaf[1]	Butternut
Mesquite	Slash[1]	Cottonwood
Mulberry, red[2]	Tamarack	Elms
Oak:		Hackberry
Bur		Hemlocks
Chestnut		Hickories
Gambel		Magnolia
Oregon white		Maples
Post		Oak (red and black species)
White		Pines (other than longleaf, slash, and eastern white)
Osage orange[2]		Poplars
Redwood		Spruces
Sassafras		Sweetgum
Walnut, black		True firs (western and eastern)
Yew, Pacific[2]		Willows
		Yellow-poplar

[1] The southern and eastern pines and baldcypress are now largely second growth with a large proportion of sapwood. Consequently, substantial quantities of heartwood lumber of these species are not available.

[2] These woods have exceptionally high decay resistance.

Precise ratings of decay resistance of heartwood of different species are not possible because of differences within species and the variety of service conditions to which wood is exposed. However, broad groupings of many of the native species, based on service records, laboratory tests, and general experience, are helpful in choosing heartwood for use under conditions favorable to decay. Table 3–10 shows such groupings for some domestic woods, according to their average heartwood decay resistance, and table 3–11 gives similar groupings for some imported woods. The extent of variations in decay resistance of individual trees or wood samples of a species is much greater for most of the more resistant species than for the slightly or nonresistant species.

Where decay hazards exist, heartwood of species in the resistant or very resistant category generally gives satisfactory service, but heartwood of species in the other two categories will usually require some form of preservative treatment. For mild decay conditions, a simple preservative treatment—such as a short soak in preservative after all cutting and boring operations are complete—will be adequate for wood low in decay resistance. For more severe decay hazards, pressure treatments are often required; even the very decay-resistant species may require preservative treatment for important structural or other uses where failure would endanger life or require expensive repairs. Preservative treatments and methods are discussed in chapter 18.

CHEMICAL RESISTANCE

Wood is highly resistant to many chemicals. In the chemical processing industry, it is the preferred material for numerous applications, such as various types of tanks and other containers, and for structures adjacent to or housing chemical equipment. Wood is widely used in cooling towers where the hot water to be cooled contains boiler conditioning chemicals as well as dissolved chlorine for algae suppression. It is also used in the fabrication of buildings for bulk chemical storage where the wood may be in direct contact with chemicals.

Wood owes its extensive use in chemical processing operations largely to its superiority over cast iron and ordinary steel in resistance to mild acids and solutions of acidic salts. While iron is superior to untreated wood in resistance to alkaline solutions, wood may be

Table 3–11.—*Grouping of some woods imported into the United States according to approximate relative heartwood decay resistance*

Resistant or very resistant	Moderately resistant	Slightly or nonresistant
Angelique	Andiroba[1]	Balsa
Apamate	Apitong[1]	Banak
Brazilian rosewood	Avodire	Cativo
Caribbean pine	Capirona	Ceiba
Courbaril	European walnut	Jelutong
Encino	Gola	Limba
Goncalo alves	Khaya	Lupuna
Greenheart	Laurel	Mahogany, Philippine:
Guijo	Mahogany, Philippine:	Mayapis
Iroko	Almon	White lauan
Jarrah	Bagtikan	Obeche
Kapur	Red lauan	Parana pine
Karri	Tanguile	Ramin
Kokrodua (Afrormosia)	Ocote pine	Sande
Lapacho	Palosapis	Virola
Lignum vitae	Sapele	
Mahogany, American		
Meranti[1]		
Peroba de campos		
Primavera		
Santa Maria		
Spanish-cedar		
Teak		

[1] More than 1 species included, some of which may vary in resistance from that indicated.

treated to greatly enhance its durability in this respect.

In general, heartwood is more resistant to chemical attack than sapwood, basically because heartwood is more resistant to penetration by liquids. The heartwoods of cypress, southern pine, Douglas-fir, and redwood are preferred for water tanks. Heartwoods of the first three of these species are preferred where resistance to chemical attack is an important factor. These four species combine moderate to high resistance to water penetration with moderate to high resistance to chemical attack and decay.

Chemical solutions may affect wood by two general types of action. The first is an almost completely reversible effect involving swelling of the wood structure. The second type of action is irreversible and involves permanent changes in the wood structure due to alteration of one or more of its chemical constituents.

In the first type, liquids such as water, alcohols, and some other organic liquids swell the wood with no degradation of the wood structure. Removal of the swelling liquid allows the wood to return to its original condition. Petroleum oils and creosote do not swell wood.

The second type of action causes permanent changes due to hydrolysis of cellulose and hemicelluloses by acids or acidic salts, oxidation of wood substance by oxidizing agents, or delignification and solution of hemicelluloses by alkalies or alkaline salt solutions. Experience and available data indicate species and conditions where wood is equal or superior to other materials in resisting degradative actions of chemicals. In general, heartwood of such species as cypress, Douglas-fir, southern pine, redwood, maple, and white oak is quite resistant to attack by dilute mineral and organic acids. Oxidizing acids, such as nitric acid, have a greater degradative action than nonoxidizing acids. Alkaline solutions are more destructive than acidic solutions, and hardwoods are more susceptible to attack by both acids and alkalies than softwoods.

Highly acidic salts tend to hydrolyze wood when present in high concentrations. Even relatively low concentrations of such salts have shown signs that the salt may migrate to the surface of railroad ties that are occasionally wet and dried in a hot, arid region. This migration, combined with the high concentrations of salt relative to the small amount of water present, causes an acidic condition sufficient to make wood brittle.

Iron salts, which develop at points of contact with tie plates, bolts, and the like, have a degradative action on wood, especially in the presence of moisture. In addition, iron salts probably precipitate toxic extractives and thus lower the natural decay resistance of wood. The softening and discoloration of wood around corroded iron fastenings is a commonly observed phenomenon; it is especially pronounced in acidic woods, such as oak, and in woods such as redwood which contain considerable tannin and related compounds. The oxide layer formed on iron is transformed through reaction with wood acids into soluble iron salts which not only degrade the surrounding wood but probably catalyze the further corrosion of the metal. The action is accelerated by moisture; oxygen may also play an important role in the process. This effect is not encountered with well-dried wood used in dry locations. Under damp use conditions, it can be avoided or minimized by using corrosion-resistant fastenings.

Many substances have been employed as impregnants to enhance the natural resistance of wood to chemical degradation. One of the more economical treatments involves pressure impregnation with a viscous coke-oven coal tar to retard liquid penetration. Acid resistance of wood is increased by impregnation with phenolic resin solutions followed by appropriate drying and curing. Treatment with furfuryl alcohol has been used to increase resistance to alkaline solutions. A newer development involves massive impregnation with a monomeric resin, such as methyl methacrylate, followed by polymerization. Chapters 16, 17, and 18 discuss coatings and finishes, other chemical treatments, and preservation.

THERMAL PROPERTIES

Four important thermal properties of wood are (1) thermal conductivity, (2) specific heat, (3) thermal diffusivity, and (4) coefficient of thermal expansion. Thermal conductivity is a measure of the rate of heat flow through materials subjected to a temperature gradient. Specific heat of a material is the ratio of the heat capacity of the material to the heat capacity of water; the heat capacity of a material is the thermal energy required to produce one unit change of temperature in one unit mass. Thermal diffusivity is a measure of how quickly a material can absorb heat from its surroundings; it is the ratio of thermal conductivity to the product of density and specific heat. The coefficient of thermal expansion is a measure of the change of dimension caused by temperature change.

Thermal Conductivity

The thermal conductivity of common structural woods is a small fraction of the conductivity of metals with which it often is mated in construction. It is about two to four times that of common insulating material. For example, structural softwood lumber has a conductivity of about 0.8 British thermal units per inch per hour per square foot per degree Fahrenheit (Btu · in/hr · sq ft · deg F) compared with 1390 for aluminum, 320 for steel, 8 for concrete, 5 for glass, 3 for plaster, and 0.3 for mineral wool.

The thermal conductivity of wood is affected by a number of basic factors: (1) density, (2) moisture content, (3) extractive content, (4) grain direction, and (5) structural irregularities such as checks and knots. It is nearly the same in the radial and tangential direction with respect to the growth rings but is 2.0 to 2.8 times greater parallel to the grain than in either the radial or tangential directions. It increases as the density, moisture content, or extractive content of the wood increases.

Figure 3–5 shows the average thermal conductivity perpendicular to the grain as related to wood density and moisture content up to approximately 40 percent moisture content. This chart is a plot of the empirical equation:

$$k = S(1.39 + 0.028M) + 0.165$$

where k is thermal conductivity in Btu · in/hr · sq ft deg F, S is specific gravity based on volume at current moisture content and weight when ovendry, and M is the moisture content in percent of dry weight. For wood at a moisture content of 40 percent or greater, the following equation has been applied:

$$k = S(1.39 + 0.038M) + 0.165$$

The equations presented were derived by averaging the results of studies on a variety of species. Individual wood specimen conductivity will vary from these predicted values because of the five variability sources noted above.

Specific Heat

The specific heat of wood depends on the temperature and moisture content of the wood but is practically independent of density or species. Specific heat of dry wood is approximately related to temperature t, in °F, by

$$\text{Specific heat} = 0.25 + 0.0006t$$

When wood contains water, the specific heat is increased because the specific heat of water is larger than that of dry wood. The apparent specific heat of moist wood, however, is larger than would be expected from a simple sum of the separate effects of wood and water. The additional apparent specific heat is due to thermal energy absorbed by the wood-water bonds. As the temperature increases the apparent specific heat increases because the energy of absorption of wood increases with temperature.

If the specific heat of water is considered to be unity, the specific heat of moist wood is given by:

$$\text{Specific heat} = \frac{M + c_o}{1 + M} + A$$

where M is the fractional moisture content of the wood, c_o is the specific heat of dry wood,

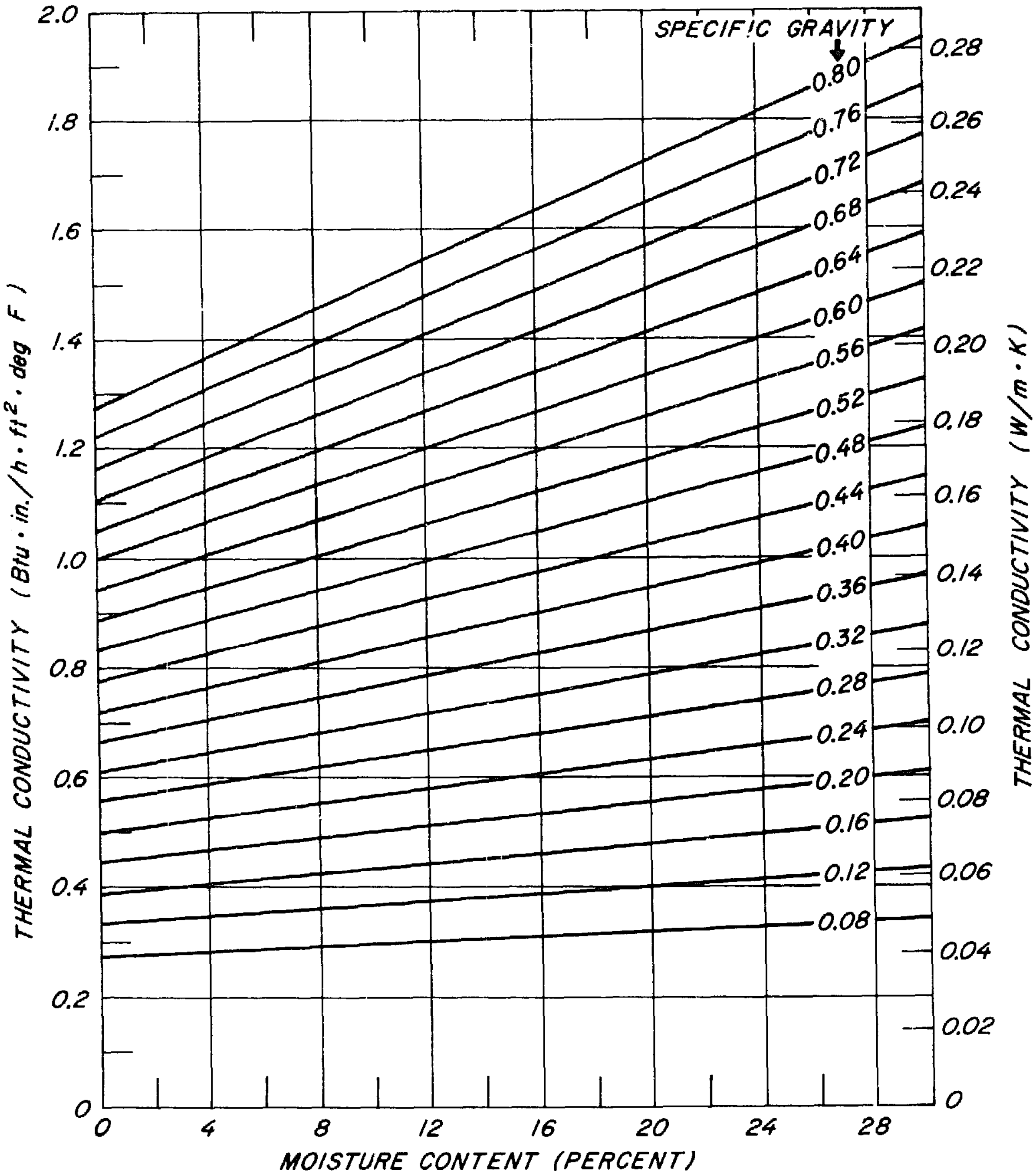

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Figure 3–5.—Computed thermal conductivity of wood perpendicular to grain as related to moisture content and specific gravity.

and A is the additional specific heat due to the wood-water bond energy. A increases with increasing temperature. For wood at 10 percent moisture content, A ranges from about 0.02 at 85° F. to about 0.04 at 140° F. A ranges from about 0.04 at 85° F. to about 0.09 at 140° F. for wood at about 30 percent moisture content.

Thermal Diffusivity

Because of the small thermal conductivity and moderate density and specific heat of wood, the thermal diffusivity of wood is much smaller than that of other structural materials such as metals, brick, and stone. A typical value for wood is 0.00025 inch^2 per second compared to 0.02 inch^2 per second for steel, and 0.001 inch^2 per second for mineral wool. For this reason wood does not feel extremely hot or cold to the touch as do some other materials.

Few investigators have measured the diffusivity of wood directly. Since diffusivity is defined as the ratio of conductivity to the product of specific heat and density, conclusions regarding its variation with temperature and density often are based on calculating the effect of these variables on specific heat and conductivity.

All investigations illustrate that diffusivity is influenced slightly by both specific gravity and moisture content in an inverse fashion. The diffusivity increases approximately 0.0001 inch^2 per second over a decreasing specific gravity range of 0.65 to 0.30. Calculations suggest the effect of moisture is to increase diffusivity by about 0.00004 inch^2 per second as the moisture content is reduced from 12 to 0 percent.

Coefficient of Thermal Expansion

The thermal expansion coefficients of completely dry wood are positive in all directions—that is, wood expands on heating and contracts on cooling. Only limited research has been carried out to explore the influence of wood property variability on thermal expansion. The linear expansion coefficient of ovendry wood parallel to the grain appears to be independent of specific gravity and species. In tests of both hardwoods and softwoods, the parallel-to-the-grain values have ranged from about 0.0000017 to 0.0000025 per degree Fahrenheit.

The linear expansion coefficients across the grain (radial and tangential) are proportional to wood density. These coefficients range from about five to over ten times greater than the parallel-to-the-grain coefficients and thus are of more practical interest. The radial and tangential thermal expansion coefficients for ovendry wood, α_r and α_t, can be approximated by the following equations, over an ovendry specific gravity range of about 0.1 to 0.8:

$$\alpha_r = [(32)(\text{specific gravity}) + 9.9][10^{-6}] \text{ per °F.}$$

$$\alpha_t = [(33)(\text{specific gravity}) + 18.4][10^{-6}] \text{ per °F.}$$

Thermal expansion coefficients can be considered independent of temperature over the temperature range of −60° to +130° F.

Wood that contains moisture reacts to varying temperature differently than does dry wood. When moist wood is heated, it tends to expand because of normal thermal expansion and to shrink because of loss in moisture content. Unless the wood is very dry initially (perhaps 3 or 4 pct. M.C. or less), the shrinkage due to moisture loss on heating will be greater than the thermal expansion, so the net dimensional change on heating will be negative. Wood at intermediate moisture levels (about 8 to 20 pct.) will expand when first heated, then gradually shrink to a volume smaller than the initial volume, as the wood gradually loses water while in the heated condition.

Even in the longitudinal (grain) direction, where dimensional change due to moisture change is very small, such changes will still predominate over corresponding dimensional changes due to thermal expansion unless the wood is very dry initially. For wood at usual moisture levels, net dimensional changes will generally be negative after prolonged heating.

ELECTRICAL PROPERTIES

The most important electrical properties of wood are (1) conductivity, (2) dielectric constant, and (3) dielectric power factor.

The conductivity of a material determines the current that will flow when the material is placed under a given voltage gradient. The dielectric constant of a nonconducting material determines the amount of electric potential energy, in the form of induced polarization, that is stored in a given volume of the material when that material is placed in an electric field. The power factor of a nonconducting material determines the fraction of stored energy that is dissipated as heat when the material experiences a complete polarize-depolarize cycle.

Examples of industrial wood processes and applications in which electrical properties of wood are important include crossarms and poles for high-voltage powerlines, linemen's tools, and the heat-curing of adhesives in wood products by high-frequency electric fields. Moisture meters for wood utilize the relation between electrical properties and moisture content to estimate the moisture content.

Electrical Conductivity

The electrical conductivity of wood varies slightly with applied voltage and approximately doubles for each temperature increase of 10° C. The electrical conductivity of wood or its reciprocal, resistivity, varies greatly with moisture content, especially below the fiber saturation point. As the moisture content of wood increases from near zero to fiber saturation, the electrical conductivity increases (resistivity decreases) by 10^{10} to 10^{13} times. The resistivity is about 10^{14} to 10^{16} ohm-meters for ovendry wood and 10^{3} to 10^{4} ohm-meters for wood at fiber saturation. As the moisture content increases from fiber saturation to complete saturation of the wood structure, the further increase in conductivity is smaller and erratic, generally amounting to less than a hundredfold.

Figure 3–6 illustrates the change in resistance along the grain with moisture content, based on tests of many domestic species. Variability between test specimens is illustrated by the shaded area. Ninety percent of the experimental data points fall within this area.

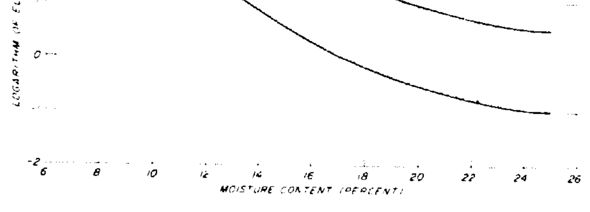

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Figure 3–6.—Change in electrical resistance of wood with varying moisture content levels for many United States species. Ninety percent of test values are represented by the shaded area.

The resistance values were obtained using a standard moisture meter electrode at 80° F. Conductivity is greater along the grain than across the grain and slightly greater in the radial direction than in the tangential direction. Relative conductivities in the longitudinal, radial, and tangential directions are in the approximate ratio of 1.0:0.55:0.50.

When wood contains abnormal quantities of water-soluble salts or other electrolytic substances, such as from preservative or fire-retardant treatment or prolonged contact with seawater, the electrical conductivity may be substantially increased. The increase is small when the moisture content of the wood is less than about 8 percent but becomes large rapidly as the moisture content exceeds 10 or 12 percent.

Dielectric Constant

The dielectric constant is the ratio of the dielectric permittivity of the material to that of free space; it is essentially a measure of the potential energy per unit volume stored in the material in the form of electric polarization when the material is in a given electric field. As measured by practical tests, the dielectric constant of a material is the ratio of the capacitance of a capacitor using the material as the dielectric, to the capacitance of the same capacitor using free space as the dielectric.

The dielectric constant of ovendry wood ranges from about 2 to 5 at room temperature, and decreases slowly but steadily with increasing frequency of the applied electric field. It increases as either temperature or moisture content increase, with a moderate positive interaction between temperature and moisture. There is an intense negative interaction between moisture and frequency: At 20 Hz the dielectric constant may range from 4 for dry wood to near 1,000,000 for wet wood; at 1 KHz, from 4 when dry to 5,000 wet; and at 1 MHz from 3 when dry to wet. The dielectric constant is larger for polarization parallel to the grain than for across the grain.

Dielectric Power Factor

When a nonconductor is placed in an electric field, it absorbs and stores potential energy. The amount of energy stored per unit volume depends upon the dielectric constant and the magnitude of the applied field. An ideal dielectric releases all of this energy to the external electric circuit when the field is removed, but practical dielectrics dissipate some of the energy as heat. The power factor is a measure of that portion of the stored energy converted to heat. Power factor values always fall between zero and unity. When the power factor does not exceed about 0.1, the fraction of the stored energy that is lost in one charge-discharge cycle is approximately equal to 2π times the power factor of the dielectric; for larger power factors, this fraction is approximated simply by the power factor itself.

The power factor of wood is large compared to inert plastic insulating materials; some materials, for example some formulations of rubber, have equally large power factors. The power factor of wood varies from about 0.01 for dry low-density woods to as large as 0.95 for dense woods at high moisture levels. It is usually, but not always, greater along the grain than across the grain.

The power factor of wood is affected by several factors, including frequency, moisture content, and temperature. These factors interact in complex ways to cause the power factor to have maximum and minimum values at various combinations of these factors.

COEFFICIENT OF FRICTION

The coefficient of friction depends on the moisture content of the wood and surface roughness. It varies little with species except for those species that contain abundant oily or waxy extractives, such as lignum vitae.

Coefficients of static friction for wood on unpolished steel have been reported to be approximately 0.70 for dry wood and 0.40 for green wood. Corresponding values for lignum vitae on unpolished steel are 0.20 and 0.34. Coefficients of static friction for smooth wood on smooth wood are 0.60 for dry wood and 0.83 for green wood.

Coefficients of sliding friction differ from those for static friction, and depend on the rate of relative movement between the rubbing parts. Coefficients for wood on steel of 0.70 for dry wood and 0.15 for green wood have been obtained at a relative movement of 4 meters per second.

NUCLEAR RADIATION

Radiation passing through matter is reduced in intensity according to the relationship

$$I = I_0 \epsilon^{\mu x}$$

where I is the reduced intensity of the beam at a depth of x in the material, I_0 is the incident intensity of a beam of radiation, and μ, the linear absorption coefficient of the material, is the fraction of energy removed from the beam per unit depth traversed. Where the density is a factor of interest in energy absorption, the linear absorption coefficient is divided by the density of the material to derive the mass absorption coefficient. The absorption coefficient of a material varies with type and energy of radiation.

The linear absorption coefficient for gamma (γ) radiation of wood is known to vary directly with moisture content and density; inversely with the γ ray energy. As an example, the radiation of ovendry yellow-poplar with 0.047 MEV γ rays yielded linear absorption coefficients ranging from about 0.065 to about 0.11 per centimeter over the ovendry specific gravity range of about 0.33 to 0.62. An increase in the linear absorption coefficient of about 0.01 per centimeter occurs with an increase in moisture content from ovendry to fiber saturation. Absorption of γ rays in wood is of practical interest, in part, for measurement of the density of wood.

The interaction of wood with beta (β) radiation is similar in character to that with γ radiation, except that the absorption coefficients are larger. The linear absorption coefficient of wood with a specific gravity of 0.5 for a 0.5 MEV β ray is about 3.0 per centimeter. The result of the larger coefficient is that even very thin wood products are virtually opaque to β rays.

The interaction of neutrons with wood is of interest because wood and the water it contains are compounds of hydrogen, and hydrogen has a relatively large probability of interaction with neutrons. High energy level neutrons lose energy much more quickly through interaction with hydrogen than with other elements found in wood. The lower energy neutrons that result from this interaction thus are a measure of the hydrogen density of the specimen. Measurement of the lower energy level neutrons can be related to the moisture content of the wood.

When neutrons interact with wood, an additional result is the production of radioactive isotopes of the elements present in the wood. The radioisotopes produced can be identified by the type, energy, and half-life of their emissions, and the specific activity of each indicates amount of isotope present. This procedure, called neutron activation analysis, provides a sensitive, nondestructive method of analysis for trace elements.

In the discussions above, moderate radiation levels that leave the wood physically unchanged have been assumed. Very large doses of γ rays or neutrons can cause substantial degradation of wood. The effect of large radiation doses on the mechanical properties of wood is discussed in chapter 4.

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Table A-3-7—*Density of wood as a function of specific gravity and moisture content*

Moisture content of wood (percent)	Density in kilograms per cubic meter when the specific gravity[1] is—																				
	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70
0	300	320	340	360	380	400	420	440	460	481	500	519	540	559	580	599	620	639	660	679	700
4	312	333	354	375	396	416	436	458	477	500	519	540	561	581	602	623	644	665	686	706	727
8	324	346	367	389	410	432	453	474	497	517	540	561	583	604	626	647	670	690	713	734	756
12	336	359	381	404	426	449	471	493	516	537	559	581	604	626	649	671	694	716	738	761	783
16	348	372	394	416	440	465	487	509	533	556	580	602	626	649	673	695	719	742	766	788	812
20	360	384	408	432	455	481	503	527	551	575	599	623	647	671	695	719	743	767	791	815	839
24	372	397	421	445	471	497	521	545	570	594	620	644	670	694	719	743	769	793	819	843	868
28	384	410	436	461	487	511	537	562	588	614	639	665	690	716	742	767	793	819	844	870	895
32	396	423	449	476	501	527	554	580	607	633	660	686	713	738	766	791	819	844	871	897	924
36	408	436	463	490	516	543	570	597	625	652	679	706	734	761	788	815	843	870	897	924	951
40	420	449	476	503	532	559	588	615	644	671	700	727	756	783	812	839	868	895	924	951	980
44	432	461	490	517	546	575	604	633	662	690	719	748	777	806	835	863	892	921	950	979	1,010
48	444	474	503	532	562	591	622	650	681	710	740	769	799	828	859	887	918	947	977	1,010	1,030
52	457	487	516	546	577	607	638	668	698	729	759	790	820	851	881	911	942	972	1,000	1,030	1,060
56	468	500	530	561	593	623	655	686	718	748	780	811	843	873	905	935	968	998	1,030	1,060	1,090
60	481	511	543	575	607	639	671	703	735	767	799	831	863	895	927	960	992	1,020	1,060	1,090	1,120
64	492	524	557	589	623	655	689	721	754	786	820	852	886	918	951	984	1,020	1,050	1,080	1,110	1,150
68	503	537	570	604	638	671	705	738	772	806	839	873	907	940	974	1,010	1,040	1,070	1,110	1,140	1,180
72	516	549	585	618	654	687	722	756	791	825	860	894	929	963	998	1,030	1,070	1,100	1,130	1,170	1,200
76	527	562	597	633	668	703	738	774	809	844	879	915	950	985	1,020	1,060	1,090	1,130	1,160	1,200	1,230
80	540	575	612	647	684	719	756	791	828	863	900	935	972	1,010	1,040	1,080	1,110	1,150	1,190	1,220	1,260
84	551	588	625	662	698	735	772	809	846	883	919	956	993	1,030	1,070	1,100	1,140	1,180	1,210	1,250	1,290
88	564	601	639	676	714	751	790	827	865	902	940	977	1,010	1,050	1,090	1,130	1,160	1,200	1,240	1,280	1,320
92	575	614	652	690	729	767	806	844	883	921	960	998	1,040	1,070	1,110	1,150	1,190	1,230	1,270	1,310	1,340
96	588	626	666	705	745	783	823	862	902	940	980	1,020	1,060	1,100	1,140	1,180	1,210	1,250	1,290	1,330	1,370
100	599	639	679	719	759	799	839	879	919	960	1,000	1,040	1,080	1,120	1,160	1,200	1,240	1,280	1,320	1,360	1,400
110	630	671	714	756	798	839	881	924	966	1,010	1,050	1,090	1,130	1,180	1,220	1,260	1,300	1,340	1,390	1,430	1,470
120	660	703	748	791	836	879	924	968	1,010	1,060	1,100	1,140	1,190	1,230	1,280	1,320	1,360	1,410	1,450	1,500	1,540
130	690	735	782	828	873	919	966	1,010	1,060	1,100	1,150	1,190	1,240	1,290	1,330	1,380	1,420	1,470	1,520	1,560	1,610
140	719	767	815	863	911	960	1,010	1,060	1,100	1,150	1,200	1,250	1,300	1,340	1,390	1,440	1,490	1,530	1,580	1,631	1,679
150	750	799	849	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,599	1,650	1,700	1,749

[1] Based on mass when ovendry and volume at tabulated moisture content.

Chapter 4

MECHANICAL PROPERTIES OF WOOD

MECHANICAL PROPERTIES OF WOOD

Mechanical properties discussed in this chapter have been obtained from tests of small pieces of wood termed "clear" and "straight grained" because they did not contain characteristics such as knots, cross grain, checks, and splits. These test pieces do contain wood structure characteristics such as growth rings that occur in consistent patterns within the piece. Clear wood specimens are usually considered "homogeneous" in wood mechanics.

Many of the mechanical properties of wood tabulated in this chapter were derived from extensive sampling and analysis procedures. These properties often are represented as the average mechanical properties of the species and are used to derive allowable properties for design. A number of other properties, particularly those less common and those for imported species, often are based on a more limited number of specimens not subject to the same sampling and analysis procedures. The appropriateness of these latter properties to represent the average properties of a species often is uncertain; nevertheless, they illustrate important wood behavior and provide guidance for wood design.

Variability, or variation in properties, is common to all materials. Since wood is a natural material and the tree is subject to numerous constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably even in clear material. This chapter provides information where possible on the nature and magnitude of property variability.

ORTHOTROPIC NATURE OF WOOD

Wood may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes—longitudinal, radial, and tangential. The longitudinal axis (L) is parallel to the fiber (grain); the radial axis (R) is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis (T) is perpendicular to the grain but tangent to the growth rings. These axes are shown in figure 4–1.

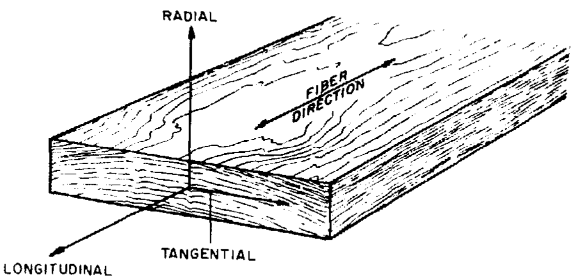

Figure 4–1.—The three principal axes of wood with respect to grain direction and growth rings.

ELASTIC PROPERTIES OF CLEAR WOOD

Twelve constants (nine are independent) are needed to describe the elastic behavior of wood: Three moduli of elasticity, E, three moduli of rigidity, G, and six Poisson's ratios, μ. The moduli of elasticity and Poisson's ratios are related by expressions of the form

$$\frac{\mu_{ij}}{E_i} = \frac{\mu_{ji}}{E_j}, i \neq j; i,j = L, R, T$$

General relations between stress and strain for a homogeneous, orthotropic material can be found in texts on anisotropic elasticity.

Modulus of Elasticity

The three moduli of elasticity denoted by E_L, E_R, and E_T are, respectively, the elastic moduli along longitudinal, radial, and tangential axes of wood. These moduli are usually obtained from compression tests; however, data for E_R and E_T are not extensive. Values of E_R and E_T for samples from a few species are presented in table 4–1 as ratios with E_L. These ratios, as well as the three elastic constants themselves, vary within and between species and with moisture content and specific gravity.

Often E_L determined from bending, rather than from an axial test, is the only E available. Average values of E_L obtained from bending tests are given in tables 4–2, 4–3, and 4–4. A representative coefficient of variation of E_L determined with bending tests for clear wood is reported in table 4–5. E_L as tabulated includes an effect of shear deflection. E_L from bending can be increased by 10 percent to approximately remove this effect. This adjusted bending E_L can be used to obtain E_R and E_T from table 4–1.

Modulus of Rigidity

The three moduli of rigidity denoted by G_{LR}, G_{LT}, G_{RT} are the elastic constants in the *LR*, *LT*, and *RT* planes, respectively. For example, G_{LR} is the modulus of rigidity based on shear strain in the *LR* plane and shear stresses in the *LT* and *RT* planes. Values of shear moduli for samples of a few species expressed as ratios with E_L are given in table 4–1. As with moduli of elasticity, the moduli of rigidity vary within and between species and with moisture content and specific gravity.

Poisson's Ratio

The six Poisson's ratios are denoted by μ_{LR}, μ_{RL}, μ_{LT}, μ_{TL}, μ_{RT}, $\mu_{\ R}$. The first letter of the subscript refers to direction of applied stress and the second letter refers to direction of lateral deformation. For example, μ_{LR} is the Poisson's ratio for deformation along the radial axis caused by stress along the longitudinal axis. Values of Poisson's ratios for samples of a few species are given in table 4–1. Poisson's ratios vary within and between species and are affected slightly by moisture content.

STRENGTH PROPERTIES OF CLEAR STRAIGHT-GRAINED WOOD

Common Properties

Strength values most commonly measured and represented as "strength properties" for design include the modulus of rupture in bending, the maximum stress in compression parallel to the grain, compression strength perpendicular to the grain, and shear strength parallel to the grain. Additional measurements often made include work to maximum load in bending, impact bending strength, tensile strength perpendicular to the grain, and hardness. These properties, grouped according to the broad forest tree categories of hardwood and softwood (not correlated with hardness or softness), are given in tables 4–2, 4–3, and 4–4 for many of the commercially important species. Coefficients of variation for these properties from a limited sampling of specimens are reported in table 4–5.

The modulus of rupture in bending reflects the maximum load-carrying capacity of the member and is proportional to the maximum moment borne by the specimen. The work to maximum load is a measure of the energy absorbed by the specimen as it is slowly loaded to failure. On the other hand, the impact bending height of drop is related to the energy absorption due to a rapid or falling load. Hardness is the load required to embed a 0.444-inch ball to one-half its diameter in a direction perpendicular to the grain.

Less Common Properties

Strength properties less commonly measured in clear wood include tensile strength parallel to the grain, torsion, toughness, creep, rolling shear, and fatigue resistance.

Tensile Strength Parallel to Grain

Relatively few data are available on the tensile strength of various species parallel to grain. In the absence of sufficient tension test data, the modulus of rupture values are sometimes substituted for tensile strength of small, clear, straight-grained pieces of wood. The modulus of rupture is considered to be a low or conservative estimate of tensile strength for these specimens. Chapter 6 should be consulted for discussion of the tensile properties of commercial structural members. Table 4–6 lists average tensile strength values for a limited number of specimens of a few species.

Torsion

For solid wood members, the torsional shear strength often is taken as the shear strength parallel to the grain. Two-thirds of this value often is used as the torsional shear stress at the proportional limit.

Toughness

Toughness represents the energy required to rapidly cause complete failure in a centrally loaded bending specimen. Table 4–7 gives average toughness values for samples of a few hardwood and softwood species. Table 4–5 records the average coefficient of variation for toughness as determined from approximately 50 species.

Fatigue Strength

The resistance of wood to fatigue is sometimes an important consideration in design. Tests indicate that wood, like many fibrous materials, is less sensitive to repeated loads than are more crystalline structural materials, such as metals. In proportion to ultimate strength values, the fatigue strength of wood is higher than for some of the metals. A brief résumé of the results of several fatigue studies is given in table 4–8. Interpretation of fatigue data, and a discussion of fatigue as a function of the service environment, are included later in this chapter.

Rolling Shear Strength

The term "rolling shear" describes the shear strength of wood where the shearing force is in a longitudinal-transverse plane and perpendicular to the grain. Test procedures for rolling shear in solid wood are of recent origin; few test values have been reported. In limited tests, rolling shear strengths were 10 to 20 percent of the parallel-to-grain shear values. Rolling shear values were about the same in the longitudinal-radial and the longitudinal-tangential planes.

VIBRATION PROPERTIES

The vibration properties of primary interest in structural materials are the speed of sound and the damping capacity or internal friction.

Speed of Sound

The speed of sound in a structural material varies directly with the square root of the modulus of elasticity and inversely with the square root of the density. For example, a parallel-to-grain value for speed of sound of 150,000 inches per second corresponds to a modulus of elasticity of about 1,800,000 p.s.i., and a density of 30 pounds per cubic foot. The speed of sound in wood varies strongly with grain angle since the transverse modulus of elasticity may be as small as 1/20 of the longitudinal value. Thus, the speed of sound across the grain is about one-fifth to one-third of the longitudinal value.

The speed of sound decreases with increasing temperature or moisture content in proportion to the influence of these variables on the modulus of elasticity and density. The speed of sound decreases slightly with increasing frequency and amplitude of vibration, although for most common applications this effect is too small to be significant. There is no recognized independent effect of species on the speed of sound. Variability in the speed of sound in wood is directly related to the variability of modulus of elasticity and density.

Internal Friction

When solid material is strained, some mechanical energy is dissipated as heat. Internal friction is the term used to denote the mechanism that causes this energy dissipation. The internal friction mechanism in wood is a complex function of temperature and moisture content. At normal ambient temperatures the internal friction generally increases as the moisture content increases, up to the fiber saturation point. At room temperature internal friction is a minimum at about 6 to 8 percent moisture content. Below room temperature the minimum occurs at a higher moisture content; above room temperature it occurs at a lower moisture content. The parallel-to-grain internal friction of wood under normal use conditions of moisture content and temperature is approximately 10 times that of structural metals, explaining in part why wood structures damp vibration more quickly than metal structures of similar design.

SUMMARY TABLES ON MECHANICAL PROPERTIES OF CLEAR STRAIGHT-GRAINED WOOD

The mechanical properties listed in tables 4–1 through 4–7 are based on a variety of sampling methods. Generally, the greatest amount of sampling is represented in tables 4–2, 4–3, and 4–4. The values in table 4–2 are averages derived for a number of species grown in the United States. The table value is intended to estimate the average clear wood property of the species. Many of the values were obtained from test specimens taken at heights between 8 and 16 feet above the stump of the tree. Values reported in table 4–3 represent average clear wood properties of species grown in Canada and commonly imported into the United States.

Methods of data collection and analysis have changed over the years that the data in tables 4–2 and 4–3 have been collected. In addition, the character of some forests changes with time. Thus, when these data are used as a basis for critical applications such as stress grades of lumber, the current appropriateness of the data should be reviewed.

Values reported in table 4–4 were collected from the world literature; thus, the appropriateness of these properties to represent a species is not known. The properties reported in tables 4–1, 4–6, 4–7, and 4–8 are not intended to represent species characteristics in the broad sense; they suggest the relative influence of species and other specimen parameters on the mechanical behavior recorded.

Variability in properties can be important in both production and consumption of wood products. Often the fact that a piece may be stronger, harder, or stiffer than the average is of less concern to the user than if it is weaker; however, this may not be true if lightweight material is selected for a specific purpose or if harder or tougher material is hard to work. It is desirable, therefore, that some indication of the spread of property values be given. Average coefficients of variation for many mechanical properties are presented in table 4–5.

The mechanical properties reported in the tables are significantly affected by the moisture content of the specimens at the time of test. Some tables include properties evaluated at differing moisture levels; these moisture levels are reported. As indicated in the tables, many of the dry test data have been adjusted to a common moisture content base of 12 percent. The differences in properties displayed in the tables as a result of differing moisture levels are not necessarily consistent for larger wood pieces such as lumber. Guidelines for adjusting clear wood properties to arrive at allowable properties for lumber are discussed in chapter 6, "Lumber Stress Grades and Allowable Properties."

Specific gravity is reported in many of the tables because it often is used as an index of clear wood properties. The specific gravity values given in tables 4–2 and 4–3 represent the estimated average clear wood specific gravity of the species. In the other tables, the specific gravity represents only the specimens tested. The variability of specific gravity, represented by the coefficient of variation derived from tests on 50 species, is included in table 4–5.

Mechanical and physical properties as measured and reported often reflect not only the characteristics of the wood but also the influence of the shape and size of test specimen and the mode of test. The methods of test used to establish properties in tables 4–2, 4–3, 4–6, and 4–7 are based on standard procedures, ASTM Designation D 143. The methods of test for properties presented in other tables are reported in the bibliography at the end of this chapter.

Names of species listed in the tables conform to standard nomenclature of the U.S. Forest Service. Other common names may be used locally, and frequently one common name is applied to several species.

Tables 4–2, 4–3, and 4–4 are repeated in metric (SI) units in appendix 4–1 at the end of this chapter.

Table 4-1.—*Elastic constants of various species*

Species	Approximate specific gravity [1]	Approximate moisture content (pct.)	Modulus of elasticity ratios		Ratio of modulus of rigidity to modulus of elasticity			Poisson's ratios					
			E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L	μ_{LR}	μ_{LT}	μ_{RT}	μ_{TR}	μ_{RL}	μ_{TL}
Balsa	0.13	9	0.015	0.046	0.054	0.037	0.005	0.229	0.488	0.665	0.217	0.011	0.007
Birch, yellow	.64	13	.050	.078	.074	.068	.017	.426	.451	.697	.447	.033	.023
Douglas-fir	.50	12	.050	.068	.064	.078	.007	.292	.449	.390	.287	.020	.022
Spruce, Sitka	.38	12	.043	.078	.064	.061	.003	.372	.467	.435	.240	.029	.020
Sweetgum	.53	11	.050	.115	.089	.061	.021	.325	.403	.682	.297	.037	.020
Walnut, black	.59	11	.056	.106	.085	.062	.021	.495	.632	.718	.379	.052	.035
Yellow-poplar	.38	11	.043	.092	.075	.069	.011	.318	.392	.703	.329	.029	.017

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[1] Based on ovendry weight and volume at the moisture content shown.

Table 4–2.—*Mechanical properties*[1] *of some commercially important woods grown in the United States*

Common names of species	Specific gravity	Static bending			Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Modulus of rupture	Modulus of elasticity[2]	Work to maximum load						
		P.s.i.	*Million p.s.i.*	*In.-lb. per cu. in.*	*In.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*Lb.*
				HARDWOODS						
Alder, red	0.37	6,500	1.17	8.0	22	2,960	250	770	390	440
	.41	9,800	1.38	8.4	20	5,820	440	1,080	420	590
Ash:										
Black	.45	6,000	1.04	12.1	33	2,300	350	860	490	520
	.49	12,600	1.60	14.9	35	5,970	760	1,570	700	850
Blue	.53	9,600	1.24	14.7	...	4,180	810	1,540	...	...
	.58	13,800	1.40	14.4	...	6,980	1,420	2,030	...	...
Green	.53	9,500	1.40	11.8	35	4,200	730	1,260	590	870
	.56	14,100	1.66	13.4	32	7,080	1,310	1,910	700	1,200
Oregon	.50	7,600	1.13	12.2	39	3,510	530	1,190	590	790
	.55	12,700	1.36	14.4	33	6,040	1,250	1,790	720	1,160
White	.55	9,600	1.44	16.6	38	3,990	670	1,380	590	960
	.60	15,400	1.74	17.6	43	7,410	1,160	1,950	940	1,320
Aspen:										
Bigtooth	.36	5,400	1.12	5.7	...	2,500	210	730	...	...
	.39	9,100	1.43	7.7	...	5,300	450	1,080	...	...
Quaking	.35	5,100	.86	6.4	22	2,140	180	660	230	300
	.38	8,400	1.18	7.6	21	4,250	370	850	260	350
Basswood, American	.32	5,000	1.04	5.3	16	2,220	170	600	280	250
	.37	8,700	1.46	7.2	16	4,730	370	990	350	410
Beech, American	.56	8,600	1.38	11.9	43	3,550	540	1,290	720	850
	.64	14,900	1.72	15.1	41	7,300	1,010	2,010	1,010	1,300
Birch:										
Paper	.48	6,400	1.17	16.2	49	2,360	270	840	380	560
	.55	12,300	1.59	16.0	34	5,690	600	1,210	...	910
Sweet	.60	9,400	1.65	15.7	48	3,740	470	1,240	430	970
	.65	16,900	2.17	18.0	47	8,540	1,080	2,240	950	1,470
Yellow	.55	8,300	1.50	16.1	48	3,380	430	1,110	430	780
	.62	16,600	2.01	20.8	55	8,170	970	1,880	920	1,260

Table 4–2.—*Mechanical properties*[1] *of some commercially important woods grown in the United States*—continued

Common names of species	Specific gravity	Static bending: Modulus of rupture	Static bending: Modulus of elasticity[2]	Static bending: Work to maximum load	Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		P.s.i.	*Million p.s.i.*	*In.-lb. per cu. in.*	*In.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*Lb.*
HARDWOODS—continued										
Butternut	.36	5,400	0.97	8.2	24	2,420	220	760	430	390
	.38	8,100	1.18	8.2	24	5,110	460	1,170	440	490
Cherry, black	.47	8,000	1.31	12.8	33	3,540	360	1,130	570	660
	.50	12,300	1.49	11.4	29	7,110	690	1,700	560	950
Chestnut, American	.40	5,600	.93	7.0	24	2,470	310	800	440	420
	.43	8,600	1.23	6.5	19	5,320	620	1,080	460	540
Cottonwood:										
Balsam poplar	.31	3,900	.75	4.2	...	1,690	140	500	....	....
	.34	6,800	1.10	5.0	...	4,020	300	790	....	....
Black	.31	4,900	1.08	5.0	20	2,200	160	610	270	250
	.35	8,500	1.27	6.7	22	4,500	300	1,040	330	350
Eastern	.37	5,300	1.01	7.3	21	2,280	200	680	410	340
	.40	8,500	1.37	7.4	20	4,910	380	930	580	430
Elm:										
American	.46	7,200	1.11	11.8	38	2,910	360	1,000	590	620
	.50	11,800	1.34	13.0	39	5,520	690	1,510	660	830
Rock	.57	9,500	1.19	19.8	54	3,780	610	1,270	....	940
	.63	14,800	1.54	19.2	56	7,050	1,230	1,920	....	1,320
Slippery	.48	8,000	1.23	15.4	47	3,320	420	1,110	640	660
	.53	13,000	1.49	16.9	45	6,360	820	1,630	530	860
Hackberry	.49	6,500	.95	14.5	48	2,650	400	1,070	630	700
	.53	11,000	1.19	12.8	43	5,440	890	1,590	580	880
Hickory, pecan:										
Bitternut	.60	10,300	1.40	20.0	66	4,570	800	1,240	....	....
	.66	17,100	1.79	18.2	66	9,040	1,680	....	....	....
Nutmeg	.56	9,100	1.29	22.8	54	3,980	760	1,030	....	....
	.60	16,600	1.70	25.1	...	6,910	1,570	....	....	....

Pecan	.60	9,800	1.37	14.6	53	3,990	780	1,480	680	1,310
	.66	13,700	1.73	13.8	44	7,850	1,720	2,080	....	1,820
Water	.61	10,700	1.56	18.8	56	4,660	880	1,440	....	....
	.62	17,800	2.02	19.3	53	8,600	1,550	....	....	....
Hickory, true:										
Mockernut	.64	11,100	1.57	26.1	88	4,480	810	1,280	....	....
	.72	19,200	2.22	22.6	77	8,940	1,730	1,740	....	....
Pignut	.66	11,700	1.65	31.7	89	4,810	920	1,370	....	....
	.75	20,100	2.26	30.4	74	9,190	1,980	2,150	....	....
Shagbark	.64	11,000	1.57	23.7	74	4,580	840	1,520	....	....
	.72	20,200	2.16	25.8	67	9,210	1,760	2,430	....	....
Shellbark	.62	10,500	1.34	29.9	104	3,920	810	1,190	....	....
	.69	18,100	1.89	23.6	88	8,000	1,800	2,110	....	....
Honeylocust	.60	10,200	1.29	12.6	47	4,420	1,150	1,660	930	1,390
		14,700	1.63	13.3	47	7,500	1,840	2,250	900	1,580
Locust, black	.66	13,800	1.85	15.4	44	6,800	1,160	1,760	770	1,570
	.69	19,400	2.05	18.4	57	10,180	1,830	2,480	640	1,700
Magnolia:										
Cucumbertree	.44	7,400	1.56	10.0	30	3,140	330	990	440	520
	.48	12,300	1.82	12.2	35	6,310	570	1,340	660	700
Southern	.46	6,800	1.11	15.4	54	2,700	460	1,040	610	740
	.50	11,200	1.40	12.8	29	5,460	860	1,530	740	1,020
Maple:										
Bigleaf	.44	7,400	1.10	8.7	23	3,240	450	1,110	600	620
	.48	10,700	1.45	7.8	28	5,950	750	1,730	540	850
Black	.52	7,900	1.33	12.8	48	3,270	600	1,130	720	840
	.57	13,300	1.62	12.5	40	6,680	1,020	1,820	670	1,180
Red	.49	7,700	1.39	11.4	32	3,280	400	1,150	....	700
	.54	13,400	1.64	12.5	32	6,540	1,000	1,850	....	950
Silver	.44	5,800	.94	11.0	29	2,490	370	1,050	560	590
	.47	8,900	1.14	8.3	25	5,220	740	1,480	500	700
Sugar	.56	9,400	1.55	13.3	40	4,020	640	1,460	....	970
	.63	15,800	1.83	16.5	39	7,830	1,470	2,330	....	1,450
Oak, red:										
Black	.56	8,200	1.18	12.2	40	3,470	710	1,220	....	1,060
	.61	13,900	1.64	13.7	41	6,520	930	1,910	....	1,210
Cherrybark	.61	10,800	1.79	14.7	54	4,620	760	1,320	800	1,240
	.68	18,100	2.28	18.3	49	8,740	1,250	2,000	840	1,480

Table 4-2.—*Mechanical properties*[1] *of some commercially important woods grown in the United States*—continued

Common names of species	Specific gravity	Static bending			Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Modulus of rupture	Modulus of elasticity[2]	Work to maximum load						
		P.s.i.	*Million p.s.i.*	*In.-lb. per cu. in.*	*In.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*Lb.*
				HARDWOODS—continued						
Oak, red (Cont.)										
Laurel	.56	7,900	1.39	11.2	39	3,170	570	1,180	770	1,000
	.63	12,600	1.69	11.8	39	6,980	1,060	1,830	790	1,210
Northern red	.56	8,300	1.35	13.2	44	3,440	610	1,210	750	1,000
	.63	14,300	1.82	14.5	43	6,760	1,010	1,780	800	1,290
Pin	.58	8,300	1.32	14.0	48	3,680	720	1,290	800	1,070
	.63	14,000	1.73	14.8	45	6,820	1,020	2,080	1,050	1,510
Scarlet	.60	10,400	1.48	15.0	54	4,090	830	1,410	700	1,200
	.67	17,400	1.91	20.5	53	8,330	1,120	1,890	870	1,400
Southern red	.52	6,900	1.14	8.0	29	3,030	550	930	480	860
	.59	10,900	1.49	9.4	26	6,090	870	1,390	510	1,060
Water	.56	8,900	1.55	11.1	39	3,740	620	1,240	820	1,010
	.63	15,400	2.02	21.5	44	6,770	1,020	2,020	920	1,190
Willow	.56	7,400	1.29	8.8	35	3,000	610	1,180	760	980
	.69	14,500	1.90	14.6	42	7,040	1,130	1,650	. .	1,460
Oak, white:										
Bur	.58	7,200	.88	10.7	44	3,290	680	1,350	800	1,110
	.64	10,300	1.03	9.8	29	6,060	1,200	1,820	680	1,370
Chestnut	.57	8,000	1.37	9.4	35	3,520	530	1,210	690	890
	.66	13,300	1.59	11.0	40	6,830	840	1,490	. . .	1,130
Live	.80	11,900	1.58	12.3		5,430	2,040	2,210		. . . .
	.88	18,400	1.98	18.9	. .	8,900	2,840	2,660		. . . .
Overcup	.57	8,000	1.15	12.6	44	3,370	540	1,320	730	960
	.63	12,600	1.42	15.7	38	6,200	810	2,000	940	1,190
Post	.60	8,100	1.09	11.0	44	3,480	860	1,280	790	1,130
	.67	13,200	1.51	13.2	46	6,600	1,430	1,840	780	1,360
Swamp chestnut	.60	8,500	1.35	12.8	45	3,540	570	1,260	670	1,110
	.67	13,900	1.77	12.0	41	7,270	1,110	1,990	690	1,240

Swampy white	.64	9,900	1.59	14.5	50	4,360	760	1,300	860	1,160
	.72	17,700	2.05	19.2	49	8,600	1,190	2,000	830	1,620
White	.60	8,300	1.25	11.6	42	3,560	670	1,250	770	1,060
	.68	15,200	1.78	14.8	37	7,440	1,070	2,000	800	1,360
Sassafras	0.42	6,000	0.91	7.1	...	2,730	370	950	...	...
	.46	9,000	1.12	8.7	...	4,760	850	1,240	...	...
Sweetgum	.46	7,100	1.20	10.1	36	3,040	370	990	540	600
	.52	12,500	1.64	11.9	32	6,320	620	1,600	760	850
Sycamore, American	.46	6,500	1.06	7.5	26	2,920	360	1,000	630	610
	.49	10,000	1.42	8.5	26	5,380	700	1,470	720	770
Tanoak	.58	10,500	1.55	13.4	...	4,650	...	...	...	...
	...	...	...	...	...	...	...	...	...	...
Tupelo:										
Black	.46	7,000	1.03	8.0	30	3,040	480	1,100	570	640
	.50	9,600	1.20	6.2	22	5,520	930	1,340	500	810
Water	.46	7,300	1.05	8.3	30	3,370	480	1,190	600	710
	.50	9,600	1.26	6.9	23	5,920	870	1,590	700	880
Walnut, black	.51	9,500	1.42	14.6	37	4,300	490	1,220	570	900
	.55	14,600	1.68	10.7	34	7,580	1,010	1,370	690	1,010
Willow, black	.36	4,800	.79	11.0	...	2,040	180	680	...	...
	.39	7,800	1.01	8.8	...	4,100	430	1,250	...	...
Yellow-poplar	.40	6,000	1.22	7.5	26	2,660	270	790	510	440
	.42	10,100	1.58	8.8	24	5,540	500	1,190	540	540
SOFTWOODS										
Baldcypress	.42	6,600	1.18	6.6	25	3,580	400	810	300	390
	.46	10,600	1.44	8.2	24	6,360	730	1,000	270	510
Cedar:										
Alaska-	.42	6,400	1.14	9.2	27	3,050	350	840	330	440
	.44	11,100	1.42	10.4	29	6,310	620	1,130	360	580
Atlantic white-	.31	4,700	.75	5.9	18	2,390	240	690	180	290
	.32	6,800	.93	4.1	13	4,700	410	800	220	350
Eastern redcedar	.44	7,000	.65	15.0	35	3,570	700	1,010	330	650
	.47	8,800	.88	8.3	22	6,020	920	...	...	900
Incense-	.35	6,200	.84	6.4	17	3,150	370	830	280	390
	.37	8,000	1.04	5.4	17	5,200	590	880	270	470
Northern white-	.29	4,200	.64	5.7	15	1,990	230	620	240	230
	.31	6,500	.80	4.8	12	3,960	310	850	240	320

Table 4-2.—*Mechanical properties*[1] *of some commercially important woods grown in the United States*—continued

Common names of species	Specific gravity	Static bending			Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Modulus of rupture	Modulus of elasticity[2]	Work to maximum load						
		P.s.i.	*Million p.s.i.*	*In.-lb. per cu. in.*	*In.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*Lb.*
SOFTWOODS—continued										
Cedar (Cont.)										
Port-Orford-	.39	6,600	1.30	7.4	21	3,140	300	840	180	380
	.43	12,700	1.70	9.1	28	6,250	720	1,370	400	630
Western redcedar	.31	5,200	.94	5.0	17	2,770	240	770	230	260
	.32	7,500	1.11	5.8	17	4,560	460	990	220	350
Douglas-fir[3]:										
Coast	.45	7,700	1.56	7.6	26	3,780	380	900	300	500
	.48	12,400	1.95	9.9	31	7,240	800	1,130	340	710
Interior West	.46	7,700	1.51	7.2	26	3,870	420	940	290	510
	.50	12,600	1.82	10.6	32	7,440	760	1,290	350	660
Interior North	.45	7,400	1.41	8.1	22	3,470	360	950	340	420
	.48	13,100	1.79	10.5	26	6,900	770	1,400	390	600
Interior South	.43	6,800	1.16	8.0	15	3,110	340	950	250	360
	.46	11,900	1.49	9.0	20	6,220	740	1,510	330	510
Fir:										
Balsam	.34	4,900	.96	4.7	16	2,400	170	610	180	290
	.36	7,600	1.23	5.1	20	4,530	300	710	180	400
California red	.36	5,800	1.17	6.4	21	2,760	330	770	380	360
	.38	10,400	1.49	8.9	24	5,470	610	1,050	390	500
Grand	.35	5,800	1.25	5.6	22	2,940	270	740	240	360
	.37	8,800	1.57	7.5	28	5,290	500	910	240	490
Noble	.37	6,200	1.38	6.0	19	3,010	270	800	230	290
	.39	10,700	1.72	8.8	23	6,100	520	1,050	220	410
Pacific silver	.40	6,400	1.42	6.0	21	3,140	220	750	240	310
	.43	10,600	1.72	9.3	24	6,530	450	1,180	....	430
Subalpine	.31	4,900	1.05	..		2,300	190	700	...	260
	.32	8,600	1.29	..	..	4,860	390	1,070	....	350
White	.37	5,900	1.16	5.6	22	2,900	280	760	300	340
	.39	9,800	1.49	7.2	20	5,810	530	1,100	300	480

Hemlock:										
Eastern	.38	6,400	1.07	6.7	21	3,080	360	850	230	400
	.40	8,900	1.20	6.8	21	5,410	650	1,060		500
Mountain	.42	6,300	1.04	11.0	32	2,880	370	930	330	470
	.45	11,500	1.33	10.4	32	6,440	860	1,540		680
Western	.42	6,600	1.31	6.9	22	3,360	280	860	290	410
	.45	11,300	1.64	8.3	23	7,110	550	1,250	340	540
Larch, western	.48	4,900	.96	10.3	29	3,760	400	870	330	510
	.52	13,100	1.87	12.6	35	7,640	930	1,360	430	830
Pine:										
Eastern white	.34	7,700	1.46	5.2	17	2,440	220	680	250	290
	.35	8,600	1.24	6.8	18	4,800	440	900	310	380
Jack	.40	6,000	1.07	7.2	26	2,950	300	750	360	400
	.43	9,900	1.35	8.3	27	5,660	580	1,170	420	570
Loblolly	.47	7,300	1.40	8.2	30	3,510	390	860	260	450
	.51	12,800	1.79	10.4	30	7,130	790	1,390	470	690
Lodgepole	.38	5,500	1.08	5.6	20	2,610	250	680	220	330
	.41	9,400	1.34	6.8	20	5,370	610	880	290	480
Longleaf	.54	8,500	1.59	8.9	35	4,320	480	1,040	330	590
	.59	14,500	1.98	11.8	34	8,470	960	1,510	470	870
Pitch	.47	6,800	1.20	9.2	- - -	2,950	- - -	860	- - -	- - -
	.52	10,800	1.43	9.2	- - -	5,940	- - -	1,360	- - -	- - -
Pond	.51	7,400	1.28	7.5	- - -	3,660	440	940	- - -	- - -
	.56	11,600	1.75	8.6	- - -	7,540	910	1,380	- - -	- - -
Ponderosa	.38	5,100	1.00	5.2	21	2,450	280	700	310	320
	.40	9,400	1.29	7.1	19	5,320	580	1,130	420	460
Red	.41	5,800	1.28	6.1	26	2,730	260	690	300	340
	.46	11,000	1.63	9.9	26	6,070	600	1,210	460	560
Sand	.46	7,500	1.02	9.6	- - -	3,440	450	1,140	- - -	- - -
	.48	11,600	1.41	9.6	- - -	6,920	836	- - -	- - -	- - -
Shortleaf	.47	7,400	1.39	8.2	30	3,530	350	910	320	440
	.51	13,100	1.75	11.0	33	7,270	820	1,390	470	690
Slash	.54	8,700	1.53	9.6	- - -	3,820	530	960	- - -	- - -
	.59	16,300	1.98	13.2	- - -	8,140	1,020	1,680	- - -	- - -
Spruce	.41	6,000	1.00		- - -	2,840	280	900	- - -	450
	.44	10,400	1.23		- - -	5,650	730	1,490	- - -	660
Sugar	.34	4,900	1.03	5.4	17	2,460	210	720	270	270
	.36	8,200	1.19	5.5	18	4,460	500	1,130	350	380

Table 4-2.—*Mechanical properties of some commercially important woods grown in the United States*—continued

Common names of species	Specific gravity	Static bending: Modulus of rupture	Static bending: Modulus of elasticity [2]	Static bending: Work to maximum load	Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		P.s.i.	*Million p.s.i.*	*In.-lb. per cu. in.*	*In.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*Lb.*
				SOFTWOODS—continued						
Pine (Cont.)										
Virginia	.45	7,300	1.22	10.9	34	3,420	390	890	400	540
	.48	13,000	1.52	13.7	32	6,710	910	1,350	380	740
Western white	.35	4,700	1.19	5.0	19	2,430	190	680	260	260
	.38	9,700	1.46	8.8	23	5,040	470	1,040	---	420
Redwood:										
Old-growth	.38	7,500	1.18	7.4	21	4,200	420	800	260	410
	.40	10,000	1.34	6.9	19	6,150	700	940	240	480
Young-growth	.34	5,900	.96	5.7	16	3,110	270	890	300	350
	.35	7,900	1.10	5.2	15	5,220	520	1,110	250	420
Spruce:										
Black	.38	5,400	1.06	7.4	24	2,570	140	660	100	370
	.40	10,300	1.53	10.5	23	5,320	530	1,030	---	520
Engelmann	.33	4,700	1.03	5.1	16	2,180	200	640	240	260
	.35	9,300	1.30	6.4	18	4,480	410	1,200	350	390
Red	.38	5,800	1.19	6.9	18	2,650	280	760	220	350
	.41	10,200	1.52	8.4	25	5,890	470	1,080	350	490
Sitka	.37	5,700	1.23	6.3	24	2,670	280	760	250	350
	.40	10,200	1.57	9.4	25	5,610	580	1,150	370	510
White	.37	5,600	1.07	6.0	22	2,570	240	690	220	320
	.40	9,800	1.34	7.7	20	5,470	460	1,080	360	480
Tamarack	.49	7,200	1.24	7.2	28	3,480	390	860	260	380
	.53	11,600	1.64	7.1	23	7,160	800	1,280	400	590

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[1] Results of tests on small, clear straight-grained specimens. [Values in the first line for each species are from tests of green material; those in the second line are adjusted to 12 pct. moisture content.]Specific gravity is based on weight when ovendry and volume when green or at 12 pct. moisture content.

[2] Modulus of elasticity measured from a simply supported, center-loaded beam, on a span-depth ratio of 14/1. The modulus can be corrected for the effect of shear deflection by increasing it 10 pct.

[3] Coast Douglas-fir is defined as Douglas-fir growing in the States of Oregon and Washington west of the summit of the Cascade Mountains. Interior West includes the State of California and all counties in Oregon and Washington east of but adjacent to the Cascade summit. Interior North includes the remainder of Oregon and Washington and the States of Idaho, Montana, and Wyoming. Interior South is made up of Utah, Colorado, Arizona, and New Mexico.

Table 4–3.—*Mechanical properties of some commercially important woods grown in Canada and imported into the United States* [1,2]

Common names of species	Specific gravity	Static bending		Compression parallel to grain —maximum crushing strength	Compression perpendicular to grain —fiber stress at protional limit	Shear parallel to grain —maximum shearing strength
		Modulus of rupture	Modulus of elasticity			
		P.s.i.	*Million P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*
		HARDWOODS				
Aspen:						
Quaking	0.37	5,500	1.31	2,350	200	720
		9,800	1.63	5,260	510	980
Big-toothed	.39	5,300	1.08	2,390	210	790
		9,500	1.26	4,760	470	1,100
Cottonwood:						
Balsam, poplar	.37	5,000	1.15	2,110	180	670
		10,100	1.67	5,020	420	890
Black	.30	4,100	.97	1,860	100	560
		7,100	1.28	4,020	260	860
Eastern	.35	4,700	.87	1,970	210	770
		7,500	1.13	3,840	470	1,160
		SOFTWOODS				
Cedar:						
Alaska-	.42	6,600	1.34	3,240	350	880
		11,600	1.59	6,640	690	1,340
Northern white-	.30	3,900	.52	1,890	200	660
		6,100	.63	3,590	390	1,000
Western redcedar	.31	5,300	1.05	2,780	280	700
		7,800	1.19	4,290	500	810
Douglas-fir	.45	7,500	1.61	3,610	460	920
		12,800	1.97	7,260	870	1,380
Fir:						
Subalpine	.33	5,200	1.26	2,500	260	680
		8,200	1.48	5,280	540	980
Pacific silver	.36	5,500	1.35	2,770	230	710
		10,000	1.64	5,930	520	1,190
Balsam	.34	5,300	1.13	2,440	240	680
		8,500	1.40	4,980	460	910
Hemlock:						
Eastern	.40	6,800	1.27	3,430	400	910
		9,700	1.41	5,970	630	1,260
Western	.41	7,000	1.48	3,580	370	750
		11,800	1.79	6,770	660	940
Larch, western	.55	8,700	1.65	4,420	520	920
		15,500	2.08	8,840	1,060	1,340

Table 4-3.—*Mechanical properties of some commercially important woods grown in Canada and imported into the United States* [1,2]—Continued

Common names of species	Specific gravity	Static bending		Compression parallel to grain —maximum crushing strength	Compression perpendicular to grain —fiber stress at proportional limit	Shear parallel to grain —maximum shearing strength
		Modulus of rupture	Modulus of elasticity			
		P.s.i.	*Million P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*
		SOFTWOODS—continued				
Pine:						
Eastern white	.36	5,100	1.18	2,590	240	640
		9,500	1.36	5,230	490	880
Jack	.42	6,300	1.17	2,950	340	820
		11,300	1.48	5,870	830	1,190
Lodgepole	.40	5,600	1.27	2,860	280	720
		11,000	1.58	6,260	530	1,240
Ponderosa	.44	5,700	1.13	2,840	350	720
		10,600	1.38	6,130	760	1,020
Red	.39	5,000	1.07	2,370	280	710
		10,100	1.38	5,500	720	1,090
Western white	.36	4,800	1.19	2,520	240	650
		9,300	1.46	5,240	470	920
Spruce:						
Black	.41	5,900	1.32	2,760	300	800
		11,400	1.52	6,040	620	1,250
Engelmann	.38	5,700	1.25	2,810	270	700
		10,100	1.55	6,150	540	1,100
Red	.38	5,900	1.32	2,810	270	810
		10,300	1.60	5,590	550	1,330
Sitka	.35	5,400	1.37	2,560	290	630
		10,100	1.63	5,480	590	930
White	.35	5,100	1.15	2,470	240	670
		9,100	1.45	5,360	500	980
Tamarack	.48	6,800	1.24	3,130	410	920
		11,000	1.36	6,510	900	1,300

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[1] Results of tests on small, clear, straight-grained specimens. Property values based on American Society for Testing and Materials Standard D 2555-70, "Standard methods for establishing clear wood values." Information on additional properties can be obtained from Department of Forestry, Canada, Publication No. 1104.

[2] The values in the first line for each species are from tests of green material; those in the second line are adjusted from the green condition to 12 pct. moisture content using dry to green clear wood property ratios as reported in ASTM D 2555-70. Specific gravity is based on weight when ovendry and volume when green.

Table 4-4.—*Mechanical properties*[1,2] *of some woods imported into the United States*

Common and botanical names of species	Moisture content	Specific gravity[3]	Static bending			Compression parallel to grain—maximum crushing strength	Shear parallel to grain—maximum shearing strength	Side hardness—load perpendicular to grain	Sample	
			Modulus of rupture	Modulus of elasticity[4]	Work to maximum load				Number of trees	Origin[5]
	Pct.		*P.s.i.*	*Million p.s.i.*	*In.-lb. per cu. in.*	*P.s.i.*	*P.s.i.*	*Lb.*		
Andiroba (*Carapa guianensis*)	Green	0.56	11,100	1.56	11.4	4,930	1,320	1,060	2	BR
	12	......	15,600	1.85	13.4	7,900	1,680	1,220	2	BR
Andiroba (*C. nicaraguensis*)	13	.45	......	......	......	6,240	......	1,240	3	EC
Angelique (*Dicorynia guianensis*)	Green	.60	11,400	1.84	12.0	5,590	1,340	1,100	2	SU
	......	......	17,400	2.19	15.2	8,770	1,660	1,290	2	SU
Apamate (*Tabebuia rosea*)	Green	.51	10,600	1.47	11.2	4,930	1,240	890	10	CS
	12	......	13,800	1.60	12.5	7,340	1,450	960	9	CS
Apitong (*Dipterocarpus* spp.)	Green	.59	9,200	1.79	......	4,410	1,040	800	57	PH
	12	......	16,200	2.35	......	8,540	1,690	1,200	53	PH
Avodire (*Turraeanthus africanus*)	12	.51	12,700	1.48	9.4	7,180	2,040	1,080	3	AF
Balsa (*Ochroma pyramidale*)	12	.17	2,800	.55	......	1,700	300	100	[6]	EC
Banak (*Virola koschnyi*)	Green	.44	6,200	1.47	5.3	3,050	660	440	8	CA
	12	......	10,800	1.72	8.1	5,720	1,300	640	8	CA
Banak (*V. surinamensis*)	Green	.42	5,600	1.64	4.1	2,390	720	320	2	BR
	12	......	10,900	2.04	10.0	5,140	980	510	2	BR
Capirona (*Calycophyllum candidissimum*)	Green	.67	14,300	1.93	18.6	6,200	1,360	1,630	2	VE
	12	......	22,300	2.27	27.0	9,670	2,120	1,940	2	VE
Capirona (*C. spruceanum*)	14	.85	......	......	......	9,280	......	2,550	1	PE
Cativo (*Prioria copaifera*)	Green	.40	5,900	.95	5.4	2,590	860	450	4	PA
	12	......	8,700	1.15	7.2	4,490	1,040	610	4	PA
Courbaril (*Hymenaea courbaril*)	Green	.72	12,900	1.82	15.7	5,800	1,770	2,030	9	CS
	12	......	19,400	2.17	17.6	9,680	2,470	2,440	9	CS
Gola (*Tetraberlinia tubmaniana*)	14	.66	16,700	2.21	......	9,010	......	......	11	AF

Table 4-4.—*Mechanical properties*[1,2] *of some woods imported into the United States*—continued

Common and botanical names of species	Moisture content	Specific gravity[3]	Static bending: Modulus of rupture	Static bending: Modulus of elasticity[4]	Static bending: Work to maximum load	Compression parallel to grain—maximum crushing strength	Shear parallel to grain—maximum shearing strength	Side hardness—load perpendicular to grain	Sample: Number of trees	Sample: Origin[5]
	Pct.		*P.s.i.*	*Million p.s.i.*	*In.-lb. per cu. in.*	*P.s.i.*	*P.s.i.*	*Lb.*		
Goncalo alves *(Astronium graveolens)*	Green	.86	12,400	1.90	7.4	6,880	1,840	1,990	4	CS
	12		17,100	2.17	10.4	10,560	2,060	2,230	4	CS
Greenheart *(Ocotea rodiaei)*	Green	.83	19,400	2.98	13.0	10,360	1,480	2,190	5	GY
	14	.93	25,500	3.70	22.0	13,040	1,830	2,630	1	GY
Ilomba *(Pycnanthus angolensis)*	12	.44	8,900	1.75		5,510		750	(7)	AF
Jarrah *(Eucalyptus marginata)*	Green	.67	9,900	1.48		5,190	1,325	1,285	28	AU
	12		16,200	1.88		8,870	2,185	1,915	28	AU
Jelutong *(Dyera costulata)*	Green	.36	5,600	1.16	5.6	3,050	760	330	3	AS
	16	.38	7,300	1.18	6.4	3,920	840	390	3	AS
Kapur *(Dryobalanops lanceolata)*	Green	.64	12,200	1.70	12.8	5,970	1,040	980	5	AS
	12		17,400	2.02	15.5	9,700	1,710	1,230	5	AS
Karri *(Eucalyptus diversicolor)*	Green	.70	10,600	2.07		5,250	1,340	1,360	26	AU
	12		19,200	2.76		10,400	2,140	2,030	21	AU
Kerving *(Dipterocarpus* spp.)	Green	.67	11,900	2.44	9.2	6,230	1,160	1,110	21	MI
	16	.69	14,500	2.63	13.3	8,000	1,360	1,160	11	MI
Khaya *(Khaya anthotheca)*	Green	.47	7,800	1.18	9.2	3,770	1,090	730	9	AF
	12		11,500	1.41	9.8	6,300	1,700	900	9	AF
Khaya *(K. ivorensis)*	Green	.43	7,400	1.16	8.3	3,500	930	640	11	AF
	12		10,700	1.39	8.3	6,460	1,500	830	11	AF
Kokrodua *(Pericopsis elata)*	Green	.66	14,800	1.77	19.5	7,490	1,670	1,600	6	AF
	12		18,400	1.94	18.5	9,940	2,090	1,560	6	AF
Lapacho *(Tabebuia heterotricha)*	Green	.80	20,100	2.12	27.3	7,680	2,140	2,530	3	PA
	12		22,600	2.32	26.0	10,930	2,280	3,010	3	PA
Lapacho *(T. serratifolia)*	Green	.92	22,800	3.06	25.6	10,660	2,050	2,970	3	SM
	12		26,300	3.31	23.0	13,420	2,070	3,670	3	SM

Lauan:										
Dark red:										
Red lauan *(Shorea negrosensis)*	Green	.44	7,700	1.38	------	3,700	930	570	15	AS
	12	------	11,300	1.63	------	5,890	1,220	680	15	AS
Tanguile *(S. polysperma)*	Green	.46	8,300	1.54	------	3,940	940	620	19	PH
	12	------	12,900	1.81	------	6,580	1,290	770	17	PH
Light red:										
Almon *(S. almon)*	Green	.41	7,500	1.44	------	3,750	840	500	12	PH
	12	.44	11,300	1.67	------	5,750	1,090	590	12	PH
Bagtikan *(Parashorea plicata)*	Green	.48	8,800	1.47	------	4,360	990	700	32	AS
	12	------	12,600	1.73	------	6,850	1,300	810	32	AS
Mayapis *(Shorea squamata)*	Green	.41	7,300	1.40	------	3,470	770	480	14	AS
	12	------	11,100	1.66	------	5,620	1,090	590	12	AS
White lauan *(Pentacme contorta)*	Green	.43	7,500	1.38	------	3,700	910	580	19	AS
	12	------	11,700	1.69	------	6,070	1,200	700	18	AS
Laurel *(Cordia alliodora)*	Green	.44	8,800	1.26	------	4,000	1,130	790	13	CA
	12	------	12,100	1.49	------	6,280	1,220	790	13	CA
Lignumvitae *(Guaiacum sanctum)*	12	1.09	------	------	------	11,400	------	4,500	------	------
Limba *(Terminalia superba)*	12	.49	11,500	1.64	------	5,290	1,010	680	(8)	SM
Lupuna *(Ceiba samauma)*	13	.54	------	------	------	------	------	740	1	PE
Mahogany *(Swietenia macrophylla)*	Green	.45	9,300	1.28	9.6	4,510	1,310	700	77	CS
	12	------	11,600	1.51	7.9	6,630	1,290	810	77	CS
Meranti, red *(Shorea dasphylla)*	Green	.43	8,600	1.50	8.8	4,450	------	560	2	AS
	12	------	12,100	1.63	11.7	6,970	------	630	2	AS
Oak *(Quercus costaricensis)*	12	.68	17,600	2.64	16.8	------	------	1,570	2	CR
Oak *(Q. eugeniaefolia)*	12	.75	16,400	2.84	14.1	------	------	2,170	1	CR
Obeche *(Triplochiton scleroxylon)*	Green	.33	5,100	.71	6.2	2,570	670	420	2	AF
	12	------	7,500	.86	6.9	3,930	990	430	2	AF
Okoume *(Aucoumea klaineana)*	12	.37	7,300	1.14	------	3,900	------	380	(9)	AF
Palosapis *(Anisoptera* spp.)	Green	.51	7,500	1.43	------	3,780	1,000	810	18	AS
	12	------	12,800	1.82	------	6,630	1,410	920	16	AS
"Parana pine" *(Araucaria angustifolia)*	Green	.46	7,100	1.35	9.8	4,000	970	560	(10)	SM
	12	------	13,500	1.62	12.2	7,650	1,730	780	(10)	SM
Pau marfim *(Balfourodendron riedelianum)*	Green	.73	14,400	------	------	6,100	1,890	1,530	5	BR
	15	------	18,900	------	------	8,200	------	------	5	BR

Table 4–4.—*Mechanical properties*[1,2] *of some woods imported into the United States*—continued

Common and botanical names of species	Moisture content	Specific gravity[3]	Static bending: Modulus of rupture	Static bending: Modulus of elasticity[4]	Static bending: Work to maximum load	Compression parallel to grain—maximum crushing strength	Shear parallel to grain—maximum shearing strength	Side hardness—load perpendicular to grain	Sample: Number of trees	Sample: Origin[5]
	Pct.		*P.s.i.*	*Million p.s.i.*	*In.-lb. per cu. in.*	*P.s.i.*	*P.s.i.*	*Lb.*		
Peroba de campos *(Paratecoma peroba)*	12	.75	15,400	1.76	10.2	8,920	2,140	1,600	(11)	BR
Pine, Caribbean (*Pinus caribaea*)	Green	.68	10,000	1.69	12.0	4,780	1,200	820	19	CA
	12		15,200	2.03	15.3	8,000	1,870	1,150	14	CA
Pine, ocote *(P. oocarpa)*	Green	.55	8,000	1.74	6.9	3,690	1,040	580	3	HO
	12		14,900	2.25	10.9	7,680	1,720	910	3	HO
Primavera *(Cybistax donnell-smithii)*	Green	.39	7,700	.98	6.9	3,630	1,050	660	4	HO
	12		10,900	1.22	10.3	6,140	1,710	700	4	HO
Ramin *(Gonystylus bancanus)*	Green	.59	9,800	1.57	9.0	5,395	994	640	9	AS
	12		18,400	2.17	17.0	10,080	1,514	1,300	9	AS
Rosewood, Indian *(Dalbergia latifolia)*	Green	.75	9,200	1.19	11.6	4,530	1,400	1,270	5	AS
	12		16,900	1.78	13.1	9,220	2,090	2,630	5	AS
Sande *(Brosimum utile)*	12	.44				6,310		500	3	EC
Santa Maria *(Calophyllum brasiliense)*	Green	.54	10,500	1.57	10.6	5,160	1,290	1,010	18	CA
	12		14,800	1.82	13.2	8,060	1,910	1,210	18	CA
Sapele *(Entandrophragma cylindricum)*	Green	.60	10,200	1.49	10.5	5,011	1,250	1,020	5	AF
	12		15,300	1.82	15.7	8,160	2,288	1,510	5	AF
Spanish-cedar *(Cedrela angustifolia)*	Green	.38	6,700	1.17	7.4	3,100	790	450	2	BR
	12		11,300	1.42	12.5	6,010	1,200	570	2	BR
Spanish-cedar *(C. oaxacensis)*	Green	.41	7,500	1.31	7.1	3,370	990	550	3	PA
	12		11,500	1.44	9.4	6,210	1,100	600	3	PA
Spanish-cedar *(C. odorata)* *(Nicaragua)*	Green	.34	5,200	.87	7.4	2,760	720	350	1	NI
(Guatemala)	Green	.43	9,500	1.48				620	1	GU
(Nicaragua)	12	.36	7,900	1.01	5.6	4,450		500	1	NI
Teak *(Tectona grandis)*	Green	.57	11,000	1.51	10.8	5,470	1,290	1,070	134	IN
	12	.62	13,300	1.39	10.3	6,770	1,600	1,110	3	HO
	12	.63	12,800	1.59	10.1	7,110	1,480	1,030	56	IN

Table 4-5.—*Average coefficient of variation for some mechanical properties of clear wood*

Property	Coefficient of variation [1]
	Pct.
Static bending:	
Fiber stress at proportional limit	22
Modulus of rupture	16
Modulus of elasticity	22
Work to maximum load	34
Impact bending, height of drop causing complete failure	25
Compression parallel to grain:	
Fiber stress at proportional limit	24
Maximum crushing strength	18
Compression perpendicular to grain, fiber stress at proportional limit	28
Shear parallel to grain, maximum shearing strength	14
Tension perpendicular to grain, maximum tensile strength	25
Hardness:	
Perpendicular to grain	20
Toughness	34
Specific gravity	10

[1] Values given are based on results of tests of green wood from approximately 50 species. Values for wood adjusted to 12 pct. moisture content may be assumed to be approximately of the same magnitude.

Table 4-6.—*Average parallel-to-grain tensile strength for specimens of some species of wood*[1]

Species	Specific gravity	Tensile strength
		P.s.i.
HARDWOODS		
Elm:		
Cedar	0.59	17,500
	.64	20,200
Winged	.68	27,000
Oak, overcup	.57	11,300
	.63	14,700
Sweetgum	.46	13,600
	.52	17,300
Willow, black	.37	10,600
	.41	15,800
Yellow-poplar	.42	15,900
	.46	22,400
SOFTWOODS		
Douglas-fir, interior north	.46	15,600
		18,900
Fir:		
California red	.37	11,300
	.39	13,100
Pacific silver	.36	13,800
	.37	15,700
Larch, western	.51	16,200
	.55	19,400
Pine:		
Eastern white	.34	10,600
	.35	11,300
Virginia	.45	13,700
	.48	15,000
Red	.42	15,300
Spruce, Engelmann	.32	12,300
	.34	13,000

[1] Results of tests on small, clear, straight-grained specimens. The values in the first line for each species are from tests of green material; those in the second line are from tests of dry material with the properties adjusted to 12 pct. moisture content. Specific gravity values are not from the tension specimens but others representing the species shipment. Specific gravity is based on weight when ovendry and volume when green and an adjustment to approximately 12 pct. moisture content.

"Virola" *(Dialyanthera otoba)*	12						300		10	AS
Walnut, European *(Juglans regia)*	Green	.47	8,710	1.31	10.4	4,010	1,060	670	10	AS
	8		13,090	1.54	9.8	7,320	1,320	860	10	AS

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[1] Results of tests on small, clear, straight-grained specimens. Property values were taken from world literature (not obtained from experiments conducted at the U.S. Forest Products Laboratory). Other species may be reported in the world literature, as well as additional data on many of these species.

[2] Some property values have been adjusted to 12 pct. moisture content; others are based on moisture content at time of test.

[3] Specific gravity based on weight when ovendry and volume at moisture content indicated.

[4] Modulus of elasticity measured from a simply supported, center loaded beam, on a span-depth ratio of 14/1. The modulus can be corrected for the effect of shear deflection by increasing it 10 pct.

[5] Key to code letters: AF, Africa; AS, Southeast Asia; AU Australia; BR, Brazil; CA, Central America; CH, Chile; CR, Costa Rica; CS, Central and South America; EC, Ecuador; GU, Guatemala; GY, Guyana (British Guiana); HO, Honduras; IN, India; MI, Malaysia—Indonesia; NI, Nicaragua; PA, Panama; PE, Peru; PH, Philippine Islands; SM, South American; SU, Surinam; and VE, Venezuela.

[6] 1,500 board feet.

[7] 1 bolt.

[8] 195 tests.

[9] 21 tests.

[10] 26 planks.

[11] 11 planks.

Table 4–7.—*Average toughness values*[1] *for samples of a few species of wood*

Species	Moisture content	Specific gravity[2]	Toughness[3]	
			Radial	Tangential
	Pct.		*In.-lb.*	*In.-lb.*
		HARDWOODS		
Birch, yellow	12	0.65	500	620
Hickory:				
(Mockernut, pignut, sand)	Green	.64	700	720
	12	.71	620	660
Maple, sugar	14	.64	370	360
Oak, red:				
Pin	12	.64	430	430
Scarlet	11	.66	510	440
Oak, white:				
Overcup	Green	.56	730	680
	13	.62	340	310
Sweetgum	Green	.48	340	330
	13	.51	260	260
Willow, black	Green	.38	310	360
	11	.40	210	230
Yellow-poplar	Green	.43	320	300
	12	.45	220	210
		SOFTWOODS		
Cedar:				
Alaska-	10	.48	210	230
Western redcedar	9	.33	90	130
Douglas-fir:				
Coast	Green	.44	210	360
	12	.47	200	360
Interior West	Green	.48	200	300
	13	.51	210	340
Interior North	Green	.43	170	240
	14	.46	160	250
Interior South	Green	.38	130	180
	14	.40	120	180
Fir:				
California red	Green	.36	130	180
	12	.39	120	170
Noble	Green	.36		240
	12	.39		220
Pacific silver	Green	.37	150	230
	13	.40	170	260
White	Green	.36	140	220
	13	.38	130	200
Hemlock:				
Mountain	Green	.41	250	280
	14	.44	140	170
Western	Green	.38	150	170
	12	.41	140	210
Larch, western	Green	.51	270	400
	12	.55	210	340

Table 4-7.—*Average toughness values*[1] *for samples of a few species of wood*—continued

Species	Moisture content	Specific gravity[2]	Toughness[3]	
			Radial	Tangential
	Pct.		*In.-lb.*	*In.-lb.*
		SOFTWOODS—Continued		
Pine:				
Eastern white	Green	.33	120	160
	12	.34	110	120
Jack	Green	.41	200	380
	12	.42	140	240
Loblolly	Green	.48	310	380
	12	.51	160	260
Lodgepole	Green	.38	160	210
Ponderosa	Green	.38	190	270
	11	.43	150	190
Red	Green	.40	210	350
	12	.43	160	290
Shortleaf	Green	.47	290	400
	13	.50	150	230
Slash	Green	.55	350	450
	12	.59	210	320
Virginia	Green	.45	340	470
	12	.49	170	250
Redwood:				
Old-growth	Green	.39	110	200
	11	.39	90	140
Young-growth	Green	.33	110	140
	12	.34	90	110
Spruce, Engelmann	Green	.34	150	190
	12	.35	110	180

[1] Results of tests on small, clear, straight-grained specimens.

[2] Based on ovendry weight and volume at moisture content of test.

[3] Properties based on specimen size of 2 cm. square by 28 cm. long; radial indicates load applied to radial face and tangential indicates load applied to tangential face of specimens.

Table 4-8.—*A summary of reported results of fatigue studies*[1]

Loading	Conditions	Range ratio (minimum stress ÷ maximum stress)	Fatigue life (million cycles)	Fatigue strength (percent of strength from static test)
Tension parallel to grain	Clear, air dry	0.10	30	50
Cantilever bending	Clear, air dry, solid wood	−1.00	30	30
Simple beam bending	Clear, green	.10	30	60
Rotational bending	Clear, air dry	−1.00	30	28

[1] Results from Forest Products Laboratory studies except for rotational bending results (from Fuller, F. B., and Oberg, T. T. 1943. Fatigue Characteristics of Natural and Resin-Impregnated Compressed Laminated Woods. J. Aero. Sci. 10(3): 81-85.)

INFLUENCE OF GROWTH CHARACTERISTICS ON THE PROPERTIES OF CLEAR STRAIGHT-GRAINED WOOD

Clear straight-grained wood is used for determining fundamental mechanical properties; however, because of natural growth characteristics of trees, wood products vary in specific gravity, may contain cross grain, or have knots and localized slope of grain. In addition, natural defects such as pitch pockets may occur due to biological or climatic elements acting on the living tree. These wood characteristics must be taken into account in assessing actual properties or estimating actual performance of wood products.

Specific Gravity

The substance of which wood is composed is actually heavier than water, its specific gravity being about 1.5 regardless of the species of wood. In spite of this fact, the dry wood of most species floats in water, and it is thus evident that part of the volume of a piece of wood is occupied by cell cavities and pores. Variations in the size of these openings and in the thickness of the cell walls cause some species to have more wood substance per unit volume than others and therefore to have higher specific gravity. Specific gravity thus is an excellent index of the amount of wood substance a piece of dry wood contains; it is a good index of mechanical properties so long as the wood is clear, straight grained, and free from defects. It should be noted, however, that specific gravity values also reflect the presence of gums, resins, and extractives, which contribute little to mechanical properties.

The relationships between specific gravity and various other properties have been expressed for clear straight-grained wood as power functions, based on average results of strength tests of more than 160 species. These relationships, given in table 4–9, are only approximate. For any single species, more consistently accurate relationships can be obtained from specific test results.

Table 4–9.—*Functions relating mechanical properties to specific gravity of clear, straight-grained wood*

Property	Specific gravity-strength relation[1]	
	Green wood	Air-dry wood (12 pct. moisture content)
Static bending:		
Fiber stress at proportional limit ... p.s.i.	$10,200G^{1.25}$	$16,700G^{1.25}$
Modulus of elasticity ... million p.s.i.	$2.36G$	$2.80G$
Modulus of rupture ... p.s.i.	$17,600G^{1.25}$	$25,700G^{1.25}$
Work to maximum load ... in.-lb. per cu in.	$35.6G^{1.75}$	$32.4G^{1.75}$
Total work ... in.-lb. per cu in.	$103G^{2}$	$72.7G^{2}$
Impact bending, height of drop causing complete failure ... in.	$114G^{1.75}$	$94.6G^{1.75}$
Compression parallel to grain:		
Fiber stress at proportional limit ... p.s.i.	$5,250G$	$8,750G$
Modulus of elasticity ... million p.s.i.	$2.91G$	$3.38G$
Maximum crushing strength ... p.s.i.	$6,730G$	$12,200G$
Compression perpendicular to grain, fiber stress at proportional limit ... p.s.i.	$3,000G^{2.25}$	$4,630G^{2.25}$
Hardness:		
End ... lb.	$3,740G^{2.25}$	$4,800G^{2.25}$
Side ... lb.	$3,420G^{2.25}$	$3,770G^{2.25}$

[1] The properties and values should be read as equations; for example: modulus of rupture for green wood = $17,600G^{1.25}$, where G represents the specific gravity of ovendry wood, based on the volume at the moisture condition indicated.

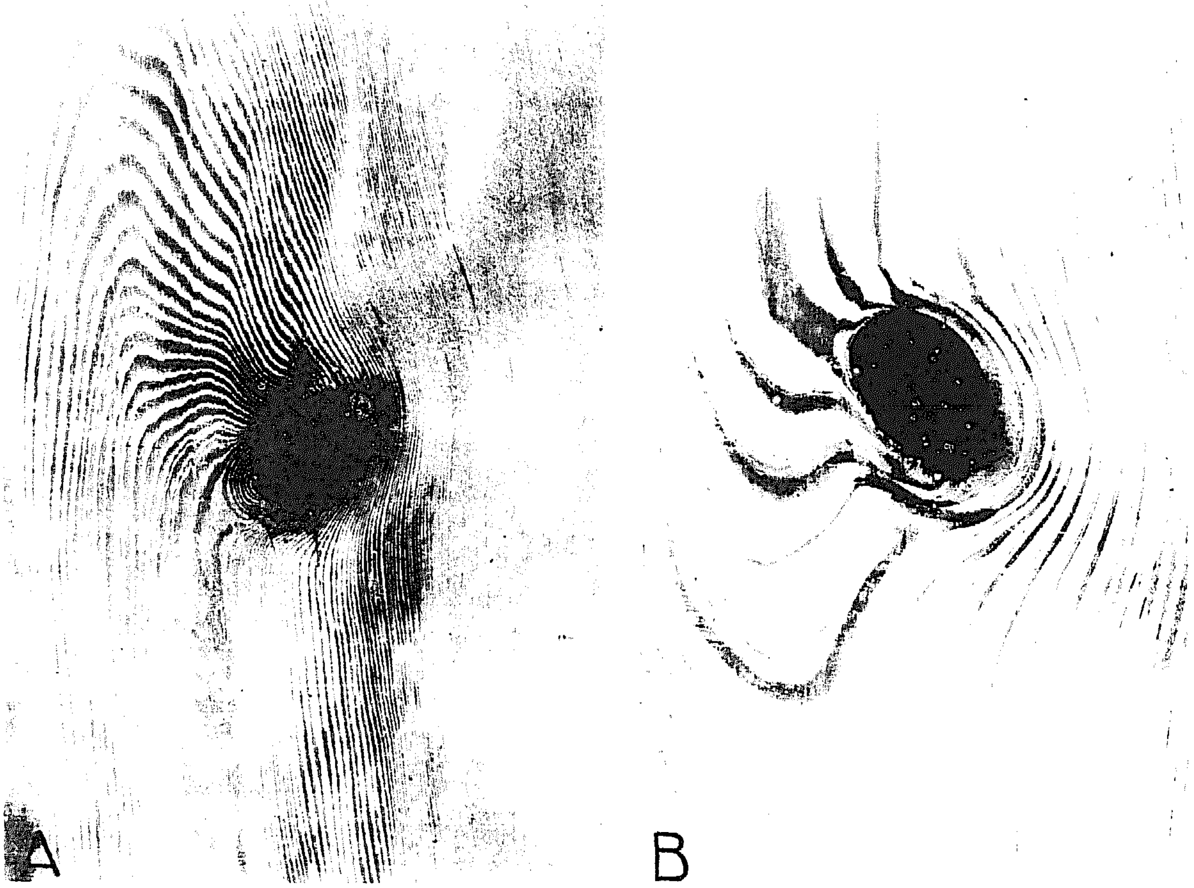

Figure 4–2.—A, Encased knot; B, intergrown knot. M 22604 F

Knots

A knot is that portion of a branch which has become incorporated in the bole of the tree. The influence of a knot on mechanical properties of a product is due to the interruption of continuity and change in direction of wood fibers. The influence of knots depends on their size, location, shape, soundness, attendant local slope of grain, and the type of stress to which they are subjected.

The shape (form) of a knot appearing on a sawed surface depends upon the direction of the exposing cut. When a branch is sawed through at right angles to its length, a nearly round knot results; when cut diagonally, an oval knot; and when sawed lengthwise, a spike knot.

Knots are further classified as intergrown or encased (fig. 4–2). As long as a limb remains alive, there is continuous growth at the junction of the limb and the trunk of the tree, and the resulting knot is called intergrown. After the branch has died, additional growth on the trunk encloses the dead limb, and an encased knot results; fibers of the trunk are not continuous with fibers of encased knots. Encased knots and knotholes tend to be accompanied by less cross grain than are intergrown knots and are, therefore, generally less serious with regard to some mechanical properties.

Knots decrease most mechanical properties because (1) the clear wood is displaced by the knot, (2) the fibers around the knot are distorted causing cross grain, (3) the discontinuity of wood fiber leads to stress concentrations, and (4) checking often occurs around knots in drying. Conversely, knots actually increase hardness and strength in compression perpendicular to the grain and are objectionable in regard to these properties only in that they cause nonuniform wear or nonuniform stress distributions at contact surfaces.

Wood members loaded uniformly in tension are usually more seriously affected by knots than if loaded in other ways. In some structural members, the effect of knots on strength depends not only on knot size but also on the location of the knot. For example, in a simply supported beam, knots on the lower side are placed in tension, those on the upper side in compression, and those at or near the neutral axis in horizontal shear. A knot has a marked effect on the maximum load a beam will sustain when on the tension side at the point of maximum stress; knots on the compression side are somewhat less serious.

In long columns, knots are important in that they affect stiffness. In short or intermediate columns, the reduction in strength caused by knots is approximately proportional to the size of the knot; however, large knots have a somewhat greater relative effect than do small knots.

Knots in round timbers, such as poles and piles, have less effect on strength than knots in sawed timbers. Although the grain is irregular around knots in both forms of timber, its angle with the surface is less in naturally round than in sawed timber.

Fatigue strength of clear wood is reduced by knots. The effect of knots, as well as an additive effect of knots and slope of grain on fatigue strength is discussed under the section on Time-Fatigue.

The effects of knots in structural lumber are discussed in chapter 6.

Fiber and Ring Orientation

In some wood product applications, the directions of important stresses may not coincide with the natural axes of fiber orientation in the wood. This may occur by choice in design, by the way the wood was removed from the log, or because of grain irregularities that occurred during growth.

Elastic properties in directions other than along the natural axes can be obtained from elastic theory. Strength properties in directions ranging from parallel to perpendicular to the fibers can be approximated using a Hankinson-type formula:

$$N = \frac{PQ}{P \sin^n \theta + Q \cos^n \theta}$$

in which N represents the strength property at an angle θ from the fiber direction, Q is the strength across the grain, P is the strength parallel to the grain, and n is an empirically determined constant. The formula has been used for modulus of elasticity as well as strength properties. Values of n and associated ratios of Q/P have been tabulated below from available literature:

Property	n	Q/P
Tensile strength	1.5–2	0.04–0.07
Compressive strength	2–2.5	0.03–0.4
Bending strength	1.5–2	0.04–0.1
Modulus of elasticity	2	0.04–0.12
Toughness	1.5–2	0.06–0.1

A Hankinson-type formula can be graphically depicted as a function of Q/P and n. Figure 4–3 shows the strength in any direction expressed as a fraction of the strength parallel to the fiber direction, plotted against angle to the fiber direction θ. The plot is for a range of values of Q/P and n.

The term "slope of grain" relates the fiber direction to the edges of a piece. Slope of grain is usually expressed by the ratio between a 1-inch deviation of the grain from the edge or long axis of the piece and the distance in inches within which this deviation occurs (tan θ). Table 4–10 gives the effect of grain slope on some properties of wood, as determined from tests. The values in table 4–10 for modulus of rupture fall very close to the curve in figure 4–3 for $Q/P = 0.1$ and $n = 1.5$. Similarly, the impact bending values fall close to the curve for $Q/P = 0.05$ and $n = 1.5$; and for compression, $Q/P = 0.1$, $n = 2.5$.

The term "cross grain" indicates the condition measured by slope of grain. Two important forms of cross grain are spiral grain and diagonal grain (fig. 4–4). Other types are wavy, dipped, interlocked, and curly grain.

Table 4–10.—*Strength of wood members with various grain slopes compared to strength of a straight-grained member, expressed as percentages*

Maximum slope of grain in member	Modulus of rupture	Impact bending—height of drop causing complete failure (50-lb. hammer)	Compression parallel to grain—maximum crushing strength
	Pct.	*Pct.*	*Pct.*
Straight-grained	100	100	100
1 in 25	96	95	100
1 in 20	93	90	100
1 in 15	89	81	100
1 in 10	81	62	99
1 in 5	55	36	93

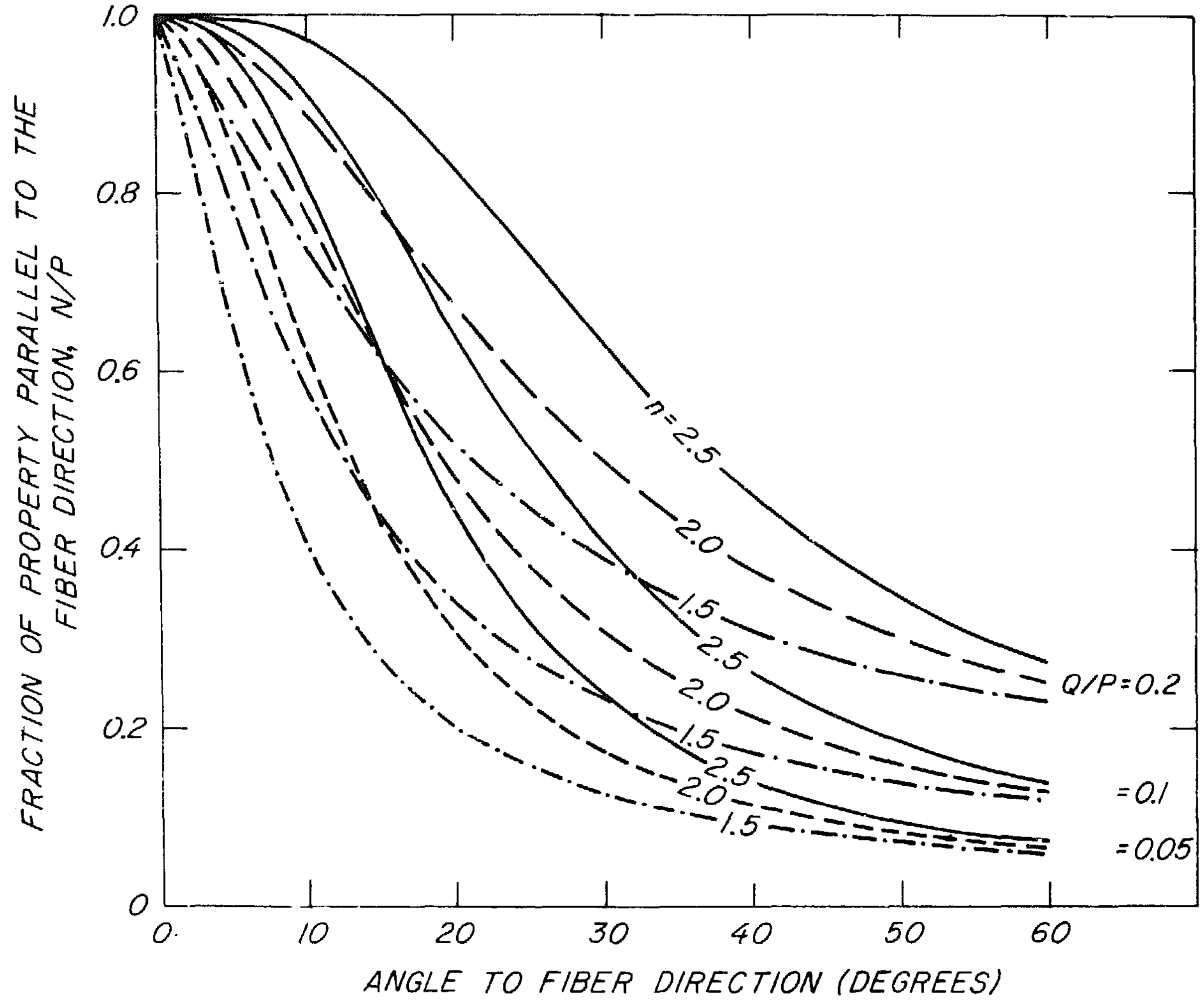

Figure 4–3.—Effect of grain angle on mechanical property of clear wood according to a Hankinson-type formula. Q/P is the ratio of the mechanical property across the grain (Q) to that parallel to the grain (P); n is an empirically determined constant.

Spiral grain in a tree is caused by fibers growing in a winding or spiral course about the bole of the tree instead of in a vertical course. In sawn products spiral grain can be defined as fibers lying in the tangential plane of the growth rings, not parallel to the longitudinal axis of the product (see fig. 4–4B for a simple case). Spiral grain often is not readily detected by ordinary visual inspection in sawn products. The best test for spiral grain is to split a sample section from the piece in the radial direction. A nondestructive method of determining the presence of spiral grain is to note the alinement of pores, rays, and resin ducts on the flat-grain face. Drying checks on a flat-sawn surface follow the fibers and indicate the fiber slope.

Diagonal grain describes cross grain caused by growth rings not parallel to one or both surfaces of the sawn piece. Diagonal grain is produced by sawing parallel to the axis (pith) of the tree in a log having pronounced taper, and is a common occurrence in sawing crooked or swelled logs.

Cross grain can be quite localized as a result of the disturbance of growth patterns by a branch. This condition, termed "local slope of grain," may be present even though the branch (knot) may have been removed in a sawing operation. Often the degree of local cross grain may be difficult to determine.

Any form of cross grain can have a serious effect on mechanical properties or machining characteristics. Spiral and diagonal grain com-

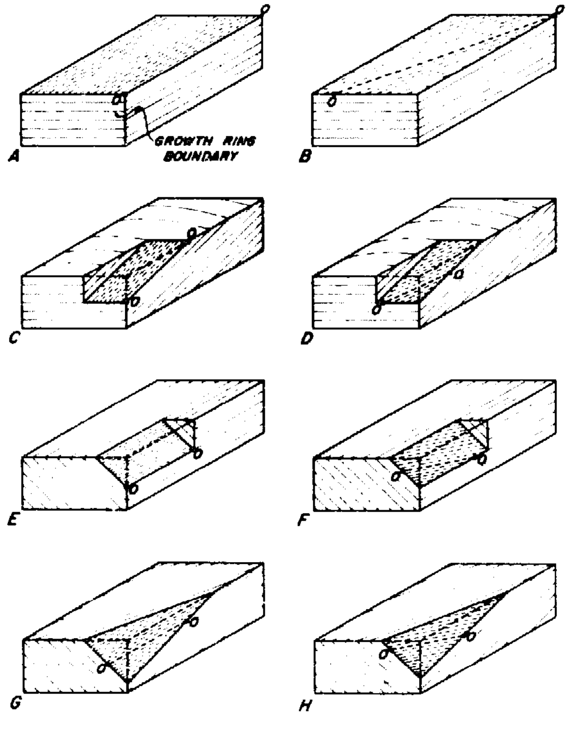

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Figure 4–4.—Schematic views of wood specimens containing straight grain and cross grain to illustrate the relationship of fiber orientation (O–O) to the axes of the piece. Specimens *A* through *D* have radial and tangential surfaces; *E* through *H* do not. *A* and *E* contain no cross grain. *B*, *D*, *F*, and *H* have spiral grain. *C*, *D*, *G*, and *H* have diagonal grain.

bine to produce a more complex cross grain. To determine net cross grain, regardless of origin, fiber slopes on contiguous surfaces of a piece must be measured and combined. The combined slope of grain is determined by taking the square root of the sum of the squares of the two slopes. For example, assume the spiral grain slope on the flat grain surface of figure 4–4D is 1 in 12 and the diagonal grain slope is 1 in 18. The combined slope is

$$\sqrt{\left(\frac{1}{18}\right)^2+\left(\frac{1}{12}\right)^2}=\frac{1}{10} \text{ or a slope of 1 in 10}$$

Stresses perpendicular to the fiber (grain) direction may be at any angle from 0° (T) to 90° (R) to the growth rings (fig. 4–5). Perpendicular-to-grain properties depend somewhat upon orientation of annual rings with respect to the direction of stress. Compression perpendicular-to-grain values in table 4–2 are derived from tests in which the load is applied parallel to the growth rings (T-direction); tension perpendicular-to-grain values are an average of an equal number of specimens with 0° and 90° growth ring orientation. Modulus of elasticity is least for the 45° orientation, intermediate at 0° , and highest at 90 to the growth rings. Proportional limit in compression increases gradually as the ring angle increases from 0° (T) to 90° (R), the total increase amounting to about one-third. Similar observations have been made in tension. For some softwoods in compression the values at 0° and 90° are about the same, with the value at 45° about two-thirds of the others.

Reaction Wood

Abnormal woody tissue is frequently associated with leaning boles and crooked limbs of both conifers and hardwoods. It is generally believed that it is formed as a natural response of the tree to return its limbs or bole to a more normal position, hence the term "reaction wood." In softwoods, the abnormal tissue is called "compression wood." It is common to all softwood species and is found on the lower side of the limb or inclined bole. In hardwoods, the abnormal tissue is known as "tension wood;" it is located on the upper side of the inclined member, although in some instances it is distributed irregularly around the cross section. Reaction wood is more prevalent in some species than in others.

Many of the anatomical, chemical, physical, and mechanical properties of reaction wood differ distinctly from those of normal wood. Perhaps most evident is the increase in the density over that of normal wood. The specific gravity of compression wood is frequently 30 to 40 percent greater than normal, while tension wood commonly ranges between 5 and 10

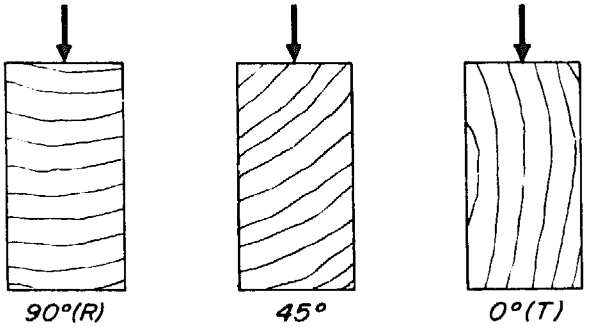

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Figure 4–5.—The direction of load in relation to the direction of the annual growth rings: 90° or perpendicular (R); 45°; 0° or parallel (T).

M 28425 F

Figure 4–6.—The darker areas shown within the rectangle are compression wood.

percent greater but may be as much as 30 percent greater.

Compression and tension wood undergo excessive longitudinal shrinkage when subjected to moisture loss reaching below the fiber saturation point. Longitudinal shrinkage ranges to 10 times normal in compression wood and perhaps five times normal or more in tension wood. When present in the same board with normal wood, unequal longitudinal shrinkage causes internal stresses that result in warping. This warp sometimes occurs in rough lumber but more often in planed, ripped, or resawed lumber. Fortunately, the most serious effects occurring in pronounced compression wood can be detected by ordinary visual examination, as compared to borderline forms that merge with normal wood and frequently are only detected by microscopic examination.

Reaction wood, particularly compression wood in the green condition, may be somewhat stronger than normal wood. However, when compared to normal wood of comparable specific gravity, the reaction wood is definitely weaker. Possible exceptions to this are compression parallel-to-grain properties of compression wood and impact bending properties of tension wood.

Because of its abnormal properties, it is frequently desirable to eliminate reaction wood from raw material. In logs, compression wood may be characterized by eccentric growth about the pith and by the large proportion of summerwood at the point of greatest eccentricity (fig. 4–6). It is more difficult to detect in lumber; however, it is usually somewhat darker because of the greater proportion of summerwood and frequently has a relatively lifeless appearance, especially in woods which normally have an abrupt transition from springwood to summerwood (fig. 4–7). Because it is more opaque than normal wood, intermediate stages of compression wood can be detected by transmitted light through thin cross sections.

Tension wood is more difficult to detect than compression wood. However, eccentric growth as seen on the transverse section frequently indicates its presence. Also, the tough tension wood fibers resist being cut cleanly and result in a woolly condition on the surfaces of sawn boards, especially when surfaced in the green condition (fig. 4–8). In some species, tension wood may show up on a smooth surface as areas of contrasting colors. Examples of this are the silvery appearance of tension wood in sugar maple and the darker color of tension wood in mahogany.

Compression Failures

Excessive bending of standing trees from wind or snow, felling trees across boulders, logs, or irregularities in the ground, or the rough handling of logs or lumber may produce excessive compression stresses along the grain that cause minute compression failures. In some instances, such failures are visible on the surface of a board as minute lines or zones formed by the crumpling or buckling of the cells (fig. 4–9A), although usually they appear only as white lines or may even be invisible to the naked eye. Their presence frequently is

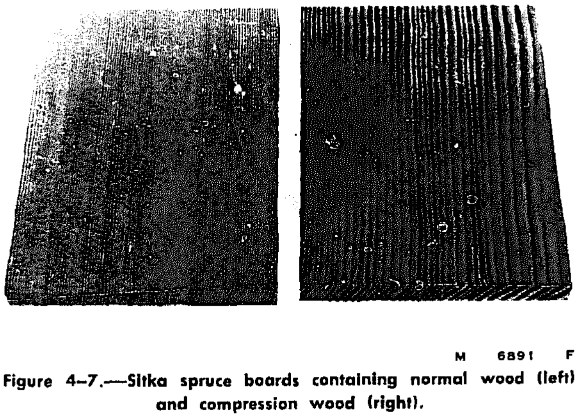

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Figure 4–7.—Sitka spruce boards containing normal wood (left) and compression wood (right).

indicated by fiber breakage on end grain (fig. 4–9B). Compression failures should not be confused with compression wood.

Products containing visible compression failures can have seriously low strength properties, especially in tensile strength and shock resistance. Tensile strength of wood containing compression failures has been found to be as low as one-third of the strength of matched clear wood. Even small compression failures, visible only under the microscope, seriously reduce strength and cause brittle fracture. Because of the low strength asssociated with compression failures, many safety codes require certain structural members, such as ladder rails and scaffold planks, to be entirely free of them.

Compression failures are often difficult to detect with the unaided eye, and special efforts including optimum lighting are required to aid detection.

Pitch Pockets

A pitch pocket is a well-defined opening that contains free resin. It extends parallel to the annual rings, and is almost flat on the pith side and curved on the bark side. Pitch pockets are confined to such species as the pines, spruces, Douglas-fir, tamarack, and western larch.

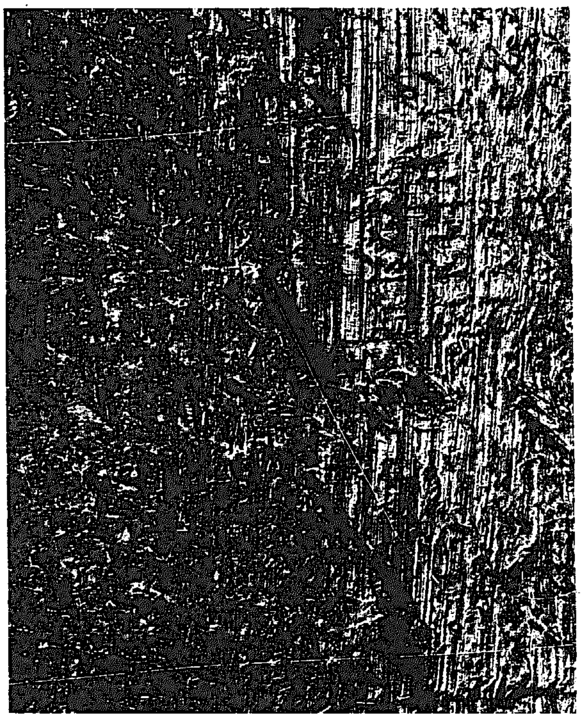

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Figure 4–8.—Projecting tension wood fibers on the sawn surface of a mahogany board.

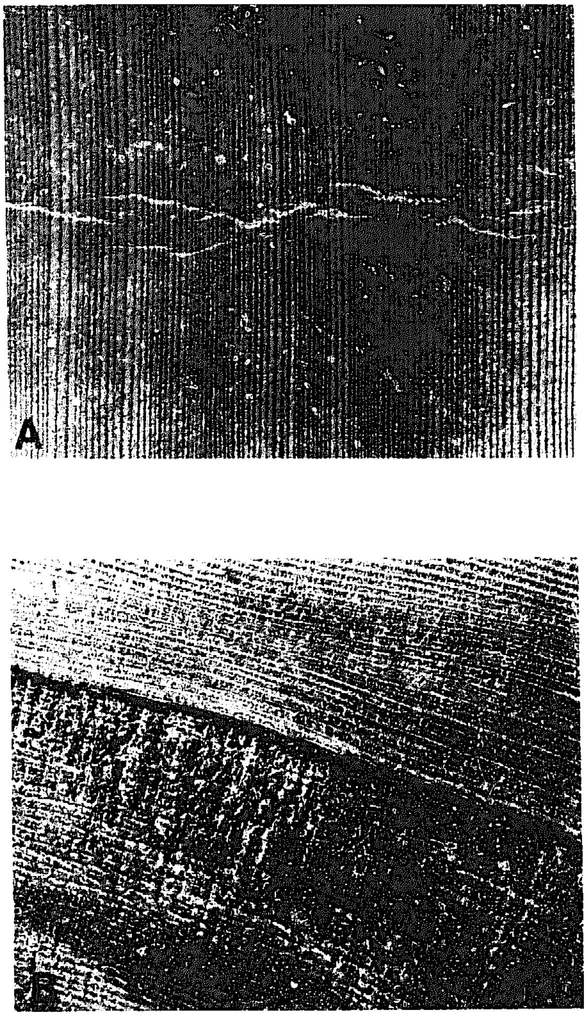

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Figure 4–9.—*A.* Compression failure is shown by the irregular lines across the grain. *B.* End-grain surfaces of surfaces of spruce lumber show fiber breakage caused by compression failures below the dark line.

The effect of pitch pockets on strength depends upon their number, size, and location in the piece. A large number of pitch pockets indicates a lack of bond between annual growth layers, and a piece containing them should be inspected for shake or separations along the grain.

Bird Peck

Maple, hickory, white ash, and a number of other species are often damaged by small holes made by woodpeckers. These holes or bird pecks are often placed in horizontal rows, sometimes encircling the tree, and a brown or black discoloration known as a mineral streak originates there. Holes for tapping maple trees are also a source of mineral streaks. The streaks are caused by oxidation and other chemical changes in the wood.

Bird pecks and mineral streaks are not generally important in regard to strength, although they do impair the appearance of the wood. However, if several bird pecks occur in a row across the outer surface of a piece of wood that is to be used in a bent product, such as a handle, the holes can appreciably weaken the product.

Extractives

Many species of wood contain extraneous materials or extractives that can be removed by solvents that do not degrade the cellulosic/lignin structure of the wood. These extractives are especially abundant in species such as larch, redwood, western redcedar, and black locust.

A small increase in modulus of rupture and in strength in compression parallel to grain has been measured for some species containing extractives. The extent to which the extractives influence the strength is apparently a function of the amount of extractives, the moisture content of the piece, and the mechanical property under consideration.

Timber From Live Versus Dead Trees

Timber from trees killed by insects, blight, wind, or fire may be as good for any structural purpose as that from live trees, provided further insect attack, staining, decay, or seasoning degrade has not occurred. In considering the subject, it may be useful to remember that the heartwood of a living tree is entirely dead, and in the sapwood only a comparatively few cells are living. Therefore, most wood is dead when cut, regardless of whether the tree itself is living or not. However, if a tree stands on the stump too long after its death, the sapwood is likely to decay or to be attacked severely by wood-boring insects, and in time the heartwood will be similarly affected. Such deterioration occurs also in logs that have been cut from live trees and improperly cared for afterwards. Because of variations in climatic and local weather conditions and in other factors that affect deterioration, the length of the period during which dead timber may stand or lie in the forest without serious deterioration varies.

Tests on wood from trees that had stood as long as 15 years after being killed by fire demonstrated that this wood was as sound and as strong as wood from live trees. Also, logs of some of the more durable species have had thoroughly sound heartwood after lying on the ground in the forest for many years.

On the other hand, decay may cause great loss of strength within a very brief time, both in trees standing dead on the stump and in logs cut from live trees and allowed to lie on the ground. The important consideration is not whether the trees from which timber products are cut are alive or dead, but whether the products themselves are free from decay or other defects that would render them unsuitable for use.

EFFECT OF MANUFACTURING AND SERVICE ENVIRONMENT ON MECHANICAL PROPERTIES OF CLEAR STRAIGHT-GRAINED WOOD

Moisture Content—Drying

Many mechanical properties are affected by changes in moisture content below the fiber saturation point. Most properties reported in tables 4–2, 4–3, and 4–4 increase with decrease in moisture content. The relation that describes these clear wood property changes in the vicinity of 70° F. is:

$$P=P_{12}\left(\frac{P_{12}}{P_g}\right)^{-\left(\frac{M-12}{M_p-12}\right)}$$

where P is the property and M the moisture content in percent. M_p is the moisture content at which property changes due to drying are first observed. This moisture content is slightly less than the fiber saturation point. (Table 4–11 gives values of M_p for a few species; for other species, $M_p=25$ may be assumed.)

P_{12} is the property value at 12 percent moisture content, and P_g (green condition) is the property value for all moisture contents greater than M_p. Average property values of P_{12} and P_g are given for many species in tables 4–2, 4–3, and 4–4.

The formula for moisture content adjustment is not recommended for work to maximum load, impact bending, and tension perpendicular. These properties are known to be erratic in

Table 4–11.—*Moisture content at which properties change due to drying for selected species*

Species	M_p
	Pct.
Ash white	24
Birch, yellow	27
Chestnut, American	24
Douglas-fir	24
Hemlock, western	28
Larch, western	28
Pine, loblolly	21
Pine, longleaf	21
Pine, red	24
Redwood	21
Spruce, red	27
Spruce, Sitka	27
Tamarack	24

their response to moisture content change, often apparently as a function of species.

The formula can be used to estimate a property at any moisture content below M_p from the species data given. For example, suppose the modulus of rupture of white ash at 8 percent moisture content is wanted. Using information from table 4–2:

$$P_8 = (15{,}400)\left(\frac{15{,}400}{9{,}600}\right)^{\left(\frac{-4}{12}\right)}$$

$$P_8 = 18{,}020 \text{ p.s.i.}$$

The increase in mechanical properties discussed above assume small, clear specimens in a drying process in which no deterioration of the product (degrade) occurs. The property changes applied to large wood specimens such as lumber are discussed in chapter 6.

Drying degrade can take several forms. Perhaps the most common degrade is surface and end checking. Checks most often limit mechanical properties. Some loss of strength, especially in shock resistance, may occur when wood is dried at excessively high temperatures, although visible signs of degrade may not be present.

Further information is included in chapter 14.

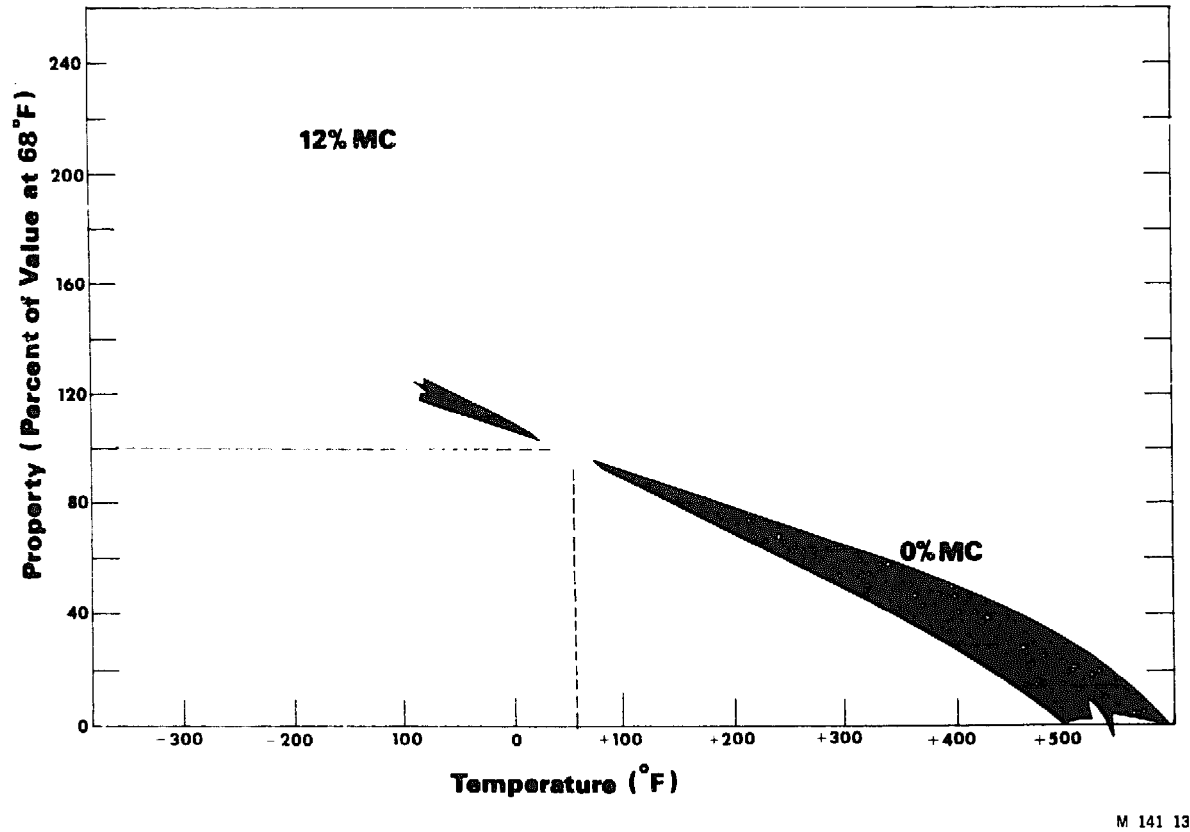

Figure 4–10.—The immediate effect of temperature on strength properties, expressed as percent of value at 68° F. Trends illustrated are composites from studies on three strength properties—modulus of rupture in bending, tensile strength perpendicular to grain, and compressive strength parallel to grain—as examined by several investigators. Variability in reported results is illustrated by the width of the bands.

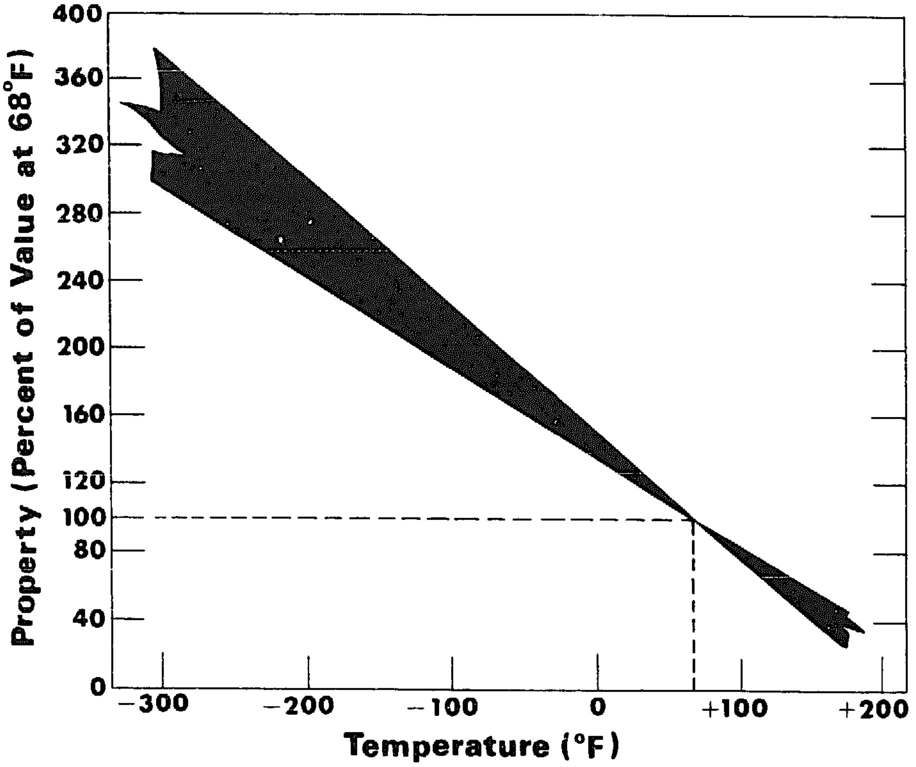

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Figure 4–11.—The immediate effect of temperature on the proportional limit in compression perpendicular to grain at approximately 12 percent moisture content relative to the value at 68° F. Variability in the reported results of several investigators is illustrated by the width of the band.

Temperature

In general, the mechanical properties of wood decrease when heated and increase when cooled. This effect is immediate, but prolonged exposure at high temperature causes an irreversible decrease in properties.

At a constant moisture content and below about 400° F. mechanical properties are essentially linearly related to temperature. The change in properties that occurs when wood is quickly heated or cooled and then tested at that condition is termed an "immediate effect." At temperatures below 200° F. the immediate effect is essentially reversible; that is, the property will return to the value at the original temperature if the temperature change is rapid.

Figure 4–10 illustrates the immediate effect of temperature on strength, based on a composite of tests for modulus of rupture in bending, tensile strength perpendicular to the grain, and compressive strength parallel to the grain relative to 68° F. Figure 4–11 gives similar information for proportional limit in compression perpendicular to grain. Figure 4–12 illustrates the immediate effect of temperature on the modulus of elasticity as a composite of measurements made in bending, in tension parallel to grain, and in compression parallel to grain. Figures 4–10 through 4–12 represent an interpretation of data from a limited number of investigators. The width of the band illustrates variability between and within reported results. The influence of moisture content is illustrated where data are available.

In addition to the reversible effect of temperature on wood, there is an irreversible effect at elevated temperature. This permanent effect is one of degradation of wood substance, which results in loss of weight and strength. Quantitatively, the loss depends on factors which include moisture content, heating medium, temperature, exposure period, and, to some extent, species and size of piece involved.

The decrease of modulus of rupture due to heating in steam and in water is shown as a function of temperature and heating time in figure 4–13, based on tests of Douglas-fir and Sitka spruce. From the same studies work to maximum load was more greatly affected than modulus of rupture by heating in water (fig. 4–14). The effect of oven heating (wood at 0 pct. moisture content) on the modulus of rupture and modulus of elasticity is shown in figures 4–15 and 4–16, respectively, as derived from tests on four softwoods and two hardwoods. Note that the permanent property losses discussed above are based on tests conducted after the specimens have been cooled to near 75° F. and conditioned to the range of 7 to 12 percent moisture content. If tested hot, presumably immediate and permanent effects would be additive. The extent of property loss is considered greater for hardwoods than for softwoods.

Repeated exposure to elevated temperature has a cumulative effect on wood properties. For example, at a given temperature the property loss will be about the same after six exposure periods of 1 month each as it would after a single 6-month exposure period.

The shape and size of wood pieces are important in analyzing the influence of temperature. If the exposure is for only a short time, so that the inner parts of a large piece do not reach the temperature of the surrounding medium, the immediate effect on strength of inner parts will be less than for outer parts. The type of loading must be considered however. If the member is to be stressed in bending, the outer fibers of a piece are subjected to the greatest load and will ordinarily govern the ultimate strength of the piece; hence, under this loading condition, the fact that the inner part is at a lower temperature may be of little significance.

For extended, noncyclic exposures, it can be assumed that the entire piece reaches the temperature of the heating medium and will, therefore, be subject to permanent strength losses throughout the volume of the piece, regardless of size and mode of stress application. However, wood often will not reach the daily extremes in temperature of the air around

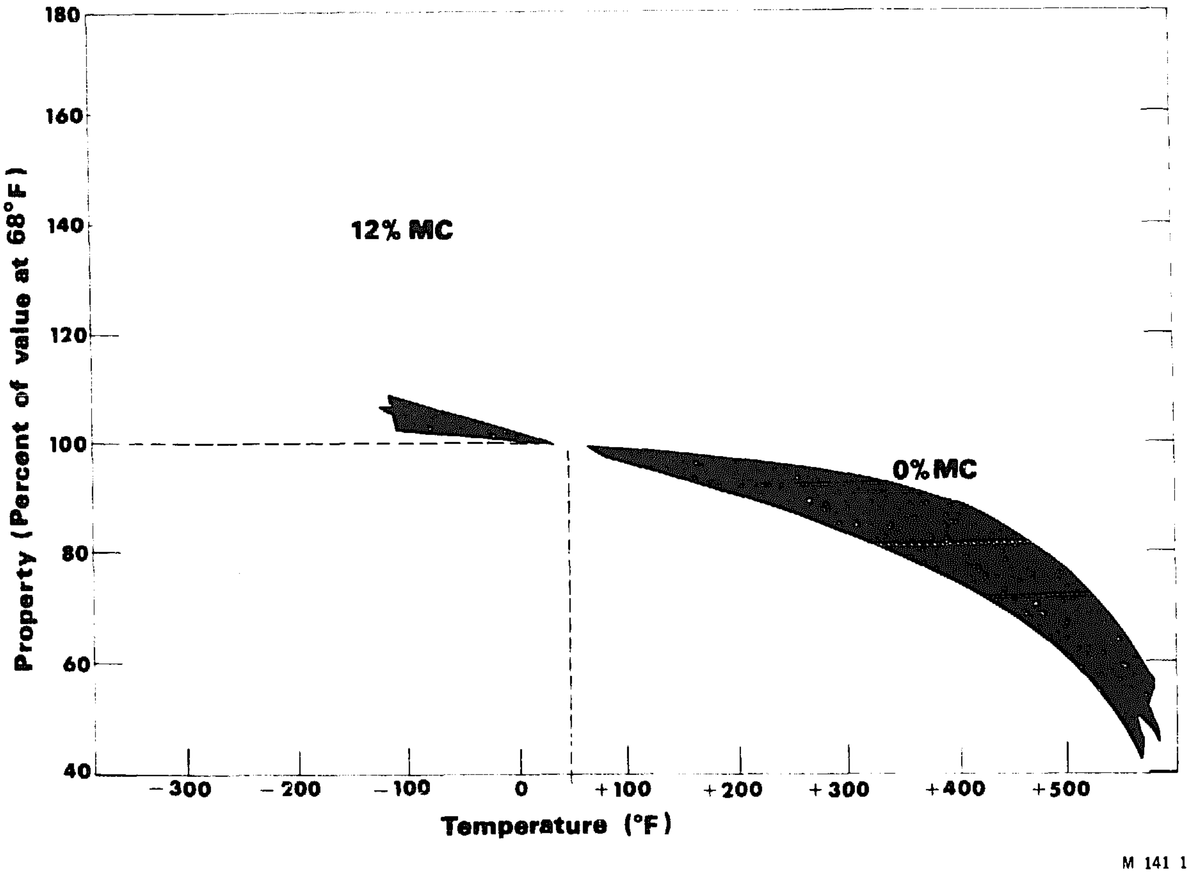

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Figure 4–12.—The immediate effect of temperature on the modulus of elasticity, relative to the value at 68° F. The plot is a composite of studies on the modulus as measured in bending, in tension parallel to the grain, and in compression parallel to grain by several investigators. Variability in reported results is illustrated by the width of the bands.

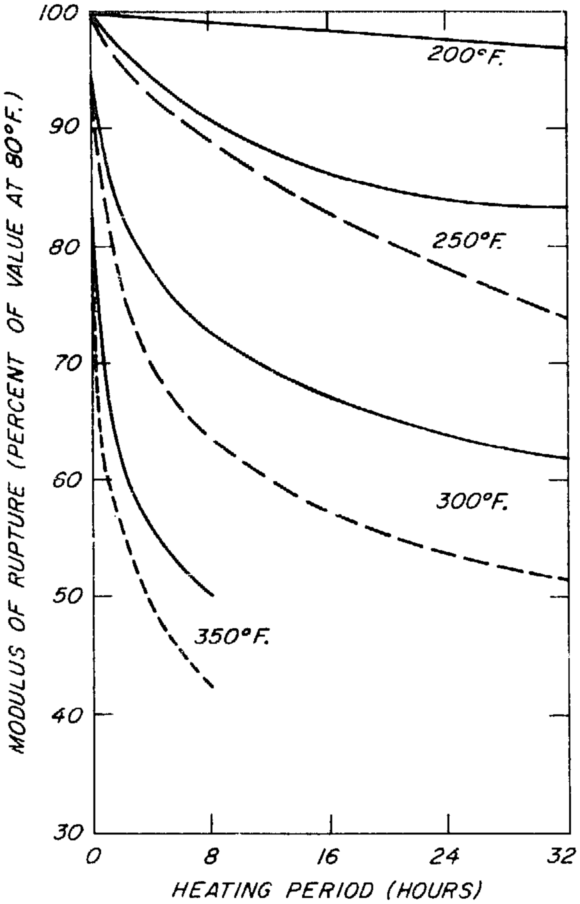

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Figure 4–13.—Permanent effect of heating in water (solid line) and in steam (dashed line) on the modulus of rupture. Data based on tests of Douglas-fir and Sitka spruce.

it in ordinary construction; thus, long-term effects should be based on the accumulated temperature experience of critical structural parts.

Time

Time—Creep/Relaxation

When first loaded, a wood member deforms elastically. If the load is maintained, additional time-dependent deformation occurs. This is called creep. Even at very low stresses, creep takes place and can continue over a period of years. For suitably high loads, failure will eventually occur. This failure phenomenon, termed "duration of load," is discussed in the next section.

At typical design levels the additional deformation due to creep may approximately equal the initial, instantaneous elastic deformation if the environmental conditions are not

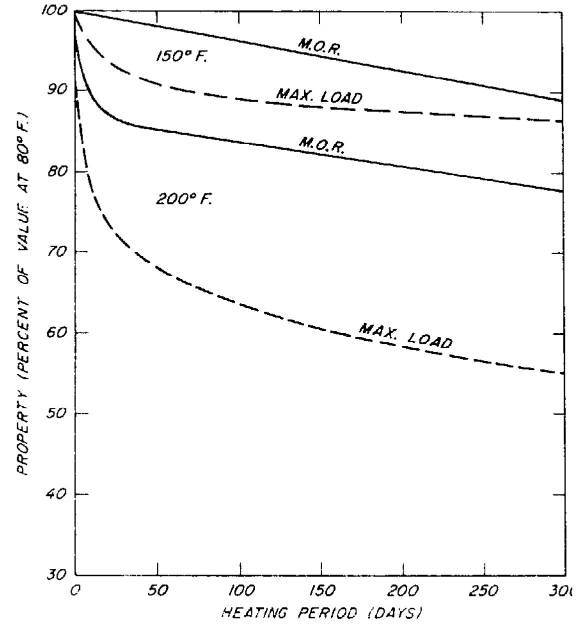

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Figure 4–14.—Permanent effect of heating in water on work to maximum load and on modulus of rupture. Data based on tests of Douglas-fir and Sitka spruce.

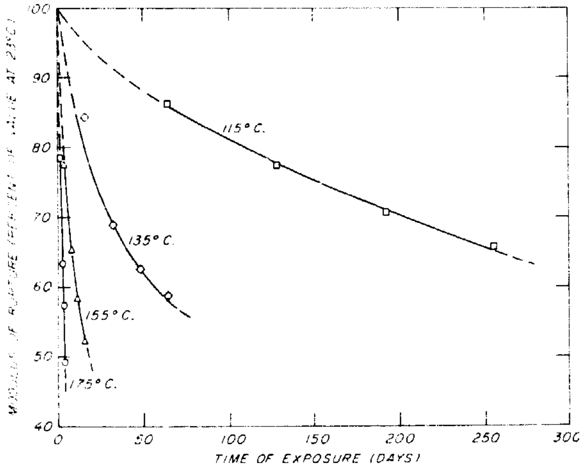

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Figure 4–15.—Permanent effect of oven heating at four temperatures on the modulus of rupture, based on four softwood and two hardwood species.

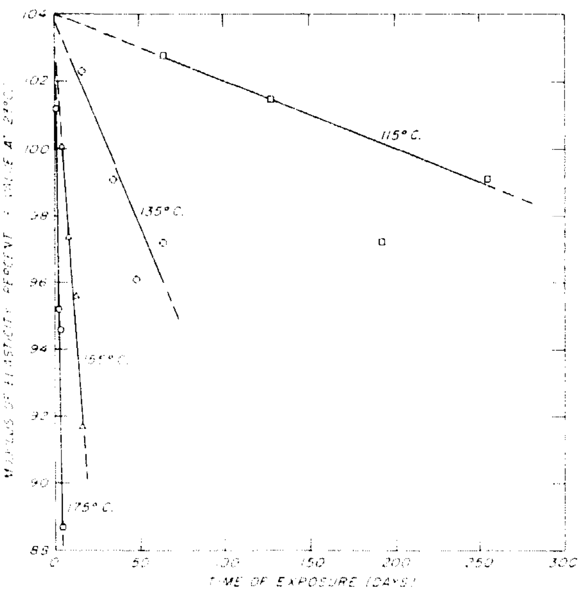

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Figure 4–16.—Permanent effect of oven heating at four temperatures on modulus of elasticity, based on four softwood and two hardwood species.

changed. For illustration, a creep curve based on one species at several stress levels is shown in figure 4–17. It suggests that creep is greater under higher stresses than lower ones.

Ordinary climatic variations in temperature and humidity will cause creep to increase. An increase of about 50° F. in temperature can cause a two- to three-fold increase in creep. Green wood may creep four to six times the initial deformation as it dries under load.

Unloading the member results in an immediate and complete disappearance of the original elastic deformation as well as a delayed recovery of approximately one half of the creep deformation. Fluctuations in temperature and humidity increase the magnitude of the recovered deformation.

Creep at low stress levels is similar in bending, tension, or compression parallel to grain. It is reported to be somewhat less in tension than in bending or compression under varying moisture conditions. Creep across the grain is qualitatively similar to, but likely to be greater than, creep parallel to the grain. The creep behavior of all species studied for creep properties is approximately the same.

If, instead of controlling load or stress, a constant deformation is imposed and maintained on a wood member, the initial stress relaxes at a decreasing rate to about 60 to 70 percent of its original value within a few months. This reduction of stress with time is commonly termed "relaxation."

In limited bending tests carried out between approximately 65° F. and 120° F. over 2 to 3 months, the curve of stress vs. time that expresses relaxation is approximately the mirror image of the creep curve (deformation vs. time). These tests were carried out at stresses up to about 50 percent of the bending strength of the wood. As with creep, relaxation is markedly affected by fluctuations in temperature and humidity.

Time—Duration of Stress

The duration of stress, or the time during which a load acts on a wood member, is an important factor in determining the load that a member can safely carry. For members that continuously carry loads for long periods of time, the load required to produce failure is much less than that determined from the strength properties in tables 4–2, 4–3, and 4–4. For example, a wood member under the continuous action of bending stress for 10 years will carry only about 60 percent of the load required to produce failure in the same specimen loaded in a standard bending strength test of only a few minutes' duration.

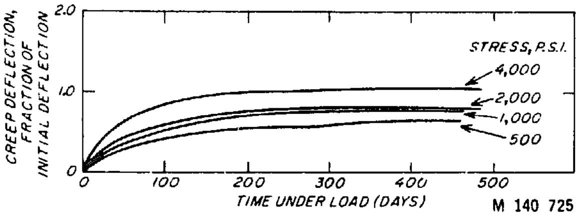

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Figure 4–17.—An illustration of creep as influenced by four levels of stress. (Adapted from Kingston.)

Conversely, if the duration of stress is very short, the load-carrying capacity may be considerably higher than that determined from strength properties given in the tables. The load required to produce failure in a wood member in 1 second is approximately 25 percent higher than that obtained in ASTM standard strength tests. As an approximate indication of relation of strength to duration of stress, the strength may be said to increase or decrease 7 to 8 percent as the duration of stress is respectively decreased or increased by a factor of 10. The duration of stress is one of the factors used in establishing safe allowable stresses for structural timbers; this aspect is discussed in chapter 6.

Time—Fatigue

Fatigue in engineering material is defined as the progressive damage and failure that occurs when a structure or part is subjected to repeated loads of a magnitude smaller than the static strength.

Fatigue should be considered in wood design when repetitions of design stress or near-design stress are expected to be more than 100,000 cycles during the normal life of a structure. In many design considerations, the fatigue criteria specified will be:
(1) Fatigue life (the number of stress cycles to be sustained), (2) range ratio (the ratio of minimum to maximum stress), and (3) the type of loading expected (tension parallel, tension perpendicular, or flexure). The problem will be to determine the greatest stress that can be sustained (proportioned to fatigue strength). If an indefinite fatigue life is specified, the fatigue limit stress should not be exceeded. This is the stress below which a material can be presumed to endure an infinite number of stress cycles.

The repetition of fatigue stresses can take different forms of range ratio, as from zero to some specified stress, or from some specified stress value to a higher stress in the same direction. They may be partially or completely reversed. Partially reversed stresses occur where repeated stresses are not of the same magnitude in the two directions; fully reversed stresses are of equal magnitude, as in compression and tension or as in positive and negative shear. Fully reversed stressing is the most severe loading condition. The range ratio is expressed as -1 for fully reversed loading, as a negative decimal for partially reversed loading, and as a positive decimal for repeated loading. Fatigue strength, fatigue life, and range ratio are reported for several types of loading in table 4–8.

Tests demonstrate that specimens of clear, straight-grained wood subjected to 2 million cycles of bending will have 60 percent of the strength of similar specimens tested under static conditions. In similar fatigue tests, specimens with small knots (ranging from 50 to 90 pct. in estimated strength ratio) had 50 percent of the static strength of clear, straight-grained wood; specimens with 1:12 slope of grain had 45 percent of the static strength value. When knots and slope of grain were both present, the specimens had approximately 30 percent of the static strength figure. This can be illustrated as follows:

Strength	Specimen	Index of Strength (Pct.)
Static	Clear, straight grained	100
Fatigue (2 x 10^6 cycles)	Clear, straight grained	60
Do	Small knots, straight grained	50
Do	Clear, 1:12 slope of grain	45
Do	Small knots, 1:12 slope of grain	30

Time—Age

In relatively dry and moderate temperature conditions where wood is protected from deteriorating influences such as decay, the mechanical properties of wood show little change with time. Test results for very old timbers suggest that significant losses in strength only occur after several centuries of normal aging conditions. The soundness of centuries-old wood in some standing trees (redwood, for example) also attests to the durability of wood.

Chemicals

The effect of chemicals on mechanical properties depends on the specific type of chemical. Nonswelling liquids, such as petroleum oils and creosote, have no appreciable effect on properties. Properties are lowered in the presence of water, alcohol, or other wood-swelling organic liquids even though these liquids do not chemically degrade the wood substance. The loss in properties largely depends on amount of swelling and this loss is regained upon removal of the swelling liquid. Liquid ammonia markedly reduces the strength and stiffness of wood, but most of the reduction is regained upon removal of the ammonia.

Chemical solutions that decompose wood substance have a permanent effect on strength. The following generalizations summarize the effect of chemicals: (1) Some species are quite resistant to attack by dilute mineral and organic acids, (2) oxidizing acids such as nitric acid degrade wood more than nonoxidizing acids, (3) alkaline solutions are more destructive than acidic solutions, and (4) hardwoods are more susceptible to attack by both acids and alkalies than are softwoods. Because both species and application are extremely important, reference to industrial sources with a specific history of use is recommended where possible. For example, large cypress tanks have survived long continuous use where exposure conditions involved mixed acids at the boiling point.

Wood products sometimes are treated with preservative or fire-retarding salts, usually in water solution, to impart resistance to decay or fire. Such products generally are kiln dried after treatment. Mechanical properties are essentially unchanged by preservative treatment.

Properties are, however, affected to some extent by the combined effects of fire-retardant chemicals, treatment methods, and kiln drying. A variety of fire-retardant treatments have been studied. Collectively the studies indicate modulus of rupture, work to maximum load, and toughness are reduced by varying amounts depending on species and type of fire retardant. Work to maximum load and toughness are most affected, with reductions of as much as 45 percent. A reduction in modulus of rupture of as much as 20 percent has been observed; a design reduction of 10 percent is frequently used. Stiffness is not appreciably affected by fire-retardant treatments.

Wood is also sometimes impregnated with monomers, such as methyl methacrylate, which are subsequently polymerized. Many of the properties of the resulting composite are higher than those of the original wood, generally as a result of filling the void spaces in the wood structure with plastic. The polymerization process and both the chemical nature and quantity of monomers are variables that influence composite properties.

A general discussion of the resistance of wood to chemical degradation is given in chapter 3.

Nuclear Radiation

Very large doses of gamma rays or neutrons can cause substantial degradation of wood. In general, irradiation with gamma rays in doses up to about 1 megarad has little effect on the strength properties of wood. As dosage increases above 1 megarad, tensile strength parallel to grain and toughness decrease. At a dosage of 300 megarads, tensile strength is reduced about 90 percent. Gamma rays also affect compressive strength parallel to grain above 1 megarad, but strength losses with further dosage are less than for tensile strength. Only about one-third of the compressive strength is lost when the total dose is 300 megarads. Effects of gamma rays on bending and shear strength are intermediate between the effects on tensile and compressive strength.

Molding and Staining Fungi

Molding and staining fungi do not seriously affect most mechanical properties of wood because they feed upon substance within the structural cell wall rather than on the structural wall itself. Specific gravity may be reduced by from 1 to 2 percent, while most of the strength properties are reduced by a comparable or only slightly greater extent. Toughness or shock resistance, however, may be reduced by up to 30 percent. The duration of infection and the species of fungi involved are important factors in determining the extent of weakening.

Although molds and stains themselves often do not have a major effect on the strength of wood products, conditions that favor the development of these organisms are likewise ideal for the growth of wood-destroying (decay) fungi, which can greatly reduce mechanical properties (see ch. 17).

Decay

Unlike the molding and staining fungi, the wood-destroying (decay) fungi seriously reduce strength. Even apparently sound wood adjacent to obviously decayed parts may contain hard-to-detect, early (incipient) decay that is decidedly weakening, especially in shock resistance.

All wood-destroying fungi do not affect wood in the same way. The fungi that cause an easily recognized pitting of the wood, for example, may be less injurious to strength than those that, in the early stages, give a slight discoloration of the wood as the only visible effect.

No method is known for estimating the amount of reduction in strength from the appearance of decayed wood. Therefore, when strength is an important consideration, the safe procedure is to discard every piece that contains even a small amount of decay. An exception may be pieces in which decay occurs in a knot but does not extend into the surrounding wood.

Insect Damage

Insect damage may occur in standing trees, logs, and unseasoned or seasoned lumber. Damage in the standing tree is difficult to control, but otherwise insect damage can be largely eliminated by proper control methods.

Insect holes are generally classified as pinholes, grub holes, and powderpost holes. The powderpost larvae, by their irregular burrows, may destroy most of the interior of a piece, while the surface shows only small holes, and the strength of the piece may be reduced virtually to zero.

No method is known for estimating the amount of reduction in strength from the appearance of insect-damaged wood, and, when strength is an important consideration, the safe procedure is to eliminate pieces containing insect holes.

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APPENDIX

In this appendix, tables 4–2, 4–3, and 4–4 have been rewritten in SI or metric units, and thus appear as tables A–4–2, A–4–3, and A–4–4. The units used follow the ASTM Metric Practice Guide, E 380–72, where the newton is the basic measure of force, the pascal that of stress, the meter that of length, and the joule that of energy.

Table A-4-2.—*Mechanical properties* [1,2] *of some commercially important woods grown in the United States*

Common names of species	Specific gravity [3]	Static bending			Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Modulus of—		Work to maximum load						
		Rupture	Elasticity [4]							
		Kilopascals	*Megapascals*	*Kilojoules per cu. m.*	*Mm.*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Newtons*
				HARDWOODS						
Alder, red	0.37	45,000	8,100	55	560	20,400	1,700	5,300	2,700	2,000
	.41	68,000	9,500	58	510	40,100	3,000	7,400	2,900	2,600
Ash:										
Black	.45	41,000	7,200	83	840	15,900	2,400	5,900	3,400	2,300
	.49	87,000	11,000	103	890	41,200	5,200	10,800	4,800	3,800
Blue	.53	66,000	8,500	101	...	24,800	5,600	10,600		...
	.58	95,000	9,700	99		48,100	9,800	14,000	...	...
Green	.53	66,000	9,700	81	890	29,000	5,000	8,700	4,100	3,900
	.56	97,000	11,400	92	810	48,800	9,000	13,200	4,800	5,300
Oregon	.50	52,000	7,800	84	990	24,200	3,700	8,200	4,100	3,500
	.55	88,000	9,400	99	840	41,600	8,600	12,300	5,000	5,200
White	.55	66,000	9,900	114	970	27,500	4,600	9,500	4,100	4,300
	.60	106,000	12,000	121	1090	51,100	8,000	13,400	6,500	5,900
Aspen:										
Bigtooth	.36	37,000	7,700	39	...	17,200	1,400	5,000	...	...
	.39	63,000	9,900	53	...	36,500	3,100	7,400	...	...
Quaking	.35	35,000	5,900	44	560	14,800	1,200	4,600	1,600	1,300
	.38	58,000	8,100	52	530	29,300	2,600	5,900	1,800	1,600
Basswood, American	.32	34,000	7,200	37	410	15,300	1,200	4,100	1,900	1,100
	.37	60,000	10,100	50	410	32,600	2,600	6,800	2,400	1,800
Beech, American	.56	59,000	9,500	82	1090	24,500	3,700	8,900	5,000	3,800
	.64	103,000	11,900	104	1040	50,300	7,000	13,900	7,000	5,800
Birch:										
Paper	.48	44,000	8,100	112	1240	16,300	1,900	5,800	2,600	2,500
	.55	85,000	11,000	110	860	39,200	4,100	8,300	...	4,000
Sweet	.60	65,000	11,400	108	1220	25,800	3,200	8,500	3,000	4,300
	.65	117,000	15,000	124	1190	58,900	7,400	15,400	6,600	6,500
Yellow	.55	57,000	10,300	111	1220	23,300	3,000	7,700	3,000	3,500
	.62	114,000	13,900	143	1400	56,300	6,700	13,000	6,300	5,600

Table A–4–2.—*Mechanical properties* [1,2] *of some commercially important woods grown in the United States*—Continued

Common names of species	Specific gravity [3]	Static bending: Modulus of— Rupture	Static bending: Modulus of— Elasticity [4]	Static bending: Work to maximum load	Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Kilopascals	*Megapascals*	*Kilojoules per cu. m.*	*Mm.*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Newtons*
HARDWOODS—continued										
Butternut	.36	37,000	6,700	57	610	16,700	1,500	5,200	3,000	1,700
	.38	56,000	8,100	57	610	35,200	3,200	8,100	3,000	2,200
Cherry, black	.47	55,000	9,000	88	840	24,400	2,500	7,800	2,900	2,900
	.50	85,000	10,300	79	740	49,000	4,800	11,700	3,900	4,200
Chestnut, American	.40	39,000	6,400	48	610	17,000	2,100	5,500	3,000	1,900
	.43	59,000	8,500	45	480	36,700	4,300	7,400	3,200	2,400
Cottonwood:										
Balsam poplar	.31	27,000	5,200	29	----	11,700	1,000	3,400	----	----
	.34	47,000	7,600	34	----	27,700	2,100	5,400	----	----
Black	.31	34,000	7,400	34	510	15,200	1,100	4,200	1,900	1,100
	.35	59,000	8,800	46	560	31,000	2,100	7,200	2,300	1,600
Eastern	.37	37,000	7,000	50	530	15,700	1,400	4,700	2,800	1,500
	.40	59,000	9,400	51	510	33,900	2,600	6,400	4,000	1,900
Elm:										
American	.46	50,000	7,700	81	970	20,100	2,500	6,900	4,100	2,800
	.50	81,000	9,200	90	990	38,100	4,800	10,400	4,600	3,700
Rock	.57	66,000	8,200	137	1370	26,100	4,200	8,800	----	----
	.63	102,000	10,600	132	1420	48,600	8,500	13,200	----	----
Slippery	.48	55,000	8,500	106	1190	22,900	2,900	7,700	4,400	2,900
	.53	90,000	10,300	117	1140	43,900	5,700	11,200	3,700	3,800
Hackberry	.49	45,000	6,600	100	1220	18,300	2,800	7,400	4,300	3,100
	.53	76,000	8,200	88	1090	37,500	6,100	11,000	4,000	3,900
Hickory, pecan:										
Bitternut	.60	71,000	9,700	138	1680	31,500	5,500	8,500	----	----
	.66	118,000	12,300	125	1680	62,300	11,600	----	----	----
Nutmeg	.56	63,000	8,900	157	1370	27,400	5,200	7,100	----	----
	.60	114,000	11,700	173	----	47,600	10,800	----	----	----

Pecan	.60	68,000	9,400	101	1350	27,500	5,400	10,200	4,700	5,800
	.66	94,000	11,900	95	1120	54,100	11,900	14,300	----	8,100
Water	.61	74,000	10,800	130	1420	32,100	6,100	9,900	----	----
	.62	123,000	13,900	133	1350	59,300	10,700	----	--	----
Hickory, true:										
Mockernut	.64	77,000	10,800	180	2240	30,900	5,600	8,800	---	----
	.72	132,000	15,300	156	1960	61,600	11,900	12,000		----
Pignut	.66	81,000	11,400	219	2260	33,200	6,300	9,400		----
	.75	139,000	15,600	210	1880	63,400	13,700	14,800		----
Shagbark	.64	76,000	10,800	163	1880	31,600	5,800	10,500	---	----
	.72	139,000	14,900	178	1700	63,500	12,100	16,800	---	----
Shellbark	.62	72,000	9,200	206	2640	27,000	5,600	8,200	---	----
	.69	125,000	13,000	163	2240	55,200	12,400	14,500	---	----
Honeylocust	.60	70,000	8,900	87	1190	30,500	7,900	11,400	6,400	6,200
		101,000	11,200	92	1190	51,700	12,700	15,500	6,200	7,000
Locust, black	.66	95,000	12,800	106	1120	46,900	8,000	12,100	5,300	7,000
	.69	134,000	14,100	127	1450	70,200	12,600	17,100	4,400	7,600
Magnolia:										
Cucumber tree	.44	51,000	10,800	69	760	21,600	2,300	6,800	3,000	2,300
	.48	85,000	12,500	84	890	43,500	3,900	9,200	4,600	3,100
Southern	.46	47,000	7,700	106	1370	18,600	3,200	7,200	4,200	3,300
	.50	77,000	9,700	88	740	37,600	5,900	10,500	5,100	4,500
Maple:										
Bigleaf	.44	51,000	7,600	60	580	22,300	3,100	7,700	4,100	2,800
	.48	74,000	10,000	54	710	41,000	5,200	11,900	3,700	3,800
Black	.52	54,000	9,200	88	1220	22,500	4,100	7,800	5,000	3,700
	.57	92,000	11,200	86	1020	46,100	7,000	12,500	4,600	5,200
Red	.49	53,000	9,600	79	810	22,600	2,800	7,900	----	3,100
	.54	92,000	11,300	86	810	45,100	6,900	12,800	----	4,200
Silver	.44	40,000	6,500	76	740	17,200	2,600	7,200	3,900	2,600
	.47	61,000	7,900	57	640	36,000	5,100	10,200	3,400	3,100
Sugar	.56	65,000	10,700	92	1020	27,700	4,400	10,100	----	4,300
	.63	109,000	12,600	114	990	54,000	10,100	16,100	----	6,400
Oak, red:										
Black	.56	57,000	8,100	84	1020	23,900	4,900	8,400	----	4,700
	.61	96,000	11,300	94	1040	45,000	6,400	13,200	----	5,400
Cherrybark	.61	74,000	12,300	101	1370	31,900	5,200	9,100	5,500	5,500
	.68	125,000	15,700	126	1240	60,300	8,600	13,800	5,800	6,600

Table A-4-2.—*Mechanical properties*[1,2] *of some commercially important woods grown in the United States*—Continued

Common names of species	Specific gravity[3]	Static bending			Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Modulus of—		Work to maximum load						
		Rupture	Elasticity[4]							
		Kilopascals	*Megapascals*	*Kilojoules per cu. m.*	*Mm.*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Newtons*
				HARDWOODS—continued						
Oak, red (cont.)										
Laurel	.56	54,000	9,600	77	990	21,900	3,900	8,100	5,300	4,400
	.63	87,000	11,700	81	990	48,100	7,300	12,600	5,400	5,400
Northern red	.56	57,000	9,300	91	1120	23,700	4,200	8,300	5,200	4,400
	.63	99,000	12,500	100	1090	46,600	7,000	12,300	5,500	5,700
Pin	.58	57,000	9,100	97	1220	25,400	5,000	8,900	5,500	4,800
	.63	97,000	11,900	102	1140	47,000	7,000	14,300	7,200	6,700
Scarlet	.60	72,000	10,200	103	1370	28,200	5,700	9,700	4,800	5,300
	.67	120,000	13,200	141	1350	57,400	7,700	13,000	6,000	6,200
Southern red	.52	48,000	7,900	55	740	20,900	3,800	6,400	3,300	3,800
	.59	75,000	10,300	65	660	42,000	6,000	9,600	3,500	4,700
Water	.56	61,000	10,700	77	990	25,800	4,300	8,500	5,700	4,500
	.63	106,000	13,900	148	1120	46,700	7,000	13,900	6,300	5,300
Willow	.56	51,000	8,900	61	890	20,700	4,200	8,100	5,200	4,400
	.69	100,000	13,100	101	1070	48,500	7,800	11,400	...	6,500
Oak, white:										
Bur	.58	50,000	6,100	74	1120	22,700	4,700	9,300	5,500	4,900
	.64	71,000	7,100	68	740	41,800	8,300	12,500	4,700	6,100
Chestnut	.57	55,000	9,400	65	890	24,300	3,700	8,300	4,800	4,000
	.66	92,000	11,000	76	1020	47,100	5,800	10,300	...	5,000
Live	.80	82,000	10,900	85	...	37,400	14,100	15,200	...	...
	.88	127,000	13,700	130	...	61,400	19,600	18,300	...	...
Overcup	.57	55,000	7,900	87	1120	23,200	3,700	9,100	5,000	4,300
	.63	87,000	9,300	108	970	42,700	5,600	13,800	6,500	5,300
Post	.60	56,000	7,500	76	1120	24,000	5,900	8,800	5,400	5,000
	.67	91,000	10,400	91	1170	45,300	9,900	12,700	5,400	6,000
Swamp chestnut	.60	59,000	9,300	88	1140	24,400	3,900	8,700	4,600	4,900
	.67	96,000	12,200	83	1040	50,100	7,700	13,700	4,800	5,500

Swamp white	.64	68,000	11,000	100	1270	30,100	5,200	9,000	5,900	5,200
	.72	122,000	14,100	132	1240	59,300	8,200	13,800	5,700	7,200
White	.60	57,000	8,600	80	1070	24,500	4,600	8,600	5,300	4,700
	.68	105,000	12,300	102	940	51,300	7,400	13,800	5,500	6,000
Sassafras	.42	41,000	6,300	49	....	18,800	2,600	6,600		....
	.46	62,000	7,700	60	....	32,800	5,900	8,500		....
Sweetgum	.46	49,000	8,300	70	910	21,000	2,600	6,800	3,700	2,700
	.52	86,000	11,300	82	810	43,600	4,300	11,000	5,200	3,800
Sycamore, American	.46	45,000	7,300	52	660	20,100	2,500	6,900	4,300	2,700
	.49	69,000	9,800	59	660	37,100	4,800	10,100	5,000	3,400
Tanoak	.58	72,000	10,700	92	....	32,100				....
Tupelo:										
Black	.46	48,000	7,100	55	760	21,000	3,300	7,600	3,900	2,800
	.50	66,000	8,300	43	560	38,100	6,400	9,200	3,400	3,600
Water	.46	50,000	7,200	57	760	23,200	3,300	8,200	4,100	3,200
	.50	66,000	8,700	48	580	40,800	6,000	11,000	4,800	3,900
Walnut, black	.51	66,000	9,800	101	940	29,600	3,400	8,400	3,900	4,000
	.55	101,000	11,600	74	860	52,300	7,000	9,400	4,800	4,500
Willow, black	.36	33,000	5,400	76	....	14,100	1,200	4,700		....
	.39	54,000	7,000	61	....	28,300	3,000	8,600		....
Yellow-poplar	.40	41,000	8,400	52	660	18,300	1,900	5,400	3,500	2,000
	.42	70,000	10,900	61	610	38,200	3,400	8,200	3,700	2,400
SOFTWOODS										
Baldcypress	.42	46,000	8,100	46	640	24,700	2,800	5,600	2,100	1,700
	.46	73,000	9,900	57	610	43,900	5,000	6,900	1,900	2,300
Cedar:										
Alaska-	.42	44,000	7,900	63	690	21,000	2,400	5,800	2,300	2,000
	.44	77,000	9,800	72	740	43,500	4,300	7,800	2,500	2,600
Atlantic white-	.31	32,000	5,200	41	460	16,500	1,700	4,800	1,200	1,300
	.32	47,000	6,400	28	330	32,400	2,800	5,500	1,500	1,600
Eastern redcedar	.44	48,000	4,500	103	890	24,600	4,800	7,000	2,300	2,900
	.47	61,000	6,100	57	560	41,500	6,300	....	....	4,000
Incense-	.35	43,000	5,800	44	430	21,700	2,600	5,700	1,900	1,700
	.37	55,000	7,200	37	430	35,900	4,100	6,100	1,900	2,100
Northern white-	.29	29,000	4,400	39	380	13,700	1,600	4,300	1,700	1,000
	.31	45,000	5,500	33	300	27,300	2,100	5,900	1,700	1,400

Table A-4-2.—*Mechanical properties* [1,2] *of some commercially important woods grown in the United States*—Continued

Common names of species	Specific gravity[3]	Static bending			Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Modulus of—		Work to maximum load						
		Rupture	Elasticity[4]							
		Kilopascals	*Megapascals*	*Kilojoules per cu. m.*	*Mm.*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Newtons*
SOFTWOODS—continued										
Cedars (cont.)										
Port-Orford-	.39	46,000	9,000	51	530	21,600	2,100	5,800	1,200	1,700
	.43	88,000	11,700	63	710	43,100	5,000	9,400	2,800	2,800
Western redcedar	.31	35,900	6,500	34	430	19,100	1,700	5,300	1,600	1,200
	.32	51,700	7,700	40	430	31,400	3,200	6,800	1,500	1,600
Douglas-fir:[5]										
Coast	.45	53,000	10,800	52	660	26,100	2,600	6,200	2,100	2,200
	.48	85,000	13,400	68	790	49,900	5,500	7,800	2,300	3,200
Interior West	.46	53,000	10,400	50	660	26,700	2,900	6,500	2,000	2,300
	.50	87,000	12,500	73	810	51,300	5,200	8,900	2,400	2,900
Interior North	.45	51,000	9,700	56	560	23,900	2,500	6,600	2,300	1,900
	.48	90,000	12,300	72	660	47,600	5,300	9,700	2,700	2,700
Interior South	.43	47,000	8,000	55	380	21,400	2,300	6,600	1,700	1,600
	.46	82,000	10,300	62	510	42,900	5,100	10,400	2,300	2,300
Fir:										
Balsam	.34	34,000	6,600	32	410	16,500	1,200	4,200	1,200	1,300
	.36	52,000	8,500	35	510	31,200	2,100	4,900	1,200	1,800
California red	.36	40,000	8,100	44	530	19,000	2,300	5,300	2,600	1,600
	.38	72,000	10,300	61	610	37,700	4,200	7,200	2,700	2,200
Grand	.35	40,000	8,600	39	560	20,300	1,900	5,100	1,700	1,600
	.37	61,000	10,800	52	710	36,500	3,400	6,300	1,700	2,200
Noble	.37	43,000	9,500	41	480	20,800	1,900	5,500	1,600	1,300
	.39	74,000	11,900	61	580	42,100	3,600	7,200	1,500	1,800
Pacific silver	.40	44,000	9,800	41	530	21,600	1,500	5,200	1,700	1,400
	.43	73,000	11,900	64	610	45,000	3,100	8,100	....	1,900
Subalpine	.31	34,000	7,200	..	..	15,900	1,300	4,800	....	1,200
	.32	59,000	8,900	..	....	33,500	2,700	7,400	....	1,600
White	.37	41,000	8,000	39	560	20,000	1,900	5,200	2,100	1,500
	.39	68,000	10,300	50	510	40,100	3,700	7,600	2,100	2,100

Hemlock:										
Eastern	.38	44,000	7,400	46	530	21,200	2,500	5,900	1,600	1,800
	.40	61,000	8,300	47	530	37,300	4,500	7,300		2,200
Mountain	.42	43,000	7,200	76	810	19,900	2,600	6,400	2,300	2,100
	.45	79,000	9,200	72	810	44,400	5,900	10,600		3,000
Western	.42	46,000	9,000	48	560	23,200	1,900	5,900	2,000	1,800
	.45	78,000	11,300	57	580	49,000	3,800	8,600	2,300	2,400
Larch, western	.48	53,000	10,100	71	740	25,900	2,800	6,000	2,300	2,300
	.52	90,000	12,900	87	890	52,700	6,400	9,400	3,000	3,700
Pine:										
Eastern white	.34	34,000	6,800	36	430	16,800	1,500	4,700	1,700	1,300
	.35	59,000	8,500	47	460	33,100	3,000	6,200	2,100	1,700
Jack	.40	41,000	7,400	50	660	20,300	2,100	5,200	2,500	1,800
	.43	68,000	9,300	57	690	39,000	4,000	8,100	2,900	2,500
Loblolly	.47	50,000	9,700	57	760	24,200	2,700	5,900	1,800	2,000
	.51	88,000	12,300	72	760	49,200	5,400	9,600	3,200	3,100
Lodgepole	.38	38,000	7,400	39	510	18,000	1,700	4,700	1,500	1,500
	.41	65,000	9,200	47	510	37,000	4,200	6,100	2,000	2,100
Longleaf	.54	59,000	11,000	61	890	29,800	3,300	7,200	2,300	2,600
	.59	100,000	13,700	81	860	58,400	6,600	10,400	3,200	3,900
Pitch	.47	47,000	8,300	63	....	20,300	....	5,900	....	
	.52	74,000	9,900	63	....	41,000		9,400		....
Pond	.51	51,000	8,800	52	....	25,200	3,000	6,500	....	....
	.56	80,000	12,100	59	....	52,000	6,300	9,500	....	....
Ponderosa	.38	35,000	6,900	36	530	16,900	1,900	4,800	2,100	1,400
	.40	65,000	8,900	49	480	36,700	4,000	7,800	2,900	2,000
Red	.41	40,000	8,800	42	660	18,800	1,800	4,800	2,100	1,500
	.46	76,000	11,200	68	660	41,900	4,100	8,400	3,200	2,500
Sand	.46	52,000	7,000	66	....	23,700	3,100	7,900	....	....
	.48	80,000	9,700	66	....	47,700	5,800	....	....	....
Shortleaf	.47	51,000	9,600	57	760	24,300	2,400	6,300	2,200	2,000
	.51	90,000	12,100	76	840	50,100	5,700	9,600	3,200	3,100
Slash	.54	60,000	10,500	66	....	26,300	3,700	6,600	....	....
	.59	112,000	13,700	91	....	56,100	7,000	11,600	....	....
Spruce	.41	41,000	6,900	....	....	19,600	1,900	6,200	....	2,000
	.44	72,000	8,500	....	....	39,000	5,000	10,300	....	2,900
Sugar	.34	34,000	7,100	37	430	17,000	1,400	5,000	1,900	1,200
	.36	57,000	8,200	38	460	30,800	3,400	7,800	2,400	1,700

Table A-4-2.—*Mechanical properties* [1,2] *of some commercially important woods grown in the United States*—Continued

Common names of species	Specific gravity [3]	Static bending — Modulus of— Rupture	Static bending — Modulus of— Elasticity [4]	Static bending — Work to maximum load	Impact bending—height of drop causing complete failure	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Tension perpendicular to grain—maximum tensile strength	Side hardness—load perpendicular to grain
		Kilopascals	*Megapascals*	*Kilojoules per cu. m.*	*Mm.*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*	*Newtons*
				SOFTWOODS—continued						
Pine (Cont.)										
Virginia	.45	50,000	8,400	75	860	23,600	2,700	6,100	2,800	2,400
	.48	90,000	10,500	94	810	46,300	6,300	9,300	2,600	3,300
Western white	.35	32,000	8,200	34	480	16,800	1,300	4,700	1,800	1,200
	.38	67,000	10,100	61	580	34,700	3,200	7,200		1,900
Redwood:										
Old-growth	.38	52,000	8,100	51	530	29,000	2,900	5,500	1,800	1,800
	.40	69,000	9,200	48	480	42,400	4,800	6.500	1,700	2,100
Young-growth	.34	41,000	6,600	39	410	21,400	1,900	6,100	2,100	1,600
	.35	54,000	7,600	36	380	36,000	3,600	7,600	1,700	1,900
Spruce:										
Black	.38	37,000	7,300	51	610	17,700	1,000	4,600	700	1,600
	.40	71,000	10,500	72	580	36,700	3,700	7,100		2,300
Engelmann	.33	32,000	7,100	35	410	15,000	1,400	4,400	1,700	1,150
	.35	64,000	8,900	44	460	30,900	2,800	8,300	2,400	1,750
Red	.38	40,000	8,200	48	460	18,300	1,900	5,200	1,500	1,600
	.41	70,000	10,500	58	640	40,600	3,200	7,400	2,400	2,200
Sitka	.37	39,000	8,500	43	610	18,400	1,900	5,200	1,700	1,600
	.40	70,000	10,800	65	640	38,700	4,000	7,900	2,600	2,300
White	.37	39,000	7,400	41	560	17,700	1,700	4,800	1,500	1,400
	.40	68,000	9,200	53	510	37,700	3,200	7,400	2,500	2,100
Tamarack	.49	50,000	8,500	50	710	24,000	2,700	5,900	1,800	1,700
	.53	80,000	11,300	49	580	49,400	5,500	8,800	2,800	2,600

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[1] Results of tests on small clear specimens in the green and air-dry condition, converted to metric units directly from table 4-2.

[2] Values in the first line for each species are from tests of green material; those in the second line are adjusted to 12 pct. moisture content.

[3] Specific gravity is based on weight when ovendry and volume when green or at 12 pct. moisture content.

[4] Modulus of elasticity measured from a simply supported, center-loaded beam, on a span-depth ratio of 14/1. The modulus can be corrected for the effect of shear deflection by increasing it 10 pct.

[5] Coast Douglas-fir is defined as Douglas-fir growing in the States of Oregon and Washington west of the summit of the Cascade Mountains. Interior West includes the State of California and all counties in Oregon and Washington east of but adjacent to the Cascade summit. Interior North includes the remainder of Oregon and Washington and the States of Idaho, Montana, and Wyoming. Interior South is made up of Utah, Colorado, Arizona, and New Mexico.

Table A–4–3.—*Mechanical properties of some commercially important woods grown in Canada and imported into the United States* [1]

Common names of species	Specific gravity	Static bending		Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength
		Modulus of rupture	Modulus of elasticity			
		Kilopascals	*Megapascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*
			HARDWOODS			
Aspen:						
Quaking	0.37	38,000	9,000	16,200	1,400	5,000
		68,000	11,200	36,300	3,500	6,800
Big-toothed	.39	36,000	7,400	16,500	1,400	5,400
		66,000	8,700	32,800	3,200	7,600
Cottonwood:						
Black	.30	28,000	6,700	12,800	700	3,900
		49,000	8,800	27,700	1,800	5,900
Eastern	.35	32,000	6,000	13,600	1,400	5,300
		52,000	7,800	26,500	3,200	8,000
Balsam, poplar	.37	34,000	7,900	14,600	1,200	4,600
		70,000	11,500	34,600	2,900	6,100
			SOFTWOODS			
Cedar:						
Alaska-	.42	46,000	9,200	22,300	2,400	6,100
		80,000	11,000	45,800	4,800	9,200
Northern white-	.30	27,000	3,600	13,000	1,400	4,600
		42,000	4,300	24,800	2,700	6,900
Western redcedar	.31	36,000	7,200	19,200	1,900	4,800
		54,000	8,200	29,600	3,400	5,600
Douglas-fir	.45	52,000	11,100	24,900	3,200	6,300
		88,000	13,600	50,000	6,000	9,500
Fir:						
Subalpine	.33	36,000	8,700	17,200	1,800	4,700
		56,000	10,200	36,400	3,700	6,800
Pacific silver	.36	38,000	9,300	19,100	1,600	4,900
		69,000	11,300	40,900	3,600	7,500
Balsam	.34	36,000	7,800	16,800	1,600	4,700
		59,000	9,600	34,300	3,200	6,300
Hemlock:						
Eastern	.40	47,000	8,800	23,600	2,800	6,300
		67,000	9,700	41,200	4,300	8,700
Western	.41	48,000	10,200	24,700	2,600	5,200
		81,000	12,300	46,700	4,600	6,500
Larch, western	.55	60,000	11,400	30,500	3,600	6,300
		107,000	14,300	61,000	7,300	9,200

Table A-4-3.—*Mechanical properties of some commercially important woods grown in Canada and imported into the United States*[1]—continued

Common name[2] of species	Specific gravity	Static bending		Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength
		Modulus of rupture	Modulus of elasticity			
		Kilopascals	*Megapascals*	*Kilopascals*	*Kilopascals*	*Kilopascals*
		SOFTWOODS—continued				
Pine:						
Eastern white	.36	35,000	8,100	17,900	1,600	4,400
		66,000	9,400	36,000	3,400	6,100
Jack	.42	43,000	8,100	20,300	2,300	5,600
		78,000	10,200	40,500	5,700	8,200
Lodgepole	.40	39,000	8,800	19,700	1,900	5,000
		76,000	10,900	43,200	3,600	8,500
Ponderosa	.44	39,000	7,800	19,600	2,400	5,000
		73,000	9,500	42,300	5,200	7,000
Red	.39	34,000	7,400	16,300	1,900	4,900
		70,000	9,500	37,900	5,000	7,500
Western white	.36	33,000	8,200	17,400	1,600	4,500
		64,100	10,100	36,100	3,200	6,300
Spruce:						
Black	.41	41,000	9,100	19,000	2,100	5,500
		79,000	10,500	41,600	4,300	8,600
Engelmann	.38	39,000	8,600	19,400	1,900	4,800
		70,000	10,700	42,400	3,700	7,600
Red	.38	41,000	9,100	19,400	1,900	5,600
		71,000	11,000	38,500	3,800	9,200
Sitka	.35	37,000	9,400	17,600	2,000	4,300
		70,000	11,200	37,800	4,100	6,800
White	.35	35,000	7,900	17,000	1,600	4,600
		63,000	10,000	37,000	3,400	6,800
Tamarack	.48	47,000	8,600	21,600	2,800	6,300
		76,000	9,400	44,900	6,200	9,000

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[1] Results of tests on small, clear, straight-grained specimens. Property values based on American Society for Testing and Materials Standard D 2555–70, "Standard methods for establishing clear wood values." Information on additional properties can be obtained from Department of Forestry, Canada, Publication No. 1104.

[2] The values in the first line for each species are from tests of green material; those in the second line are adjusted from the green condition to 12 pct. moisture content using dry to green clear wood property ratios as reported in ASTM D 2555–70. Specific gravity is based on weight when ovendry and volume when green.

Table A–4–4.—*Mechanical properties*[1,2] *of some woods imported into the United States*

Common and botanical names of species	Moisture content	Specific gravity[3]	Static bending: Modulus of rupture	Static bending: Modulus of elasticity[4]	Static bending: Work to maximum load	Compression parallel to grain—maximum crushing strength	Shear parallel to grain—maximum shearing strength	Side hardness—load perpendicular to grain	Sample: No. of trees	Sample: Origin[5]
	Pct.		*Kilopascals*	*Megapascals*	*Kilojoules per cu. m.*	*Kilopascals*	*Kilopascals*	*Newtons*		
Andiroba (*Carapa guianensis*)	Green	0.56	76,600	10,800	79	34,000	9,100	4,700	2	BR
	12	....	107,700	12,800	92	54,500	11,600	5,400	2	BR
Andiroba (*C. nicaraguensis*)	13	.45	....	..	....	43,000		5,500	3	EC
Angelique (*Dicorynia guianensis*)	Green	.60	78,700	12,700	83	38,600	9,200	4,900	2	SU
	....	....	119,900	15,100	105	60,500	11,400	5,700	2	SU
Apamate (*Tabebuia rosea*)	Green	.51	73,400	10,100	77	34,000	8,500	4,000	10	CS
	12	....	95,000	11,000	86	50,600	10,000	4,300	9	CS
Apitong (*Dipterocarpus* spp.)	Green	.59	63,600	12,300	....	30,400	7,200	3,600	57	PH
	12	....	111,800	16,200	....	58,900	11,700	5,300	53	PH
Avodire (*Turraeanthus africanus*)	12	.51	87,800	10,200	65	49,500	14,100	4,800	3	AF
Balsa (*Ochroma pyramidale*)	12	.17	19,300	3,800	....	11,700	2,100	400	(*6*)	EC
Banak (*Virola koschnyi*)	Green	.44	42,700	10,100	37	21,000	4,600	2,000	8	CA
	12	....	74,500	11,900	56	39,400	9,000	2,800	8	CA
Banak (*V. surinamensis*)	Green	.42	38,600	11,300	28	16,500	5,000	1,400	2	BR
	12	....	75,500	14,100	69	35,400	6,800	2,300	2	BR
Capirona (*Calycophyllum candidissimum*)	Green	.67	98,500	13,300	128	42,700	11,400	7,300	2	VE
	12	....	153,800	15,700	186	66,700	14,600	8,600	2	VE
Capirona (*C. spruceanum*)	14	.85	....	....	....	64,000	....	11,300	1	PE
Cativo (*Prioria copaifera*)	Green	.40	40,900	6,600	37	17,900	5,900	2,000	4	PA
	12	....	60,200	7,900	50	31,000	7,200	2,700	4	PA
Courbaril (*Hymenaea courbaril*)	Green	.72	89,300	12,500	108	40,000	12,200	9,000	9	CS
	12	....	133,800	15,000	121	66,700	17,000	10,900	9	CS
Gola (*Tetraberlinia tubmaniana*)	14	.66	115,500	15,200	....	62,100	....	....	11	AF

Table A–4–4.—*Mechanical properties*[1,2] *of some woods imported into the United States* —continued

Common and botanical names of species	Moisture content	Specific gravity[3]	Static bending			Compression parallel to grain—maximum crushing strength	Shear parallel to grain—maximum shearing strength	Side hardness—load perpendicular to grain	Sample	
			Modulus of rupture	Modulus of elasticity[4]	Work to maximum load				No. of trees	Origin[5]
	Pct.		*Kilo-pascals*	*Mega-pascals*	*Kilo-joules per cu. m.*	*Kilo-pascals*	*Kilo-pascals*	*Newtons*		
Goncalo alves (*Astronium graveolens*)	Green	.86	85,500	13,100	51	47,400	12,700	8,900	4	CS
	12		117,700	15,000	72	72,800	14,200	9,900	4	CS
Greenheart (*Ocotea rodiaei*)	Green	.83	133,800	20,600	90	71,400	10,200	9,700	5	GY
	14	.93	175,800	25,500	152	89,900	12,600	11,700	1	GY
Ilomba (*Pycnanthus angolensis*)	12	.44	61,400	12,100		38,000		3,300	(7)	AF
Jarrah (*Eucalyptus marginata*)	Green	.67	68,100	10,200		35,800	9,100	5,700	28	AU
	12		111,700	13,000		61,200	15,100	8,500	28	AU
Jelutong (*Dyera costulata*)	Green	.36	38,600	8,000	39	21,000	5,200	1,500	3	AS
	16	.38	50,300	8,100	44	27,000	5,800	1,700	3	AS
Kapur (*Dryobalanops lanceolata*)	Green	.64	83,800	11,700	88	41,200	7,200	4,400	5	AS
	12		120,000	13,900	107	66,900	11,800	5,500	5	AS
Karri (*Eucalytus diversicolor*)	Green	.70	73,100	14,300		36,200	9,200	6,100	26	AU
	12		132,400	19,000		71,700	14,700	9,000	21	AU
Kerving (*Dipterocarpus* supp.)	Green	.67	81,800	16,900	63	42,900	8,000	4,900	21	MI
	12	.69	99,900	18,100	92	55,100	9,400	5,200	11	MI
Khaya (*Khaya anthotheca*)	Green	.47	53,800	8,100	63	26,000	7,500	3,200	9	AF
	12		79,000	9,700	68	43,400	11,700	4,000	9	AF
Khaya (*K. ivorensis*)	Green	.43	51,000	8,000	57	24,100	6,400	2,800	11	AF
	12		73,800	9,600	57	44,500	10,300	3,700	11	AF
Kokrodua (*Pericopsis elata*)	Green	.66	102,200	12,200	134	51,600	11,500	7,100	6	AF
	12		127,100	13,400	128	68,500	14,400	6,900	6	AF
Lapacho (*Tabebuia heterotricha*)	Green	.80	138,400	14,600	188	53,000	14,800	11,300	3	PA
	12		156,000	16,000	179	75,400	15,700	13,400	3	PA
Lapacho (*T. serratifolia*)	Green	.92	157,500	21,100	177	73,500	14,100	13,200	3	SM
	12		181,400	22,800	159	92,500	14,300	16,300	3	SM

Lauan:										
Dark red:										
Red lauan (*Shorea negrosensis*)	Green	.44	53,100	9,500	...	25,500	6,400	2,500	15	AS
	12	...	77,900	11,200	...	40,600	8,400	3,000	15	AS
Tanguile (*S. polysperma*)	Green	.46	57,200	10,600	...	27,200	6,500	2,800	19	PH
	12	...	88,900	12,500	...	45,400	8,900	3,400	17	PH
Light red:										
Almon (*Shorea almon*)	Green	.41	51,700	9,900	...	25,900	5,800	2,200	12	PH
	12	.44	77,900	11,500	...	39,600	7,500	2,600	12	PH
Bagtikan (*Parashorea plicata*)	Green	.48	60,700	10,100	...	30,100	6,800	3,100	32	AS
	12	...	86,600	11,900	...	47,300	9,000	3,600	32	AS
Mayapis (*Shorea squamata*)	Green	.41	50,300	9,700	...	23,900	5,300	2,100	14	AS
	12	...	76,500	11,400	...	38,700	7,500	2,600	12	AS
White lauan (*Pentacme contorta*)	Green	.43	51,700	9,500	...	25,500	6,300	2,600	19	AS
	12	...	80,700	11,700	...	41,900	8,300	3,100	18	AS
Laurel (*Cordia alliodora*)	Green	.44	61,000	8,700	...	27,600	7,800	3,500	13	CA
	12	...	83,200	10,300	...	43,300	8,400	3,500	13	CA
Lignumvitae (*Guaiacum sanctum*)	12	1.09			...	78,600		20,000		...
Limba (*Terminalia superba*)	12	.49	79,300	8,800	...	36,500	7,000	3,000	(*8*)	AF
Lupuna (*Ceiba samauma*)	13	.54		...	...	...	...	3,300	1	PE
Mahogany (*Swietenia macrophylla*)	Green	.45	64,000	11,300	66	31,100	9,000	3,100	77	CS
	12	...	80,300	10,400	54	45,700	8,900	3,600	77	CS
Meranti, red (*Shorea dasphylla*)	Green	.43	59,600	10,300	61	30,700	...	2,500	2	AS
	12	...	83,200	11,200	81	48,100	...	2,800	2	AS
Oak (*Quercus costaricensis*)	12	.68	121,100	18,200	116	...	...	7,000	2	CR
Oak (*Q. eugeniaefolia*)	12	.75	113,100	19,600	97	...	...	9,700	1	CR
Obeche (*Triplochiton scleroxylon*)	Green	.33	35,400	4,900	43	17,700	4,600	1,900	2	AF
	12		51,700	5,900	48	27,100	6,800	1,900	2	AF
Okoume (*Aucoumea klaineana*)	12	.37	50,700	7,900	...	26,900	6,800	1,700	(*9*)	AF
Palosapis (*Anisoptera* spp.)	Green	.51	52,100	9,900	...	26,100	6,900	3,600	18	AS
	12	...	88,100	12,500	...	45,700	9,700	4,100	16	AS
"Parana pine" (*Araucaria angustifolia*)	Green	.46	49,200	9,300	68	27,600	6,700	2,500	(*10*)	SM
	12		93,100	11,200	84	52,700	11,900	3,500	(*10*)	SM
Pau marfim (*Balfourodendron riedelianum*)	Green	.73	99,300		...	42,100	13,000	6,800	5	BR
	15	...	130,300		...	56,500	...	...	5	BR

Table A-4-4.—*Mechanical properties*[1,2] *of some woods imported into the United States* —continued

Common and botanical names of species	Moisture content	Specific gravity[3]	Static bending			Compression parallel to grain—maximum crushing strength	Shear parallel to grain—maximum shearing strength	Side hardness—load perpendicular to grain	Sample	
			Modulus of rupture	Modulus of elasticity[4]	Work to maximum load				No. of trees	Origin[5]
	Pct.		*Kilopascals*	*Megapascals*	*Kilojoules per cu. m.*	*Kilopascals*	*Kilopascals*	*Newtons*		
Peroba de campos (*Paratecoma peroba*)	12	.75	106,200	12,100	70	61,500	14,800	7,100	(*11*)	BR
Pine, Caribbean (*Pinus caribaea*)	Green	.68	68,800	11,700	83	33,000	8,300	3,600	19	CA
	12	....	105,000	14,000	105	55,200	12,900	5,100	14	CA
Pine, ocote (*P. oocarpa*)	Green	.55	55,000	12,000	48	25,400	7,200	2,600	3	HO
	12	....	102,600	15,500	75	53,000	11,900	4,000	3	HO
Primavera (*Cybistax donnell-smithii*)	Green	.39	53,200	6,800	48	25,000	7,200	2,900	4	HO
	12	....	75,200	8,400	71	42,300	11,800	3,100	4	HO
Ramin (*Gonystylus bancanus*)	Green	.59	67,500	10,800	62	37,200	6,900	2,800	9	AS
	12	....	127,100	15,000	117	69,500	10,400	5,800	9	AS
Rosewood, Indian (*Dalbergia latifolia*)	Green	.75	63,400	8,200	80	31,200	9,700	5,600	5	AS
	12	....	116,700	12,300	90	63,600	14,400	11,700	5	AS
Sande (*Brosimum utile*)	12	.44	....	....	....	43,500	....	2,200	3	EC
Santa Maria (*Calophyllum brasiliense*)	Green	.54	72,200	10,800	73	35,600	8,900	4,500	18	CA
	12	....	101,800	12,500	91	55,600	13,200	5,400	18	CA
Sapele (*Entandrophragma cylindricum*)	Green	.60	70,100	10,300	72	34,500	8,600	4,500	5	AF
	12	....	105,500	12,500	108	56,300	15,800	6,700	5	AF
Spanish-cedar (*Cedrela angustifolia*)	Green	.38	44,400	8,100	51	21,400	5,400	2,000	2	BR
	12	....	77,900	9,800	86	41,400	8,300	2,500	2	BR
Spanish-cedar (*C. oaxancensis*)	Green	.41	51,800	9,000	49	23,200	6,800	2,400	3	PA
	12	....	79,500	9,900	65	42,800	7,600	2,700	3	PA
Spanish-cedar (*C. odorata*) (Nicaragua)	Green	.34	35,900	6,000	51	19,000	5,000	1,600	1	NI
(Guatemala)	Green	.43	65,500	10,200	....	....	....	2,800	1	GU
(Guatemala)	12	.36	54,200	7,000	39	30,700	....	2,200	1	NI
Teak (*Tectona grandis*) (India)	Green	.57	75,700	10,400	75	37,700	8,900	4,800	134	IN
(Honduras)	12	.62	91,800	9,600	71	46,900	11,000	4,900	356	HO
(India)	12	.63	88,100	11,000	70	49,000	10,200	4,600	....	IN

"Virola" (*Dialyanthera otoba*)	12	.34		...	....	....	2,100		1	EC
Walnut, European (*Juglans regia*)	Green	.47	60,100	9,000	72	27,700	7,300	3,000	10	AS
	8	....	90,300	10,600	68	50,500	9,100	3,800	10	AS

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[1] Results of tests on small clear, straight-grained specimens. Property values were taken from world literature (not obtained from experiments conducted at the U.S. Forest Products Laboratory). Other species may be reported in the world literature as well as additional data on many of these species.

[2] Some property values have been adjusted to 12 pct. moisture content; others are based on moisture content at time of test.

[3] Specific gravity based on weight when ovendry and volume at moisture content indicated.

[4] Modulus of elasticity measured from a simply supported, center loaded beam. The modulus can be corrected for the effect of shear deflection by increasing it 10 pct.

[5] Key to code letters: AF, Africa; AS, Southeast Asia; AU, Australia; BR, Brazil; CA, Central America; CH, Chile; CR, Costa Rica; CS, Central and South America; EC, Equador; GU, Guatemala; GY, Guyana (British Guana); HO, Honduras; MI, Malaysia-Indonesia; IN, India; NI, Nicaragua; PA, Panama; PE, Peru; PH, Philippine Islands; SM, South America; SU, Surinam; and VE, Venezuela.

[6] 1,500 bd. ft.

[7] 1 bolt.

[8] 195 tests.

[9] 21 tests.

[10] 26 planks.

[11] 11 planks.

Chapter 5

COMMERCIAL LUMBER

COMMERCIAL LUMBER

A log when sawed yields lumber of varying quality. The objective of grading is to enable a user to buy the quality that best suits his purpose. This is accomplished by dividing the lumber from the log into use categories, each having an appropriate range in quality.

Except as noted later, the grade of a piece of lumber is based on the number, character, and location of features that may lower the strength, durability, or utility value of the lumber. Among the more common visual features are knots, checks, pitch pockets, shake, and stain, some of which are a natural part of the tree. Some grades are free or practically free from these features. Other grades comprising the great bulk of lumber contain fairly numerous knots and other features that may affect quality. With proper grading, lumber containing these features is entirely satisfactory for many uses.

The principal grading operation for most lumber takes place at the sawmill. Establishment of grading procedures is largely the responsibility of manufacturing associations. Because of the wide variety of wood species, industrial practices, and customer needs, different lumber grading practices coexist. The grading practices of most interest are considered in the sections that follow, under the major categories of Hardwood Lumber and Softwood Lumber.

HARDWOOD LUMBER

Hardwood lumber is graded according to three basic marketing categories: Factory Lumber, Dimension Parts, and Finished Market Products. Both factory lumber and dimension parts are intended to serve the industrial customer; the important difference is that the factory lumber grades reflect the proportion of a piece that can be cut into useful smaller pieces while the dimension grades are based on use of the entire piece. Finished market products are graded for their unique end use with little or no remanufacture. Examples of finished products include molding, stair treads, and hardwood flooring.

Factory Grades

The rules adopted by the National Hardwood Lumber Association are considered standard in grading hardwood lumber for cutting into smaller pieces to make furniture or other fabricated products. In these rules the grade of a piece of hardwood lumber is determined by the proportion of a piece that can be cut into a certain number of smaller pieces of material generally clear on one side and not smaller than a specified size. In other words, the grade classification is based upon the amount of usable lumber in the piece rather than upon the number or size of growth features that characterize softwood grades. This usable material, commonly termed 'cuttings," must have one face clear and the reverse face sound, which means free from such things as wane, rot, pith, and shake that materially impair the strength of the cutting. The lowest cutting grades require only that the cuttings be sound.

Cutting Grades

The highest cutting grade is termed "Firsts" and the next grade "Seconds." First and Seconds are nearly always combined in one grade and referred to as "FAS." The third grade is termed "Selects" followed by No. 1 Common, No. 2 Common, Sound Wormy, No. 3A Common, and No. 3B Common. A description of the standard hardwood cutting grades is given in table 5–1. This table illustrates, for example, that Firsts call for pieces that will allow 91⅔ percent of their surface measure to be cut into clear face material. Not more than 8⅓ percent of each piece can be wasted in making the required cuttings. In general the minimum acceptable length, width surface measure, and percent of piece that must work into a cutting decreases with decreasing grade. The grade of hardwood lumber called "Sound Wormy" has the same requirements as No. 1 Common and Better except that wormholes and limited sound knots and other imperfections are allowed in the cuttings. Figure 5–1 is an illustration of grading for cuttings.

Table 5–1.—*Standard hardwood cutting grades*[1]

Grade and lengths allowed (feet)	Widths allowed	Surface measure of pieces	Amount of each piece that must work into clear-face cuttings	Maximum cuttings allowed	Minimum size of cuttings required
	In.	*Sq. ft.*	*Pct.*	*Number*	
Firsts:[2] 8 to 16 (will admit 30 percent of 8- to 11-foot, ½ of which may be 8- and 9-foot.)	6+	4 to 9	91 ⅔	1	4 inches by 5 feet, or 3 inches by 7 feet
		10 to 14	91 ⅔	2	
		15+	91 ⅔	3	
Seconds:[2] 8 to 16 (will admit 30 percent of 8- to 1'-foot, ½ of which may be 8- and 9-foot).	6+	4 and 5	83 ⅓	1	Do.
		6 and 7	83 ⅓	1	
		6 and 7	91 ⅔	2	
		8 to 11	83 ⅓	2	
		8 to 11	91 ⅔	3	
		12 to 15	83 ½	3	
		12 to 15	91 ⅔	4	
		16+	83 ⅓	4	
Selects: 6 to 16 (will admit 30 percent of 6- to 11-foot, ⅙ of which may be 6- and 7-foot).	4+	2 and 3	91⅔	1	Do.
		4+	(3)		
No. 1 Common: 4 to 16 (will admit 10 percent of 4- to 7-foot, ½ of which may be 4- and 5-foot).	3+	1	100	0	4 inches by 2 feet, or 3 inches by 3 feet
		2	75	1	
		3 and 4	66 ⅔	1	
		3 and 4	75	2	
		5 to 7	66 ⅔	2	
		5 to 7	75	3	
		8 to 10	66 ⅔	3	
		11 to 13	66 ⅔	4	
		14+	66 ⅔	5	
No. 2 Common: 4 to 16 (will admit 30 percent of 4- to 7-foot, ⅓ of which may be 4- and 5-foot).	3+	1	66 ⅔	1	3 inches by 2 feet
		2 and 3	50	1	
		2 and 3	66 ⅔	2	
		4 and 5	50	2	
		4 and 5	66 ⅔	3	
		6 and 7	50	3	
		6 and 7	66 ⅔	4	
		8 and 9	50	4	
		10 and 11	50	5	
		12 and 13	50	6	
		14+	50	7	
No. 3A Common: 4 to 16 (will admit 50 percent of 4- to 7-foot, ½ of which may be 4- and 5-foot).	3+	1+	[4]33 ⅓	(5)	Do.
No. 3B Common: 4 to 16 (will admit 50 percent of 4- to 7-foot, ½ of which may be 4- and 5-foot).	3+	1+	[6]25	(5)	1 ½ inches by 2 feet

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[1] Inspection to be made on the poorer side of the piece, except in Selects.

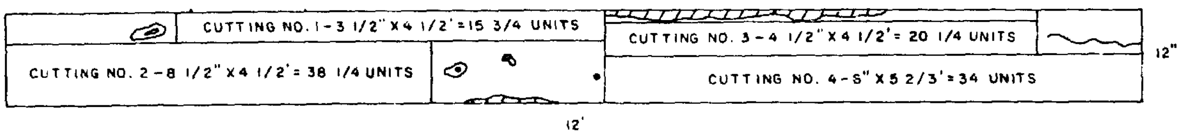
[2] Firsts and Seconds are combined as 1 grade (FAS). The percentage of Firsts required in the combined grade varies from 20 to 40 percent, depending on the species.

[3] Same as Seconds with reverse side of board not below No. 1 Common or reverse side of cuttings sound.

[4] This grade also admits pieces that grade not below No. 2 Common on the good face and have the reverse face sound.

[5] Unlimited.

[6] The cuttings must be sound; clear face not required.



1. Determine Surface Measure (S.M.) using lumber scale stick or from formula:

$$\frac{\text{Width in inches x length in feet}}{12} = \frac{12'' \times 12'}{12}$$

= 12 sq. ft. S.M.

2. No. 1 Common is assumed grade of board. Percent of clear-cutting area required for No. 1 Common--66-2/3% or 8/12.

3. Determine maximum number of cuttings permitted.

For No. 1 Common grade (S.M. + 1) ÷ 3

$$= \frac{(12 + 1)}{3} = \frac{13}{3} = 4 \text{ cuttings.}$$

4. Determine minimum size of cuttings.

For No. 1 Common grade 4" x 2' or 3" x 3'.

5. Determine clear-face cutting units needed.

For No. 1 Common grade S.M. x 8 = 12 x 8 = 96 units.

6. Determine total area of permitted clear-face cutting in units.

Width in inches and fractions of inches x length in feet and fractions of feet.

Cutting #1--3-1/2" x 4-1/2' = 15-3/4 units
Cutting #2--8-1/2" x 4-1/2' = 38 units
Cutting #3--4-1/2" x 4-1/2' = 20-1/4 units
Cutting #4--6" x 5-2/3' = 34 units

Total Units 108

Units required for No. 1 Common--96.

7. Conclusion: Board meets requirements for No. 1 Common grade.

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Figure 5-1.—An example of hardwood grading for cuttings using a No. 1 Common factory grade.

This brief summary of the factory grades should not be regarded as a complete set of grading rules, as numerous details, exceptions, and special rules for certain species are not included. The complete official rules of the National Hardwood Lumber Association should be followed as the only full description of existing grades.

Cutting Sizes

Standard lengths

Standard lengths are 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16 feet, but not more than 50 percent of odd lengths are allowed in any single shipment.

Standard thickness

Standard thicknesses for hardwood lumber, rough and surfaced (S2S), are given in table 5-2. The thickness of S1S lumber is subject to contract agreement.

Standard widths

Hardwood lumber is usually manufactured to random width. The hardwood factory grades do not specify standard widths; however, the grades do specify minimum widths for each grade as follows:

Firsts	6 inches
Seconds	6 inches
Selects	4 inches
Nos. 1, 2, 3A, 3B Common	3 inches

If width is specified by purchase agreement, S1E or S2E lumber is ⅜ inch scant of nominal in lumber less than 8 inches wide and ½ inch scant in lumber 8 inches and wider.

Table 5-2.—*Standard thickness for rough and surfaced (S2S) hardwood lumber*

Rough	Surfaced	Rough	Surfaced
In.	*In.*	*In.*	*In.*
⅜	3/16	2 ½	2 ¼
½	5/16	3	2 ¾
⅝	7/16	3 ½	3 ¼
¾	9/16	4	3 ¾
1	13/16	4 ½	(1)
1 ¼	1 1/16	5	(1)
1 ½	1 5/16	5 ½	(1)
1 ¾	1 ½	6	(1)
2	1 ¾		

[1] Finished size not specified in rules. Thickness subject to special contract.

Species Graded by Hardwood Factory Grades[1]

- Alder, red
- Ash
- Aspen
- Basswood
- Beech
- Birch
- Boxelder
- Buckeye
- Butternut
- Cedar, aromatic red
- Cedar, Spanish-
- Cherry
- Chestnut
- Cottonwood
- Cypress
- Elm:
  - Rock (or cork)
  - Soft
- Gum:
  - Black
  - Red and sap
  - Tupelo
- Hackberry
- Hardwoods (Philippine)
- Hardwoods (Tropical American other than mahogany and Spanish cedar)
- Hickory
- Locust
- Magnolia
- Mahogany
  - African
  - Cuban and San Dominican
  - Philippine
- Maple:
  - Hard (or sugar)
  - Soft
  - Pacific Coast
- Oak:
  - Red
  - White
- Pecan
- Poplar
- Sycamore
- Walnut
- Willow

Dimension Parts

Hardwood dimension parts are generally graded under the rules of the Hardwood Dimension Manufacturers Association. Dimension signifies primarily that the stock is processed so it can be used virtually in the sizes provided.

Hardwood dimension rules encompass three classes of material: Solid dimension flat stock, kiln-dried dimension flat stock, and solid dimension squares. Each class may be rough, semifabricated, or fabricated. Rough dimension blanks are usually kiln dried and are supplied sawn and ripped to size. Surfaced or semifabricated stock has been further processed by gluing, surfacing, tenoning, etc. Fabricated stock has been completely processed for the end use. Solid dimension flat stock has five grades: Clear—two faces, clear—one face, paint, core, and sound. Squares have three grades if rough (clear, select, sound) and four if surfaced (clear, select, paint, second).

Finished Market Products

Some hardwood lumber products are graded in relatively finished form, with little or no further processing anticipated. Flooring is probably the highest volume finished product. Other examples are lath, siding, ties, planks, carstock, construction boards, timbers, trim, molding, stair treads, and risers. Grading rules promulgated for flooring anticipate final consumer use and are summarized in this section. Details on grades of other finished products are found in appropriate association grading rules.

Hardwood flooring generally is graded under the rules of the Maple Flooring Manufacturers Association and the rules of the National Oak Flooring Manufacturers Association. Tongued-and-grooved and end-matched hardwood flooring is commonly furnished. Square edge and square end strip flooring is also available as well as parquet flooring suitable for laying on a mastic base or on an ordinary subfloor.

The Maple Flooring Manufacturers Association grading rules cover flooring manufactured from hard maple, beech, and birch. Each species is graded into four categories—First grade, Second grade, Third grade, and Fourth grade. Combination grades of Second and Better and Third and Better are sometimes specified. There are also three special grades—Selected First grade light northern hard maple, Selected First grade amber northern hard maple, Selected First grade red (produced from northern beech or birch) which are made up of special stock selected for color.

First grade flooring must have one face practically free from all imperfections. Variations in the natural color of the wood are allowed. Second grade flooring admits tight, sound knots and other slight imperfections but must lay without waste. Third grade flooring has few restrictions as to imperfections in the grain but must permit proper laying and provide a good, serviceable floor.

The standard thickness of maple, beech, and birch flooring is $\frac{25}{32}$ inch. Face widths are 1½, 2, 2¼, and 3¼ inches. Standard lengths are 2 feet and longer in First and Second grade flooring and 1¼ feet and longer in Third grade flooring.

The grading rules of the National Oak Flooring Manufacturers Association mainly cover quartersawed and plain-sawed oak flooring. Quartersawed flooring has two grades—Clear and Select. Plainsawed flooring has four grades—Clear, Select, No. 1 Common, and No. 2 Common. The Clear grade in both plainsawed and quartersawed flooring must have the face free from surface imperfections except for three-eighths inch of bright sap. Color is not

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[1] Species names are those used in grading rules of the National Hardwood Lumber Association. Two woods—cedar (eastern redcedar, known as aromatic red) and cypress (baldcypress)—are not hardwoods. Cypress lumber has a different set of grading rules from those used for the hardwoods.

Table 5-3.--*Nomenclature for some types of hardwood lumber*

Commercial name for lumber	Official common tree name	Botanical name
Alder, red	Red alder	*Alnus rubra*
Ash:		
Black	Black ash	*Fraxinus nigra*
Oregon	Oregon ash	*F. latifolia*
White	Blue ash	*F. quadrangulata*
	Green ash	*F. pennsylvanica*
	White ash	*F. americana*
Aspen (popple)	Bigtooth aspen	*Populus grandidentata*
	Quaking aspen	*P. tremuloides*
Basswood	American basswood	*Tilia americana*
	White basswood	*T. heterophylla*
Beech	Beech	*Fagus grandifolia*
Birch	Gray birch	*Betula populifolia*
	Paper birch	*B. papyrifera*
	River birch	*B. nigra*
	Sweet birch	*B. lenta*
	Yellow birch	*B. alleghaniensis*
Box elder	Boxelder	*Acer negundo*
Buckeye	Ohio buckeye	*Aesculus glabra*
	Yellow buckeye	*A. octandra*
Butternut	Butternut	*Juglans cinerea*
Cherry	Black cherry	*Frunus serotina*
Chestnut	Chestnut	*Castanea dentata*
Cottonwood	Balsam poplar	*Populus balsamifera*
	Eastern cottonwood	*P. deltoides*
	Plains cottonwood	*F. sargentii*
Cucumber	Cucumbertree	*Magnolia acuminata*
Dogwood	Flowering dogwood	*Cornus florida*
	Pacific dogwood	*C. nuttallii*
Elm:		
Rock	Cedar elm	*Ulmus crassifolia*
	Rock elm	*U. thomasii*
	September elm	*U. serotina*
	Winged elm	*U. alata*
Soft	American elm	*U. americana*
	Slippery elm	*U. rubra*
Gum	Sweetgum	*Liquidambar styraciflua*
Hackberry	Hackberry	*Celtis occidentalis*
	Sugarberry	*C. laevigata*
Hickory	Mockernut hickory	*Carya tomentosa*
	Pignut hickory	*C. glabra*
	Shagbark hickory	*C. ovata*
	Shellbark hickory	*C. laciniosa*
Holly	American holly	*Ilex opaca*
Ironwood	Eastern hophornbeam	*Ostrya virginiana*
Locust	Black locust	*Robinia pseudoacacia*
	Honeylocust	*Gleditsia triacanthos*
Madrone	Pacific madrone	*Arbutus menziesii*
Magnolia	Southern magnolia	*Magnolia grandiflora*
	Sweetbay	*M. virginiana*

Table 5–3.—*Nomenclature for some types of hardwood lumber*—continued

Commercial name for lumber	Official common tree name	Botanical name
Maple:		
Hard	Black maple	*Acer nigrum*
	Sugar maple	*A. saccharum*
Oregon	Big leaf maple	*A. macrophyllum*
Soft	Red maple	*A. rubrum*
	Silver maple	*A. saccharinum*
Oak:		
Red	Black oak	*Quercus velutina*
	Blackjack oak	*Q. marilandica*
	California black oak	*Q. kelloggi*
	Cherrybark oak	*Q. falcata var. pagodaefolia*
	Laurel oak	*Q. laurifolia*
	Northern pin oak	*Q. ellipsoidalis*
	Northern red oak	*Q. rubra*
	Nuttall oak	*Q. nuttallii*
	Pin oak	*Q. palustris*
	Scarlet oak	*Q. coccinea*
	Shumard oak	*Q. shumardii*
	Southern red oak	*Q. falcata*
	Turkey oak	*Q. laevis*
	Willow oak	*Q. phellos*
White	Arizona white oak	*Q. arizonica*
	Blue oak	*Q. douglasii*
	Bur oak	*Q. macrocarpa*
	California white oak	*Q. lobata*
	Chestnut oak	*Q. primus*
	Chinkapin oak	*Q. muehlenbergii*
	Emory oak	*Q. emoryi*
	Gambel oak	*Q. gambelii*
	Mexican blue oak	*Q. oblongifolia*
	Live oak	*Q. virginiana*
	Oregon white oak	*Q. garryana*
	Overcup oak	*Q. lyrata*
	Post oak	*Q. stellata*
	Swamp chestnut oak	*Q. michauxii*
	Swamp white oak	*Q. bicolor*
	White oak	*Q. alba*
Oregon myrtle	California-laurel	*Umbellularia californica*
Osage orange (bois d'arc)	Osage-orange	*Maclura pomifera*
Pecan	Bitternut hickory	*Carya cordiformis*
	Nutmeg hickory	*C. myristicaeformis*
	Water hickory	*C. aquatica*
	Pecan	*C. illinoensis*
Persimmon	Common persimmon	*Diospyros virginiana*
Poplar	Yellow-poplar	*Liriodendron tulipifera*
Sassafras	Sassafras	*Sassafras albidum*
Sycamore	American sycamore	*Platanus occidentalis*
Tupelo	Black tupelo	*Nyssa sylvatica*
	Ogeechee tupelo	*N. ogeche*
	Water tupelo	*N. aquatica*
Walnut	Black walnut	*Juglans nigra*
Willow	Black willow	*Salix nigra*
	Peachleaf willow	*S. amygdaloides*

considered in the Clear grade. Select flooring (plain-sawed or quartersawed) may contain sap and will admit a few features such as pin wormholes and small tight knots. No. 1 Common plain-sawed flooring must contain material that will make a sound floor without cutting. No. 2 Common may contain grain and surface imperfections of all kinds but must provide a serviceable floor.

Standard thicknesses of oak flooring are 25/32, ½, and ⅜ inch. Standard face widths are 1½, 2, 2¼, and 3¼ inches. Lengths in upper grades are 2 feet and up with a required average of 4½ feet in a shipment. In the lower grades lengths are 1¼ feet and up with a required average of 2½ or 3 feet per shipment.

A voluntary commercial standard (CS 56) has been in effect for oak flooring since 1936, being revised periodically.

The rules of the National Oak Flooring Manufacturers Association also include specifications for flooring of pecan, hard maple, beech, and birch. The grades of pecan flooring are: First grade, practically clear but unselected for color; First grade red, practically clear with an all-heartwood face; First grade white, practically clear with an all-bright sapwood face; Second grade, admits sound tight knots, pin wormholes, streak, and slight machining imperfections; Second grade red, similar to Second grade but must have a heartwood face; Third grade, must make a sound floor without cutting; and Fourth grade, must provide a serviceable floor. The standard sizes for pecan flooring are the same as those for oak flooring.

The National Oak Flooring Manufacturers Association rules for hard maple, beech, and birch flooring are the same as those of the Maple Flooring Manufacturers Association.

Hardwood Lumber Species

The names used by the trade to describe commercial lumber in the United States are not always the same as the names of trees adopted as official by the USDA Forest Service. Table 5-3 shows the common trade name, the USDA Forest Service tree name, and the botanical name. Table 5–4 lists United States agencies and associations that prepare rules for and supervise grading of hardwoods.

Table 5–4.—*Hardwood grading associations in United States*

Name and Address	Species Covered by Grading Rules
National Hardwood Lumber Association 59 East Van Buren Street Chicago, Illinois 60605	Hardwoods (furniture cuttings, construction lumber, siding, panels)
Hardwood Dimension Manufacturers Association 3813 Hillsboro Road Nashville, Tennessee 37215	Hardwoods (hardwood furniture dimension, squares, laminated stock, interior trim, stair treads and risers)
Maple Flooring Manufacturers Association 424 Washington Avenue, Suite 104 Oshkosh, Wisconsin 54901	Maple, beech, birch (flooring)
National Oak Flooring Manufacturers Association 814 Sterick Building Memphis, Tennessee 38103	Oak, pecan, beech, birch, and hard maple (flooring)
Northern Hardwood and Pine Manufacturers Association Suite 207, Northern Building Green Bay, Wisconsin 54301	Aspen (construction lumber—see discussion Softwood Lumber Grading)

SOFTWOOD LUMBER

Softwood lumber for many years has demonstrated the versatility of wood by serving as a primary raw material for construction and manufacture. In this role it has been produced in a wide variety of products from many different species. The first industry-sponsored grading rules (product descriptions) for softwoods were established before 1900 and were comparatively simple because the sawmills marketed their lumber locally and grades had only local significance. As new timber sources were developed and lumber was transported to distant points, each producing region continued to establish its own grading rules, so lumber from various regions differed in size, grade name, and permitted grade characteristics. When different species were graded under different rules and competed in the chief consuming areas, confusion and dissatisfaction were inevitable.

To eliminate unnecessary differences in the grading rules of softwood lumber and to improve and simplify these rules, a number of conferences were organized from 1919 to 1925 by the U.S. Department of Commerce. These were attended by representatives of lumber manufacturers, distributors, wholesalers, retailers, engineers, architects, and contractors. The result was a relative standardization of sizes, definitions, and procedures for deriving properties, formulated as a voluntary American Lumber Standard. This standard has been modified several times since. The current edition of the standard is issued in pamphlet form as the American Softwood Lumber Standard PS 20-70.

Softwood lumber is classified for market use by form of manufacture, species, and grade. For many products the American Softwood Lumber Standard serves as a basic reference. For specific information on other products, reference must be made to industry marketing aids, trade journals, and grade rules. The following sections outline general classifications of softwood lumber.

Softwood Lumber Grades

Softwood lumber grades can be considered in the context of two major categories of use: (1) Construction and (2) remanufacture. Construction relates principally to lumber expected to function as graded and sized after primary processing (sawing and planing). Remanufacture refers to lumber that will undergo a number of further manufacturing steps and reach the consumer in a significantly different form.

Lumber for Construction

The grading requirements of construction lumber are related specifically to the major construction uses intended and little or no further grading occurs once the piece leaves the sawmill. Construction lumber can be placed in three general categories—stress-graded, nonstress-graded, and appearance lumber. Stress-graded and nonstress-graded lumber are employed where the structural integrity of the piece is the primary requirement. Appearance lumber, as categorized here, encompasses those lumber products in which appearance is of primary importance; structural integrity, while sometimes important, is a secondary feature.

Stress-graded lumber

Almost all softwood lumber nominally 2 to 4 inches thick is stress graded under the national grading rules promulgated within the American Softwood Lumber Standard. For lumber of this kind there is a single set of grade names and descriptions used throughout the United States. Other stress-graded products include timbers, posts, stringers, beams, decking, and some boards. Stress grades and the National Grading Rule are discussed in chapter 6.

Nonstress-graded lumber

Traditionally, much of the lumber intended for general building purposes with little or no remanufacture has not been assigned allowable properties (stress graded). This category of lumber has been referred to as yard lumber; however, the assignment of allowable properties to an increasing number of former "yard" items has diluted the meaning of the term yard lumber.

In nonstress-graded structural lumber, the section properties (shape, size) of the pieces combine with the visual grade requirements to provide the degree of structural integrity intended. Typical nonstress-graded items include boards, lath, battens, crossarms, planks, and foundation stock.

Boards, sometimes referred to as "commons," are one of the more important nonstress-graded products. Common grades of boards are suitable for construction and general utility purposes. They are separated into three to five different grades depending upon the species and lumber manufacturing association involved. Grades may be described by number (No. 1, No. 2) or by descriptive terms (Construction, Standard).

Since there are differences in the inherent properties of the various species and in corresponding names, the grades for different species are not always interchangeable in use. First-grade boards are usually graded primarily for serviceability, but appearance is also considered. This grade is used for such purposes as siding, cornice, shelving, and paneling. Features such as knots and knotholes are permitted to be larger and more frequent as the grade level becomes lower. Second- and third-grade boards are often used together for such purposes as subfloors, roof and wall sheathing, and rough concrete work. Fourth-grade boards are not selected for appearance but for adequate strength. They are used for roof and wall sheathing, subfloor, and rough concrete form work.

Grading provisions for other nonstress-graded products vary by species, product, and grading association. Lath, for example, is available generally in two grades, No. 1 and No. 2; one grade of batten is listed in one grade rule and six in another. For detailed descriptions it is necessary to consult the appropriate grade rule for these products.

Appearance lumber

Appearance lumber often is nonstress-graded but forms a separate category because of the distinct importance of appearance in the grading process. This category of construction lumber includes most lumber worked to a pattern. Secondary manufacture on these items is usually restricted to onsite fitting such as cutting to length and mitering. There is an increasing trend toward prefinishing many items. The appearance category of lumber includes trim, siding, flooring, ceiling, paneling, casing, base, stepping, and finish boards. Finish boards are commonly used for shelving and built-in cabinetwork.

Most appearance lumber grades are described by letters and combinations of letters (B&BTR, C&BTR, D). (See Standard Lumber Abbreviations at the end of this chapter for definitions of letter grades.) Appearance grades are also often known as "Select" grades. Descriptive terms such as "prime" and "clear" are applied to a limited number of species. The specification FG (flat grain), VG (vertical grain), or MG (mixed grain) is offered as a purchase option for some appearance lumber products. In cedar and redwood, where there is a pronounced difference in color between heartwood and sapwood and heartwood has high natural resistance to decay, grades of heartwood are denoted as "heart." In some species and products two, or at most three, grades are available. A typical example is casing and base in the grades of C&BTR and D in some species and in B&BTR, C,C&BTR, and D in other species. Although several grades may be described in grade rules, often fewer are offered on the retail market.

Grade B&BTR allows a few small imperfections, mainly in the form of minor skips in manufacture, small checks or stains due to seasoning, and, depending on the species, small pitch areas, pin knots, or the like. Since appearance grades emphasize the quality of one face, the reverse side may be lower in quality. In construction, grade C&BTR is the grade combination most commonly available. It is used for high-quality interior and exterior trim, paneling, and cabinetwork, especially where these are to receive a natural finish. It is the principal grade used for flooring in homes, offices, and public buildings. In industrial uses it meets the special requirements for large sized, practically clear stock.

The number and size of imperfections permitted increases as the grades drop from B&BTR to D and E. Appearance grades are not uniform across species and products, however, and official grade rules must be used for detailed reference. C is used for many of the same purposes as B&BTR, often where the best paint finish is desired. Grade D allows larger and more numerous surface imperfections that do not detract from the appearance of the finish when painted. Grade D is used in finish construction for many of the same uses as C. It is also adaptable to industrial uses requiring short-length clear lumber.

Lumber for Remanufacture

A wide variety of species, grades, and sizes of softwood lumber is supplied to industrial accounts for cutting to specific smaller sizes which become integral parts of other products. In this secondary manufacturing process, grade descriptions, sizes, and often the entire appearance of the wood piece are changed. Thus the role of the grading process for these remanufacture items is to describe as accurately as possible the yield to be obtained in the subsequent cutting operation. Typical of lumber for secondary manufacture are the factory grades, industrial clears, box lumber, molding stock, and ladder stock. The variety of species available for these purposes has led to a variety of grade names and grade definitions. The following section briefly outlines some of the more common classifications. For details, reference must be made to industry sources. Availability and grade designation often vary by region and species.

Factory (Shop) grades.

Traditionally softwood lumber used for cuttings has been termed Factory or Shop. This lumber forms the basic raw material for many secondary manufacturing operations. Some grading associations refer to cutting grades as Factory while others refer to Shop. All impose a somewhat similar nomenclature in the grade structure. Factory Select and Select Shop are typical high grades, followed by No. 1, No. 2, and No. 3 Shop. Door cuttings and sash cuttings are specialized grade categories under which grade levels of No. 1, No. 2, and No. 3 Cuttings and No. 1, No. 2, and No. 3 Shop are applied.

Grade characteristics of cuttings are influenced by the width, length, and thickness of the basic piece and are based on the amount of high-quality material that can be removed by cutting. Typically, a Select Shop would be required to contain either (a) 70 percent of cuttings of specified size, clear on both sides or (b) 70 percent cuttings of different size equal to a B&BTR Finish grade on one side. No. 1 Shop would be required to have 50 percent of (a) or (b); No. 2 Shop would be required to have 33⅓ percent. Because of different characteristics assigned to grades with similar nomenclature, grades labeled Factory or Shop must be referenced to the appropriate industry source.

Industrial clears

These grades are used for cabinet stock, door stock, and other product components where excellent appearance, mechanical and physical properties, and finishing characteristics are important. The principal grades are B&BTR, C, and D. Grading is based primarily on the best face, although the influence of edge characteristics is important and varies depending upon piece width and thickness. In redwood this grade may include an "all heart" requirement for decay resistance in manufacture of cooling towers, tanks, pipe, and similar products.

Molding, ladder, pole, tank, and pencil stock

Within producing regions, grading rules delineate the requirements for a variety of lumber items oriented to specific consumer products. Custom and the characteristics of the wood supply lead to different grade descriptions and terminology. For example, in West Coast species, the ladder industry can choose from one "ladder and pole stock" grade plus two ladder rail grades and one ladder rail stock grade. In southern pine, ladder stock is available as Select and Industrial. Molding stock, tank stock, pole stock, stave stock, stadium seat stock, box lumber, and pencil stock are other typical industrial grades oriented to the final product. Some have only one grade level; a few offer two or three levels. Special features of these grades may include a restriction on sapwood related to desired decay resistance, specific requirements for slope of grain and growth ring orientation for high-stress use such as ladders, and particular cutting requirements as in pencil stock. All references to these grades should be made directly to current lumber association grading rules.

Structural laminations

Structural laminating grades describe the characteristics used to segregate lumber for structural glued-laminated timbers. Three typical basic categories, L1, L2, and L3, exist with additional provisions for "Dense." The grade characteristics permitted are based on anticipated performance as a portion of the laminated product; however, allowable properties are not assigned separately to the laminating grades.

Softwood Lumber Manufacture

Size

Lumber length is recorded in actual dimensions while width and thickness are traditionally recorded in "nominal" dimensions—the actual dimension being somewhat less.

Softwood lumber is manufactured in length multiples of 1 foot as specified in various grading rules. In practice, 2-foot multiples (in even numbers) are the rule for most construction lumber. Width of softwood lumber varies, commonly from 2 to 16 inch nominal. The thickness of lumber can be generally categorized as follows:

Boards.—lumber less than 2 inches in nominal thickness.

Dimension.—lumber from 2 inches to, but not including, 5 inches in nominal thickness.

Timbers.—lumber 5 or more inches in nominal thickness in the least dimension.

To standardize and clarify nominal-actual sizes the American Lumber Standard specifies thickness and width for lumber that falls under the standard.

The standard sizes for stress-graded and nonstress-graded construction lumber are given in table 5–5. Timbers are usually surfaced while green and only green sizes are given. Dimension and boards may be surfaced green or dry at the prerogative of the manufacturer; therefore, both green and dry standard sizes are given. The sizes are such that a piece of green lumber, surfaced to the standard green size, will shrink to approximately the standard dry size as it dries down to about 15 percent moisture content. The American Lumber Standard definition of dry is a *moisture content of 19 percent or less.* Many types of lumber are dried before surfacing and only dry sizes for these products are given in the standard.

Lumber for remanufacture is offered in specified sizes to fit end product requirements. Factory grades for general cuttings (Shop) are offered in thicknesses from less than 1 inch to over 3 inches depending on species. Thicknesses of door and sash cuttings start at $1\frac{3}{8}$ inches. Cuttings are various lengths and widths. Laminating stock sometimes is offered oversize, compared to standard dimension sizes, to permit resurfacing prior to laminating. Industrial Clears can be offered rough or surfaced in a variety of sizes starting from less than 2 inches thick and as narrow as 3 inches. Sizes

Table 5–5.—*American Standard lumber sizes for stress-graded and non-stress-graded lumber for construction* [1]

Item	Thickness			Face width		
	Nominal	Minimum dressed		Nominal	Minimum dressed	
		Dry	Green		Dry	Green
	In.	*In.*	*In.*	*In.*	*In.*	*In.*
Boards	1	$\frac{3}{4}$	$\frac{25}{32}$	2	$1\frac{1}{2}$	$1\frac{9}{16}$
	$1\frac{1}{4}$	1	$1\frac{1}{32}$	3	$2\frac{1}{2}$	$2\frac{9}{16}$
	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{9}{32}$	4	$3\frac{1}{2}$	$3\frac{9}{16}$
				5	$4\frac{1}{2}$	$4\frac{5}{8}$
				6	$5\frac{1}{2}$	$5\frac{5}{8}$
				7	$6\frac{1}{2}$	$6\frac{5}{8}$
				8	$7\frac{1}{4}$	$7\frac{1}{2}$
				9	$8\frac{1}{4}$	$8\frac{1}{2}$
				10	$9\frac{1}{4}$	$9\frac{1}{2}$
				11	$10\frac{1}{4}$	$10\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14	$13\frac{1}{4}$	$13\frac{1}{2}$
				16	$15\frac{1}{4}$	$15\frac{1}{2}$
Dimension	2	$1\frac{1}{2}$	$1\frac{9}{16}$	2	$1\frac{1}{2}$	$1\frac{9}{16}$
	$2\frac{1}{2}$	2	$2\frac{1}{16}$	3	$2\frac{1}{2}$	$2\frac{9}{16}$
	3	$2\frac{1}{2}$	$2\frac{9}{16}$	4	$3\frac{1}{2}$	$3\frac{9}{16}$
	$3\frac{1}{2}$	3	$3\frac{1}{16}$	5	$4\frac{1}{2}$	$4\frac{5}{8}$
	4	$3\frac{1}{2}$	$3\frac{9}{16}$	6	$5\frac{1}{2}$	$5\frac{5}{8}$
	$4\frac{1}{2}$	4	$4\frac{1}{16}$	8	$7\frac{1}{4}$	$7\frac{1}{2}$
				10	$9\frac{1}{4}$	$9\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14	$13\frac{1}{4}$	$13\frac{1}{2}$
				16	$15\frac{1}{4}$	$15\frac{1}{2}$
Timbers	5 and greater		$\frac{1}{2}$ less than nominal	5 and greater		$\frac{1}{2}$ less than nominal

[1] Nominal sizes in the table are used for convenience. No inference should be drawn that they represent actual sizes.

for special product grades such as molding stock and ladder stock are specified in appropriate grading rules or handled by purchase agreements.

Surfacing

Lumber can be produced either rough or surfaced (dressed). Rough lumber has surface imperfections caused by the primary sawing operations. It may be oversize by variable amounts in both thickness and width, depending upon the type of sawmill equipment. Rough lumber serves as a raw material for further manufacture and also for some decorative purposes. A rough sawn surface is common in post and timber products. Because of surface roughness, grading of rough lumber generally is difficult.

Surfaced lumber has been planed or sanded on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or combinations of sides and edges (S1S1E, S2S1E, S1S2E, or S4S). Surfacing may be done to attain smoothness or uniformity of size or both.

A number of surfaced lumber imperfections or blemishes are classified as "manufacturing imperfections" or "mismanufacture." For example, chipped and torn grain are irregularities of the surface where the particles of the surface have been torn out by the surfacing operation. Chipped grain is a "barely perceptible" characteristic, while torn grain is classified by depth. Raised grain, skip, machine burn and gouge, chip marks, and wavy dressing are other defined manufacturing imperfections. Manufacturing imperfections are defined in the American Lumber Standard and further detailed in the grade rules. Classifications of manufacturing imperfections (combinations of the imperfections allowed in the rules) are established in the rules as STANDARD "A", STANDARD "B", etc. For example, STANDARD "A" admits very light torn grain, occasional slight chip marks, and very slight knife marks. These classifications are used as part of the grade description of some lumber products to specify the allowable surfacing quality.

Patterns

Lumber which, in addition to being surfaced, has been matched, shiplapped, or otherwise patterned is often classed as "worked lumber." Figure 5–2 shows typical patterns of lumber.

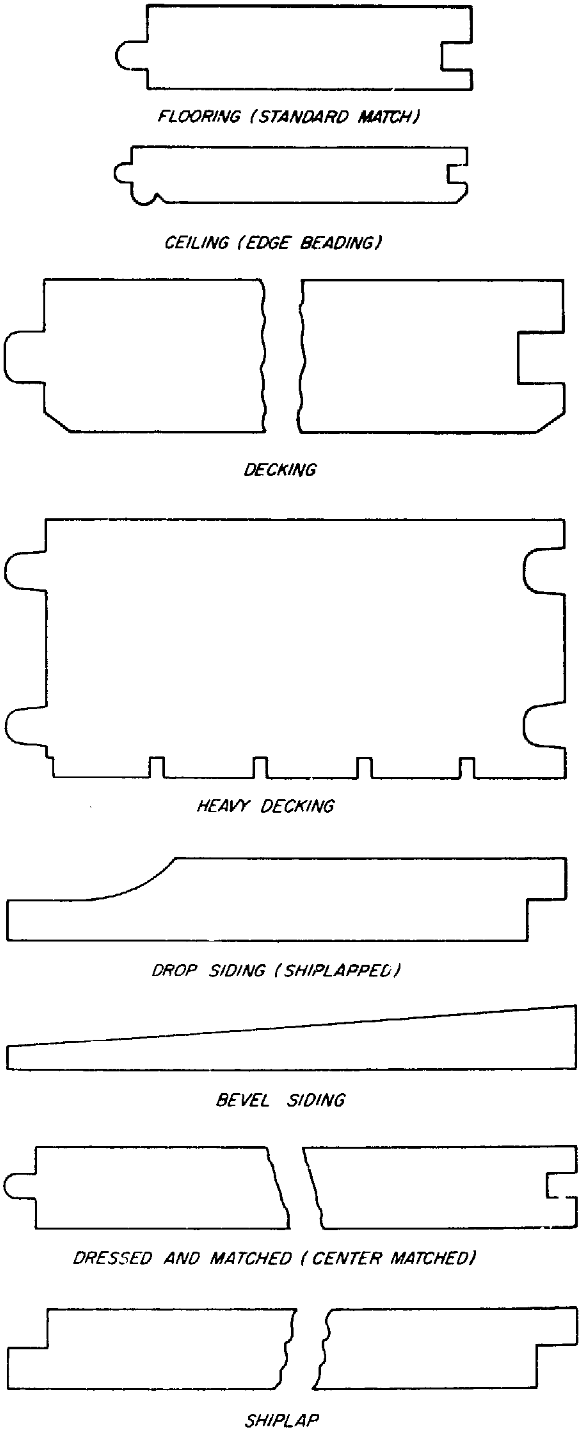

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Figure 5–2.—Typical patterns of lumber.

Table 5–6.—*Nomenclature of commercial softwood lumber*

Standard lumber name under American Lumber Standards	Official Forest Service tree name used in this handbook	Botanical name
Cedar:		
Alaska	Alaska-cedar	*Chamaecyparis nootkatensis*
Eastern red	Eastern redcedar	*Juniperus virginiana*
Incense	Incense-cedar	*Libocedrus decurrens*
Northern white	Northern white-cedar	*Thuja occidentalis*
Port Orford	Port-Orford-cedar	*Chamaecyparis lawsoniana*
Southern white	Atlantic white-cedar	*C. thyoides*
Western red	Western redcedar	*Thuja plicata*
Cypress, red (coast type), yellow (inland type), white (inland type)	Baldcypress	*Taxodium distichum*
Douglas-fir	Douglas-fir	*Pseudotsuga menziesii*
Fir:		
Balsam	Balsam fir	*Abies balsamea*
	Fraser fir	*A. fraseri*
Noble	Noble fir	*A. procera*
White	California red fir	*A. magnifica*
	Grand fir	*A. grandis*
	Pacific silver fir	*A. amabilis*
	Subalpine fir	*A. lasiocarpa*
	White fir	*A. concolor*
Hemlock:		
Eastern	Eastern hemlock	*Tsuga canadensis*
Mountain	Mountain hemlock	*T. mertensiana*
West Coast	Western hemlock	*T. heterophylla*
Juniper, western	Alligator juniper	*Juniperus deppeana*
	Rocky Mountain juniper	*J. scopulorum*
	Utah juniper	*J. osteosperma*
	Western juniper	*J. occidentalis*
Larch, western	Western larch	*Larix occidentalis*
Pine:		
Idaho white	Western white pine	*Pinus monticola*
Jack	Jack pine	*P. banksiana*
Lodgepole	Lodgepole pine	*P. contorta*
Longleaf yellow[1]	Longleaf pine	*P. palustris*
	Slash pine	*P. elliottii*
Northern white	Eastern white pine	*P. strobus*
Norway	Red pine	*P. resinosa*
Southern yellow	Longleaf pine	*P. palustris*
	Shortleaf pine	*P. echinata*
	Loblolly pine	*P. taeda*
	Slash pine	*P. elliottii*
	Pitch pine	*P. rigida*
	Virginia pine	*P. virginiana*
Sugar	Sugar pine	*P. lambertiana*
Redwood	Redwood	*Sequoia sempervirens*
Spruce:		
Eastern	Black spruce	*Picea mariana*
	Red spruce	*P. rubens*
	White spruce	*P. glauca*
Engelmann	Blue spruce	*P. pungens*
	Engelmann spruce	*P. engelmannii*
Sitka	Sitka spruce	*P. sitchensis*
Tamarack	Tamarack	*Larix laricina*
Yew, Pacific	Pacific yew	*Taxus brevifolia*

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[1] The commercial requirements for longleaf yellow pine lumber are that not only must it be produced from the species *Pinus elliottii* and *P. palustris,* but each piece must average either on 1 end or the other not less than 6 annual rings per inch and not less than ⅓ summerwood. Longleaf yellow pine lumber is sometimes designated as pitch pine in the export trade.

With softwood flooring, "standard match" means that the upper lip of the groove is thicker than the lower. The thickness of the lower lip is the same for all standard thicknesses of flooring and hence the difference between upper and lower lips becomes more pronounced in the greater thicknesses. Ceiling is usually machined with a "V" while partition usually has a bead and "V" but may be patterned on both sides. Decking is available in a variety of patterns including grooved V-joint and striated. It is available in panel form as well as in single pieces. Drop siding probably is made in more patterns than any other product except molding. Some siding patterns are shiplapped, others are tongued-and-grooved. Bevel siding is made by resawing 4/4- or 5/4-inch lumber on an angle. Square-edged lumber in boards, timbers, or dimension forms only rectangles of different dimensions. Dressed and matched (D&M) boards have the tongue and groove in the center, making the pieces center matched. Dressed and matched boards are considered preferable to shiplap boards for some uses.

Softwood Lumber Species

The names of lumber as adopted by the trade as American Standard may vary from the names of trees adopted as official by the USDA Forest Service. Table 5–6 shows the American Lumber Standard commercial name for lumber, the USDA Forest Service tree name, and the botanical name. Some softwood species are marketed primarily in combinations. Designations such as Southern Pine and Hem-Fir represent typical combinations. The grading organizations listed in table 5–7 should be contacted for questions regarding combination names and species not listed in table 5–6. Further discussion of species grouping is contained in chapter 6.

Table 5–7.—*Organizations promulgating softwood grades*

Name and Address	Species Covered by Grading Rules
National Hardwood Lumber Association 59 East Van Buren Street Chicago, Illinois 60605	Baldcypress, eastern redcedar
Northeastern Lumber Manufacturers Association, Inc. 13 South Street Glens Falls, New York 12801	Balsam fir, eastern white pine, red pine, eastern hemlock, black spruce, white spruce, red spruce, pitch pine, tamarack, jack pine, northern white cedar
Northern Hardwood and Pine Manufacturers Association Suite 207, Northern Building Green Bay, Wisconsin 54301	Bigtooth aspen, quaking aspen, eastern white pine, red pine, jack pine, black spruce, white spruce, red spruce, balsam fir, eastern hemlock, tamarack
Red Cedar Shingle & Handsplit Shake Bureau 5510 White Building Seattle, Washington 98101	Western redcedar (shingles and shakes)
Redwood Inspection Service 617 Montgomery Street San Francisco, California 94111	Redwood
Southern Cypress Manufacturers Association P.O. Box 5816 Jacksonville, Florida 32207	Baldcypress
Southern Pine Inspection Bureau Box 846 Pensacola, Florida 32502	Longleaf pine, slash pine, shortleaf pine, loblolly pine, Virginia pine, pond pine, pitch pine
West Coast Lumber Inspection Bureau Box 25406 1750 SW. Skyline Boulevard Portland, Oregon 97225	Douglas-fir, western hemlock, western redcedar, incense-cedar, Port-Orford-cedar, Alaska-cedar, western true firs, mountain hemlock, Sitka spruce
Western Wood Products Association 700 Yeon Building Portland, Oregon 97204	Ponderosa pine, western white pine, Douglas-fir, sugar pine, western true firs, western larch, Engelmann spruce, incense-cedar, western hemlock, lodgepole pine, western redcedar, mountain hemlock, red alder

Softwood Lumber Grading

Most lumber is graded under the supervision of inspection bureaus and grading agencies. These organizations supervise lumber mill grading, and provide reinspection services to resolve disputes concerning lumber shipments. Some of the agencies also author grading rules which reflect the species and products in the geographic regions they represent.[2] Many of the grading rules and procedures fall under the American Softwood Lumber Standard. This can be an important consideration because it provides for recognized uniform grading procedures. Names and addresses of rules-writing organizations in the United States, and the species for which they are concerned, are given in table 5–7. Canadian softwood lumber imported into the United States is graded by inspection agencies in Canada. Names and addresses of Canadian grading agencies may be obtained from the Canadian Lumber Standards Administration Board, 1460–1055 West Hastings Street, Vancouver 1, B.C., Canada.

PURCHASING LUMBER

After primary manufacture, most lumber products are marketed through wholesalers to remanufacture plants or to retail outlets. Because of the extremely wide variety of lumber products, wholesaling is very specialized with some organizations dealing only with a limited number of species or products. Where the primary manufacturer can readily identify the customers, direct sales may be made. Examples are manufacturer sales to large retail chains, contractors, and to truss rafter fabricators. There is an increasing trend to direct sales, particularly for mobile and modular housing.

Lumber Distribution

Large primary manufacturers and wholesale organizations set up distribution yards in lumber-consuming areas to more effectively distribute both hardwood and softwood products. Retail yards draw inventory from distribution yards and, in wood-producing areas, from local lumber producers. Few lumber products are readily available at the retail level in the wide range of grades and species suggested by the grade rules.

Transportation is a vital factor in lumber distribution. On the eastern seaboard of the United States, lumber from the Pacific Coast is readily available because of low-cost water transportation via the Panama Canal. Often the lumber shipped by water is green because weight is not a major factor in this type of shipping. On the other hand, lumber reaching the East Coast from the Pacific Coast by rail is largely kiln dried because rail shipping rates are based on weight. A shorter rail haul places southern and northeastern species in a favorable shipping cost position in this same market.

Changing transportation costs have influenced shifts in market distribution of species and products. Trucks have become a major factor in lumber transport for regional remanufacture plants, for retail supply from distribution yards, and for much construction lumber distribution where the distance from primary manufacture to customer is within an approximate 1,500-mile radius. The development of foreign hardwood and softwood manufacturing and the availability of water transport has brought foreign lumber products to the United States market, particularly in coastal areas.

Retail Yard Inventory

The small retail yards throughout the United States carry softwoods required for ordinary construction purposes and often small stocks of one or two hardwoods in the grades suitable for finishing or cabinetwork. Special orders must be made for other hardwoods. Trim items such as molding in either softwood or hardwood are available cut to size and standard pattern. Cabinets are usually made by millwork plants ready for installation and many common styles and sizes are carried or cataloged by the modern retail yard. Hardwood flooring is available to the buyer only in standard patterns. Some retail yards may carry specialty stress grades of lumber such as structural light framing for truss rafter fabrication.

The assortment of species in general construction items carried by retail yards depends largely upon geographic location, and both transportation costs and tradition are important factors. Retail yards within, or close to, a major lumber-producing region may therefore emphasize the local timber. For example, a

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[2] A limited number of hardwoods are also being graded under the provisions of the standards used for grading softwoods. These hardwoods include aspen and red alder.

local retail yard on the coast in the Pacific Northwest may stock only green Douglas-fir and cedar in dimension grades, dry pine and hemlock in boards and molding, plus assorted specialty items such as redwood posts, cedar shingles and shakes, and rough cedar siding. The only hardwoods carried may be walnut and "Philippine mahogany."[3] Retail yards farther from a major softwood supply, such as in the Midwest on the other hand, may draw from several species-growing areas and may stock spruce or southern pine. Being located in a major hardwood production area, these yards will stock, or have available to them, a different and wider variety of hardwoods.

Geography has less influence where consumer demands are more specific. For example, where long length construction lumber (20 to 26 ft.) is required, west coast species often are marketed because the size of the trees in several of the species makes long lengths a practical market item. As another example, ease of treatability makes treated southern pine construction lumber available in a wide geographic area.

Some lumber grades and sizes serve a variety of construction needs. Some species or species groups are available at the retail level only in grade groups. Typical are house framing grades such as joist and plank which are often sold as No. 2 and Better (2&BTR). The percentage of each grade in a grouping is part of the purchase agreement between the primary lumber manufacturer and the wholesaler; however, this ratio may be altered at the retail level by sorting. Where grade grouping is the practice, a requirement for a specific grade such as No. 1 at the retail level will require sorting or special purchase. Grade grouping occurs for reasons of tradition and of efficiency in distribution.

Another important factor in retail yard inventory is that not all grades, sizes, and species described by the grade rules are produced and not all those produced are distributed uniformly to all marketing areas. Regional consumer interest, building code requirements, and transportation costs influence distribution patterns. Often small retail yards will stock only a limited number of species and grades. Large yards, on the other hand, may cater to particular construction industry needs and carry more dry dimension grades along with clears, finish, and decking. The effect of these variable retail practices is that the grades, sizes, and species outlined in the grade rules must be examined to determine what actually is available. A brief description of lumber products commonly carried by retail yards follows:

Stress-Graded Lumber for Construction

Dimension is the principal stress-graded lumber item available in a retail yard. It is primarily framing lumber for joists, rafters, and studs. Strength, stiffness, and uniformity of size are essential requirements. Dimension is stocked in all yards, frequently in only one or two of the general purpose construction woods such as pine, fir, hemlock, or spruce. Two by six, 2 by 8, and 2 by 10 dimension are found in grades of Select Structural, No. 1, No. 2, and No. 3; often in combinations of No. 2&BTR or possibly No. 3&BTR. In 2 by 4, the grades available would normally be Construction and Standard, sold as Standard and Better (STD&BTR), Utility and Better (UTIL&BTR), or Stud, in lengths of 10 feet and shorter.

Dimension is often found in nominal 2–, 4–, 6–, 8–, 10–, or 12–inch widths and 8– to 18–foot lengths in multiples of 2 feet. Dimension formed by structural end-jointing procedures may be found. Dimension thicker than 2 inches and longer than 18 feet is not available in large quantity.

Other stress-graded products generally present are posts and timbers, with some beams and stringers also possibly in stock. Typical stress grades in these products are Select Structural and No. 1 Structural in Douglas-fir and No. 1SR and No. 2SR in southern pine.

Nonstress-Graded Lumber for Construction

Boards are the most common nonstress-graded general purpose construction lumber in the retail yard. Boards are stocked in one or more species, usually in nominal 1-inch thickness. Standard nominal widths are 2, 3, 4, 6, 8, 10, and 12 inches. Grades most generally available in retail yards are No. 1, No. 2, and No. 3 (or Construction, Standard, and Utility). These will often be combined in grade groups. Boards are sold square edged, dressed and matched (tongued and grooved) or with a shiplapped joint. Boards formed by end-jointing of shorter sections may form an appreciable portion of the inventory.

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[3] Common market name encompassing many species including tanguile, red lauan, and white lauan.

Appearance Lumber

Completion of a construction project usually depends on a variety of lumber items available in finished or semifinished form. The following items often may be stocked in only a few species, finishes, or in limited sizes depending on the yards.

Finish

Finish boards usually are available in a local yard in one or two species principally in grade C&BTR. Redwood and cedar have different grade designations. Grades such as Clear Heart, A, or B are used in cedar; Clear All Heart, Clear, and Select are typical redwood grades. Finish boards are usually a nominal 1 inch thick, dressed two sides to ¾ inch. The widths usually stocked are nominal 2 to 12 inches in even-numbered inches.

Siding

Siding, as the name implies, is intended specifically to cover exterior walls. Beveled siding is ordinarily stocked only in white pine, ponderosa pine, western redcedar, cypress, or redwood. Drop siding, also known as rustic siding or barn siding, is usually stocked in the same species as beveled siding. Siding may be stocked as B&BTR or C&BTR except in cedar where Clear, A, and B may be available and redwood where Clear All Heart and Clear will be found. Vertical grain (VG) is sometimes a part of the grade designation. Drop siding sometimes is stocked also in sound knotted C and D grades of southern pine, Douglas-fir, and hemlock. Drop siding may be dressed, matched, or shiplapped.

Flooring

Flooring is made chiefly from hardwoods such as oak and maple, and the harder softwood species, such as Douglas-fir, western larch, and southern pine. Often at least one softwood and one hardwood are stocked. Flooring is usually nominal 1 inch thick dressed to 25/32 inch, and 3- and 4-inch nominal width. Thicker flooring is available for heavy-duty floors both in hardwoods and softwoods. Thinner flooring is available in hardwoods, especially for recovering old floors. Vertical and flat grain (also called quartersawed and plainsawed) flooring is manufactured from both softwoods and hardwoods. Vertical-grained flooring shrinks and swells less than flat-grained flooring, is more uniform in texture, wears more uniformly, and the joints do not open as much.

Softwood flooring is usually available in B and Better grade, C Select, or D Select. The chief grades in maple are Clear No. 1 and No. 2. The grades in quartersawed oak are Clear and Select, and in plain-sawed Clear, Select, and No. 1 Common. Quartersawed hardwood flooring has the same advantages as vertical-grained softwood flooring. In addition, the silver or flaked grain of quartersawed flooring is frequently preferred to the figure of plain-sawed flooring. Beech, birch, and walnut and mahogany (for fancy parquet flooring) are also occasionally used.

Casing and base

Casing and base are standard items in the more important softwoods and are stocked by most yards in at least one species. The chief grade, B and Better, is designed to meet the requirements of interior trim for dwellings. Many casing and base patterns are dressed to 11/16 by 2¼; other sizes used include 9/16 by 3, 3¼, and 3½. Hardwoods for the same purposes, such as oak and birch, may be carried in stock in the retail yard or may be obtained on special order.

Shingles and shakes

Shingles usually available are sawn from western redcedar, northern white-cedar, and redwood. The shingle grades are: Western redcedar, No. 1, No. 2, No. 3; northern white-cedar, Extra, Clear, 2nd Clear, Clear Wall, Utility; redwood, No. 1, No. 2 VG, and No. 2 MG.

Shingles that are all heartwood give greater resistance to decay than do shingles that contain sapwood. Edge-grained shingles are less likely to warp than flat-grained shingles; thick-butted shingles less likely than thin shingles; and narrow shingles less likely than wide shingles. The standard thicknesses of shingles are described as 4/2, 5/2, ¼, and 5/2 (four shingles to 2 in. of butt thickness, five shingles to 2¼ in. of butt thickness, and five shingles to 2 in. of butt thickness). Lengths may be 16, 18, or 24 inches. Random widths and specified widths ("dimension" shingles) are available in western redcedar, redwood, and cypress.

Shingles are usually packed four bundles to the square. A square of shingles will cover 100 square feet of roof area when the shingles are applied at standard weather exposures.

Shakes are handsplit or handsplit and resawn from western redcedar. Shakes are of a single grade and must be 100 percent clear, graded from the split face in the case of handsplit and resawn material. Handsplit shakes are graded from the best face. Shakes must be 100 percent heartwood free of bark and sapwood. The standard thickness of shakes ranges from ⅜ to 1¼ inches. Lengths are 18 and 24 inches, and a 15-inch "Starter-Finish Course" length.

Important Purchase Considerations

The following outline lists some of the points to consider when ordering lumber or timbers.

1. *Quantity.*—Feet, board measure, number of pieces of definite size and length. Consider that the board measure depends on the thickness and width nomenclature used and that the interpretation of this must be clearly delineated. In other words, nominal or actual, pattern size, etc., must be considered.

2. *Size.*—Thickness in inches—nominal and actual if surfaced on faces. Width in inches—nominal and also actual if surfaced on edges. Length in feet—may be nominal average length, limiting length, or a single uniform length. Often a trade designation, "random" length, is used to denote a nonspecified assortment of lengths. Note that such an assortment should contain critical lengths as well as a range. The limits allowed in making the assortment "random" can be established at the time of purchase.

3. *Grade.*—As indicated in grading rules of lumber manufacturing associations. Some grade combinations (B&BTR) are official grades; other [Standard and Better (STD&BTR) light framing, for example] are grade combinations and subject to purchase agreement. A typical assortment is 75 percent Construction and 25 percent Standard, sold under the label STD&BTR. In softwood, each piece of such lumber typically is stamped with its grade, a name or number identifying the producing mill, the dryness at the time of surfacing, and a symbol identifying the inspection agency supervising the grading inspection. The grade designation stamped on a piece indicates the quality at the time the piece was graded. Subsequent exposure to unfavorable storage conditions, improper drying, or careless handling may cause the material to fall below its original grade.

Note that working or rerunning a graded product to a pattern may result in changing or invalidating the original grade. The purchase specification should be clear regarding regrading or acceptance of worked lumber. In softwood lumber, grades for dry lumber generally are determined after kiln drying and surfacing. This practice is not general for hardwood factory lumber, however, where the grade is generally based on grade and size prior to kiln drying.

4. *Species or groupings of wood.*—Douglas-fir, cypress, Hem-Fir, etc. Some species have been grouped for marketing convenience; others are traded under a variety of names. Be sure the species or species group is correctly and clearly depicted on the purchase specification.

5. *Product.*—Flooring, siding, timbers, boards, etc. Nomenclature varies by species, region, and grading association. To be certain the nomenclature is correct for the product, refer to the grading rule by number and paragraph.

6. *Condition of seasoning.*—Air dry, kiln dry, etc. Softwood lumber dried to 19 percent moisture content or less (S–DRY) is defined as dry by the American Lumber Standard. Other degrees of dryness are partially air dried (PAD), green (S–GRN), and 15 percent max. (KD in southern pine). There are several specified levels of moisture content for redwood. If the moisture requirement is critical, the levels and determination of moisture content must be specified.

7. *Surfacing and working.*—Rough (unplaned), dressed (surfaced), or patterned stock. Specify condition. If surfaced, indicate S4S, S1S1E, etc. If patterned, list pattern number with reference to the appropriate grade rules.

8. *Grading rules.*—Official grading agency name, product identification, paragraph number or page number or both, date of rules or official rule volume (rule No. 16, for example).

9. *Manufacturer.*—Name of manufacturer or trade name of specific product or both. Most lumber products are sold without reference to a specific manufacturer. If proprietary names or quality features of a manufacturer are required, this must be stipulated clearly on the purchase agreement.

10. *Reinspection.*—Procedures for resolution of purchase disputes. The American Lumber Standard (ALS) provides for procedures to be followed in resolution of manufacturer-wholesaler-consumer conflicts over quality or quantity of softwood lumber graded under ALS jurisdiction. The dispute may be resolved by

reinspecting the shipment. Time limits, liability, costs, and complaint procedures are outlined in the grade rules of both softwood and hardwood agencies under which the disputed shipment was graded and purchased.

STANDARD LUMBER ABBREVIATIONS

The following standard lumber abbreviations are commonly used in contracts and other documents for purchase and sale of lumber.

AAR	Association of American Railroads
AD	air dried
ADF	after deducting freight
ALS	American Lumber Standard
AST	antistain treated. At ship tackle (western softwoods)
AV or avg	average
AW&L	all widths and lengths
B1S	see EB1S, CB1S, and E&CB1S
B2S	see EB2S, CB2S, and E&CB2S
B&B, B&BTR	B and Better
B&S	beams and stringers
BD	board
BD FT	board feet
BDL	bundle
BEV	bevel or beveled
BH	boxed heart
B/L, BL	bill of lading
BM	board measure
BSND	bright sapwood no defect
BTR	better
c	allowable stress in compression in pounds per square inch
CB	center beaded
CB1S	center bead on one side
CB2S	center bead on two sides
CC	cubical content
cft or cu. ft.	cubic foot or feet
CF	cost and freight
CIF	cost, insurance, and freight
CIFE	cost, insurance, freight, and exchange
CG2E	center groove on two edges
C/L	carload
CLG	ceiling
CLR	clear
CM	center matched
Com	common
CS	calking seam
CSG	casing
CV	center V
CV1S	center V on one side
CV2S	center V on two sides
DB Clg	double beaded ceiling (E&CB1S)
DB Part	double beaded partition (E&CB2S)
DET	double end trimmed
DF	Douglas-fir
DIM	dimension
DKG	decking
D/S, DS, D/Sdg	drop siding
D1S, D2S	See S1S and S2S
D&M	dressed and matched
D&CM	dressed and center matched
D&SM	dressed and standard matched
D2S&CM	dressed two sides and center matched
D2S&SM	dressed two sides and standard matched
E	edge
EB1S	edge bead one side
EB2S, SB2S	edge bead on two sides
EE	eased edges
EG	edge (vertical or rift) grain
EM	end matched
EV1S, SV1S	edge V one side
EV2S, SV2S	edge V two sides
E&CB1S	edge and center bead one side
E&CB2S, DB2S, BC&2S	edge and center bead two sides
E&CV1S, DV1S, V&CV1S	edge and center V one side
E&CV2S, DV2S, V&CV2S	edge and center V two sides
f	allowable stress in bending in pounds per square inch
FA	facial area
Fac	factory
FAS	free alongside (vessel)
FAS	Firsts and Seconds
FBM, Ft. BM	feet board measure
FG	flat or slash grain
FJ	finger joint. End-jointed lumber using a finger joint configuration
FLG, Flg	flooring
FOB	free on board (named point)
FOHC	free of heart center
FOK	free of knots
FRT, Frt	freight
FT, ft	foot or feet
FT. SM	feet surface measure
G	girth
GM	grade marked
G/R	grooved roofing
HB, H. B.	hollow back
HEM	hemlock
Hrt	heart
H&M	hit and miss
H or M	hit or miss
IN, in.	inch or inches
Ind	industrial
J&P	joists and planks
JTD	jointed
KD	kiln dried
LBR, Lbr	lumber
LCL	less than carload
LGR	longer
LGTH	length
Lft, Lf	lineal foot or feet
LIN, Lin	lineal
LL	longleaf
LNG, Lng	lining
M	thousand
MBM, MBF, M. BM	thousand (feet) board measure
MC, M.C.	moisture content
MERCH, Merch	merchantable
MG	medium grain or mixed grain
MLDG, Mldg	molding
Mft	thousand feet
MSR	machine stress rated

N	nosed
NBM	net board measure
No.	number
N1E or N2E	nosed one or two edges
Ord	order
PAD	partially air dry
PAR, Par	paragraph
PART, Part	partition
PAT, Pat	pattern
Pcs.	pieces
PE	plain end
PET	precision end trimmed
P&T	posts and timbers
P1S, P2S	see S1S and S2S
RDM	random
REG, Reg	regular
Rfg.	roofing
RGH, Rgh	rough
R/L, RL	random lengths
R/W, RW	random widths
RES	resawn
SB1S	single bead one side
SDG, Sdg	siding
S-DRY	surfaced dry. Lumber 19 percent moisture content or less per American Lumber Standard for softwood
SE	square edge
SEL, Sel	select or select grade
SE&S	square edge and sound
SG	slash or flat grain
S-GRN	surfaced green. Lumber unseasoned, in excess of 19 percent moisture content per American Lumber Standard for softwood
SGSSND	Sapwood, gum spots and streaks, no defect
SIT. SPR	Sitka spruce
S/L, SL, S/Lap	shiplap
STD. M	standard matched
SM	surface measure
Specs	specifications
SQ	square
SQRS	squares
SR	stress rated
STD, Std	standard
Std. lgths.	standard lengths
SSND	sap stain no defect (stained)
STK	stock
STPG	stepping
STR, STRUCT	structural
SYP	southern yellow pine
S&E	side and edge (surfaced on)
S1E	surfaced one edge
S2E	surfaced two edges
S1S	surfaced one side
S2S	surfaced two sides
S4S	surfaced four sides
S1S&CM	surfaced one side and center matched
S2S&CM	surfaced two sides and center matched
S4S&CS	surfaced four sides and calking seam
S1S1E	surfaced one side, one edge
S1S2E	surfaced one side, two edges
S2S1E	surfaced two sides, one edge
S2S&SL	surfaced two sides and shiplapped
S2S&SM	surfaced two sides and standard matched
t	allowable stress in tension in pounds per square inch
TBR	timber
T&G	tongued and grooved
VG	vertical (edge) grain
V1S	see EV1S, CV1S, and E&CV1S
V2S	see EV2S, CV2S, and E&CV2S
WCH	west coast hemlock
WDR, wdr	wider
WHAD	worm holes a defect
WHND	worm holes no defect
WT	weight
WTH	width
WRD	western redcedar
YP	yellow pine

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Chapter 6

LUMBER STRESS GRADES AND ALLOWABLE PROPERTIES

LUMBER STRESS GRADES AND ALLOWABLE PROPERTIES

Lumber of any species and size, as it is sawed from the log, is quite variable in its mechanical properties. Pieces may differ in strength by several hundred percent. For simplicity and economy in use, pieces of lumber of similar mechanical properties can be placed in a single class called a stress grade.

A stress grade is characterized by:

1. One or more sorting criteria
2. A set of allowable properties for engineering design
3. A unique grade name

This chapter discusses sorting criteria for two stress grading methods, along with the philosophy of how allowable properties are derived. The allowable properties depend upon the particular sorting criteria and on additional factors that are independent of the sorting criteria. Allowable properties are different from, and usually much lower than, the properties of clear, straight-grained wood tabulated in chapter 4.

From one to six allowable properties are associated with a stress grade—modulus of elasticity and stresses in tension and compression parallel to the grain, in compression perpendicular to the grain, in shear parallel to the grain, and in extreme fiber in bending. As with any structural material, the strength properties used to derive the five allowable stresses must be inferred or measured nondestructively to avoid damage to pieces of lumber. Any nondestructive test provides both sorting criteria and a means of calculating appropriate mechanical properties.

The philosophies contained in this chapter are used by a number of organizations to develop commercial stress grades. The exact procedures they use and the resulting allowable stresses are not detailed in the Wood Handbook, but reference to them is given.

DEVELOPING VISUAL GRADES

Visual Sorting Criteria

Visual grading is the oldest stress grading method. It is based on the premise that mechanical properties of lumber differ from mechanical properties of clear wood because of characteristics that can be seen and judged by eye. These visual characteristics are used to sort the lumber into stress grades. The following are major visual sorting criteria:

Density

Strength is related to the weight or the density of clear wood. Properties assigned to lumber are sometimes modified by using the rate of growth and the percentage of latewood as measures of density. Selection for rate of growth required that the number of annual rings per inch be within a specified range. It is possible to eliminate some very low strength pieces from a grade by excluding those that are exceptionally light in weight.

Decay

Decay in most forms should be severely restricted or prohibited in stress grades because its extent is difficult to determine and its effect on strength is often greater than visual observation would indicate. Limited decay of the pocket type (e.g., *Fomes pini*) can be permitted to some degree in stress grades, as can decay that occurs in knots but does not extend into the surrounding wood.

Heartwood and Sapwood

Heartwood and sapwood of the same species have equal mechanical properties, and no heartwood requirement need be made in stress grading. Since heartwood of some species is more resistant to decay than sapwood, heartwood may be required if the untreated wood is to be exposed to a decay hazard. On the other hand, sapwood takes preservative treatment more readily and should not be limited in lumber that is to be treated.

Slope of Grain

In zones of cross grain, the direction of the wood fibers is not parallel to the edges of the lumber. Cross grain reduces the mechanical properties of lumber. Severely cross-grained pieces are also undesirable because they tend to warp with changes in moisture content. Stresses caused by shrinkage during drying are greater in structural lumber than in small, clear specimens and are increased in zones of sloping or distorted grain. To provide a margin of safety, the reduction of strength due to cross grain in visually graded structural lumber should be about twice the reduction observed in tests of small, clear specimens that contain similar cross grain.

Knots

Knots interrupt the direction of grain and cause localized cross grain with steep slopes. Intergrown or live knots resist some kinds of stress, but encased knots or knotholes transmit little or no stress. On the other hand, distortion of grain is greater around an intergrown knot than around an encased or dead knot. As a result, overall strength effects are roughly equalized, and often no distinction is made in stress grading between live knots, dead knots, and knotholes.

The zone of distorted grain (cross grain) around a knot has less "parallel to piece" stiffness than straight-grained wood; thus, localized areas of low stiffness are often associated with knots. Such zones generally comprise only a minor part of the total volume of a piece of lumber, however, and overall piece stiffness reflects the character of all parts.

The presence of a knot in a piece modifies some of the clear wood strength properties more than it affects the overall stiffness. The effect of a knot on strength depends approximately on the proportion of the cross section of the piece of lumber occupied by the knot, upon knot location, and upon the distribution of stress in the piece. Limits on knot sizes are therefore made in relation to the width of and location on the face in which the knot appears. Compression members are stressed about equally throughout, and no limitation related to location of knots is imposed. In tension, knots along the edge of a member produce an eccentricity that induces bending stresses, and should therefore be more restricted than knots away from the edge. In structural members subjected to bending, stresses are greater in the middle part of the length and are greater at the top and bottom edges than at midheight. These facts can be recognized in differing limitations on the sizes of knots in different locations.

Knots in glued-laminated structural members are not continuous as in sawed structural lumber, and different methods are used for evaluating their effect on strength (see ch. 10).

Shake

Shake in members subjected to bending reduces the resistance to shear and therefore is limited most closely in those parts of a bending member where shear stresses are highest. In members subjected only to tension or compression, shake does not greatly affect strength; it may be limited because of appearance and because it permits entrance of moisture that results in decay.

Checks and Splits

While shake indicates a weakness of fiber bond that is presumed to extend lengthwise without limit, checks and splits are rated only by the area of actual opening. An end split is considered equal to an end check that extends through the full thickness of the piece. The effects of checks and splits upon strength and the principles of their limitation are the same as for shake.

Wane

Requirements of appearance, fabrication, or the need for ample bearing or nailing surfaces generally impose stricter limitations on wane than does strength. Wane is therefore limited in structural lumber on those bases.

Pitch Pockets

Pitch pockets ordinarily have so little effect on structural lumber that they can be disregarded in stress grading if they are small and limited in number. The presence of a large number of pitch pockets, however, may indicate shake or weakness of bond between annual rings.

Deriving Properties for Visually Graded Lumber

The derivation of mechanical properties of visually graded lumber is based on clear wood properties and on the lumber characteristics allowed by the visual sorting criteria. The influence of the sorting criteria is handled with "strength ratios" for the strength properties of wood and with "quality factors" for the modulus of elasticity.

From piece to piece, there is variation both in the clear wood properties and in the occurrence of the property-modifying characteristics. The influence of this variability on lumber properites is handled differently for strength than for modulus of elasticity.

Once the clear wood properties have been modified for the influence of sorting criteria and variability, additional modifications for size, moisture content, and load duration are applied. The composite of these adjustments is an "allowable property," to be discussed in more detail later in the chapter.

Strength Properties

Each strength property of a piece of lumber is derived from the product of the clear wood strength for the species and the limiting strength ratio. The strength ratio is the hypothetical ratio of the strength of a piece of lumber with visible strength-reducing characteristics to its strength if those characteristics were absent.

The true strength ratio of a piece of lumber is never known and must be estimated. The strength ratio assigned to a lumber characteristic, therefore, serves as a predictor of lumber strength. Strength ratio usually is expressed in percent, ranging from zero to 100, although it may be greater than 100 when related to growth rate and percentage of latewood.

Estimated strength ratios for cross grain and density have been obtained empirically; strength ratios for other wood characteristics have been derived theoretically. For example, to account for the weakening effect of knots, the assumption is made that the knot is effectively a hole through the piece, reducing the cross section as shown in figure 6–1. The ratio of the moment a beam with the reduced cross section will carry to the moment of the beam without the knot is

$$SR=\left(1-\frac{k}{h}\right)^2$$

where SR is strength ratio, k is the knot size, and h is the width of the face containing the knot. This is the basic expression for the effect of a knot at the edge of the vertical face of a beam that is deflected vertically. Figure 6–2 shows how strength ratio changes with knot size in the formula.

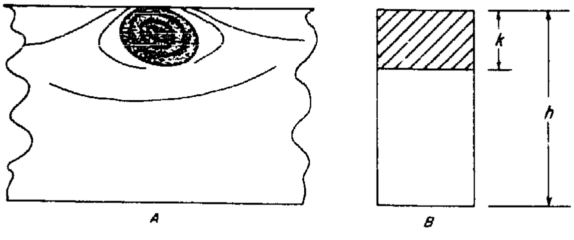

Figure 6–1.—An edge knot in lumber, A, and the assumed loss of cross section, B.

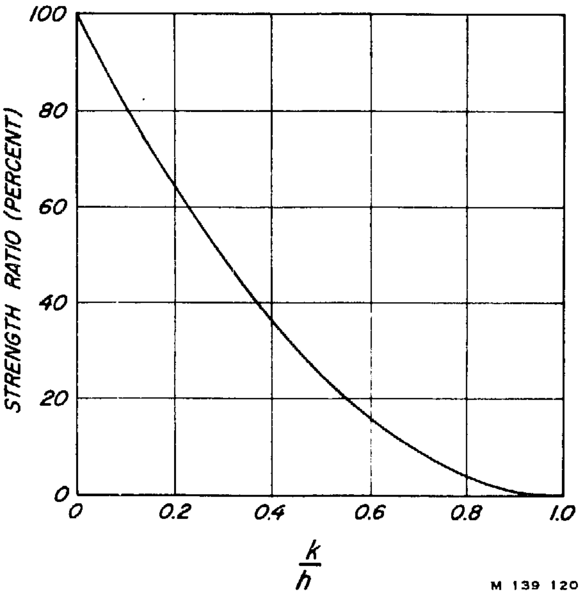

Figure 6–2.—A relation between strength ratio and size of edge knot expressed as a fraction of face width.

Strength ratios for all knots, shakes, checks, and splits are derived using similar concepts. Strength ratio formulas are given in American Society for Testing and Materials Designation D 245. The same reference contains rules for measuring the various growth characteristics.

An individual piece of lumber often will have several characteristics that can affect any particular strength property. Only the characteristic that gives the lowest strength ratio is used to derive the estimated piece strength. A visual stress grade contains lumber ranging from pieces having the minimum strength ratio permitted in the grade to pieces having the minimum for the next higher grade.

The range of strength ratios in a grade, and the natural variation in clear wood strength, give rise to variation in strength between pieces in the grade. To account for this variation, and provide for safety in design, it is intended that any strength property associated with a grade be less than the actual strength of at least 95 percent of the pieces in the grade. In visual grading according to ASTM Designation D 245, this is handled by using a near-minimum clear wood strength value, and multiplying it by the minimum strength ratio permitted in the grade to obtain the grade strength property. The near-minimum value is called the 5 percent exclusion limit. ASTM Designation D 2555 provides clear wood strength data and gives a method for estimating the 5 percent exclusion limit.

Suppose a typical 5 percent exclusion limit for the clear wood bending strength for a species in the green condition is 7,000 p.s.i. Suppose also that among the characteristics allowed in a grade of lumber, one characteristic (a knot, for example) provides the lowest strength ratio in bending—assumed in this example as 40 percent. Using these numbers, the bending strength for the grade can be obtained by multiplying the strength ratio (0.40) by 7,000 p.s.i., equalling 2,800 p.s.i. This is shown in figure 6–3. The bending strength in the green condition of 95 percent of the pieces in this species that have a strength ratio of 40 percent is expected to be 2,800 p.s.i. or more. Similar procedures are followed for other strength properties, using the appropriate clear wood property value and strength ratio. As noted, additional multiplying factors then are applied to produce allowable properties for design, as summarized later in this chapter.

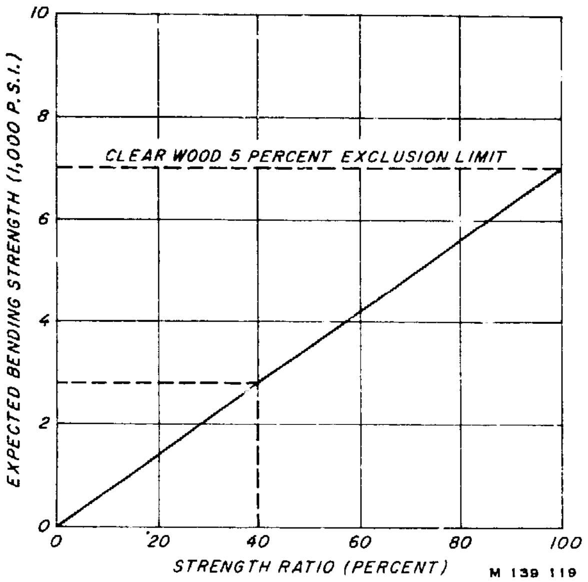

Figure 6–3.—An example of the relation between strength and strength ratio.

Modulus of Elasticity

In visual grading, the modulus of elasticity assigned is an estimate of the mean modulus of the lumber grade. The average modulus of elasticity for clear wood of the species, as recorded in ASTM D 2555, is used as a base. The clear wood average is multiplied by empirically derived "quality factors" to represent the reduction in modulus of elasticity that occurs by lumber grade. This procedure is outlined in ASTM D 245.

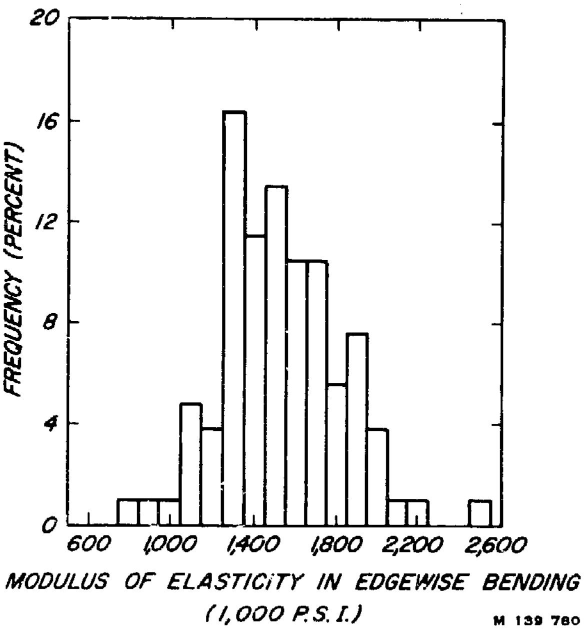

Figure 6–4.—Histogram of modulus of elasticity observed in a single visual grade. From pieces selected over a broad geographical range.

For example, assume a clear wood average modulus of elasticity of 1.8 million p.s.i. for the example shown earlier. The limiting bending strength ratio was 40 percent. ASTM D 245 assigns a quality multiplying factor of 0.80 for lumber with this bending strength ratio. The modulus of elasticity for that grade would be the product of the clear wood modulus and the quality factor; i.e., 1.44 million p.s.i.

Actual modulus of elasticity of individual pieces of the grade varies from the mean assumed for design. Figure 6–4 shows a typical histogram of the modulus of elasticity, measured within a single visual grade, sampled from a wide selection of sources. Small individual lots of lumber can be expected to deviate from the distribution shown by the histogram. The additional multiplying factors used to derive final design values of modulus of elasticity are discussed later in this chapter.

DEVELOPING MECHANICAL GRADES

Mechanical stress grading is based on an observed relation between modulus of elasticity and bending strength, tensile strength, or compressive strength parallel to the grain. The modulus of elasticity of lumber thus is the sorting criterion used in this method of grading. Mechanical devices operating up to relatively high rates of speed measure the modulus of elasticity or stiffness for a series of stress grades.

Mechanical Sorting Criteria

The modulus of elasticity used as a sorting criterion for mechanical properties of lumber can be measured in a variety of ways. Usually the apparent modulus or a stiffness-related deflection is the actual measurement made. Because lumber is heterogeneous, the apparent modulus of elasticity depends upon span, orientation (edgewise or flatwise in bending), mode of test (static or dynamic), and method of loading (tension, bending, concentrated, uniform, etc.). Any of the apparent moduli can be used, so long as the grading machine is properly calibrated to give the appropriate strength property. Most grading machines in the United States are designed to detect the lowest flatwise bending stiffness that occurs in any approximate 4-foot span.

Deriving Properties of Mechanically Graded Lumber

A stress grade derived for mechanically graded lumber relates allowable strength in bending and in compression and tension parallel to grain to the modulus of elasticity levels by which the grade is identified. This relationship between properties is chosen so that 95 percent of the pieces encountered will be at least as strong as indicated by the grading process. Figure 6–5 shows an example of a relation between bending strength, and the modulus of elasticity measured in flatwise bending over an 84-inch span.

As in visual grading, the modulus of elastic-

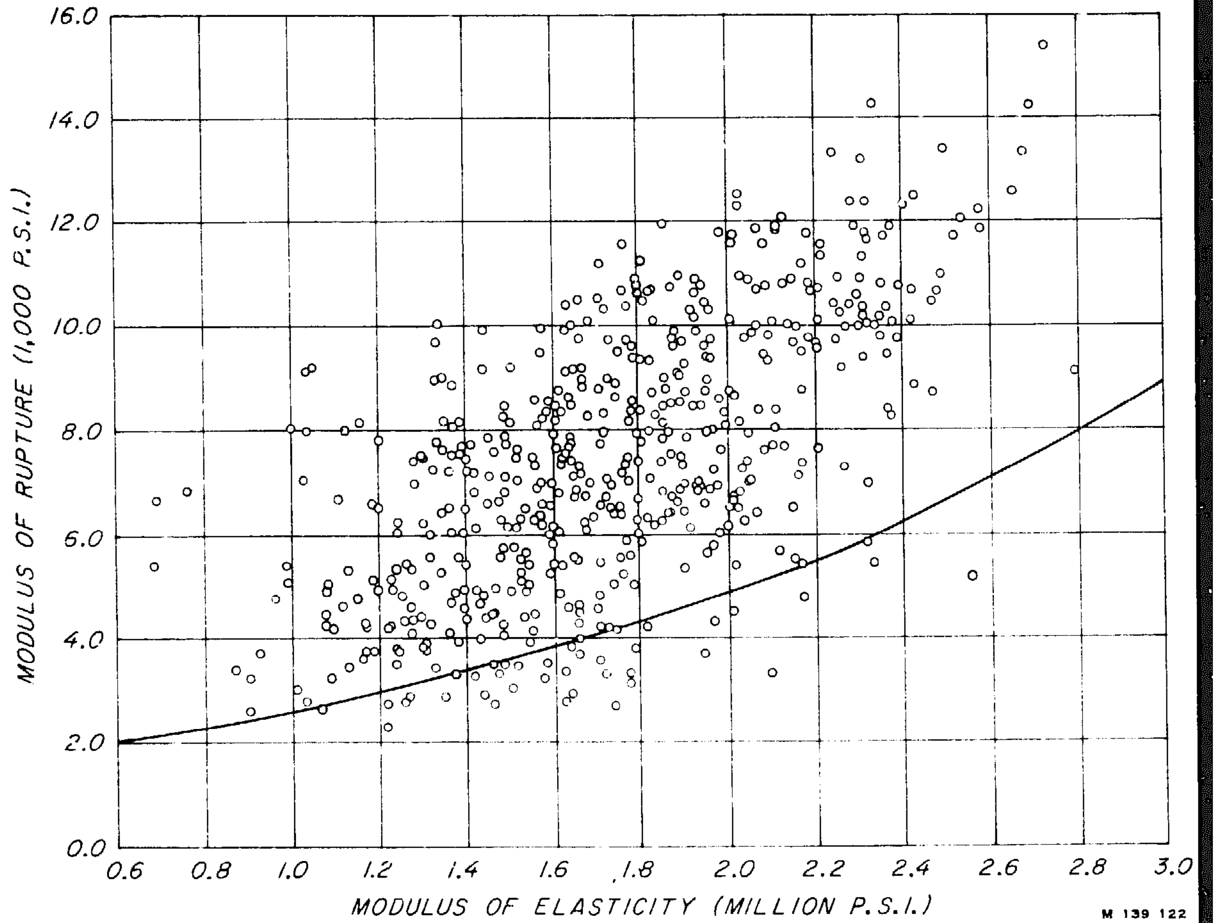

Figure 6–5.—Modulus of elasticity as a predictor of modulus of rupture. The line is a 5 percent exclusion line; the points are test results.

ity assigned to a grade is intended to be an average value for the grade. However, because the basis for mechanical stress grading is the sorting of lumber by modulus of elasticity classes, machines can be adjusted so the modulus for a grade varies less in a mechanical stress grade than in a visual stress grade. Figure 6–6 presents a typical histogram of the dispersion of modulus of elasticity within a single grade, obtained by mechanical stress rating. The characteristics of small lots of lumber can be expected to deviate from such a histogram.

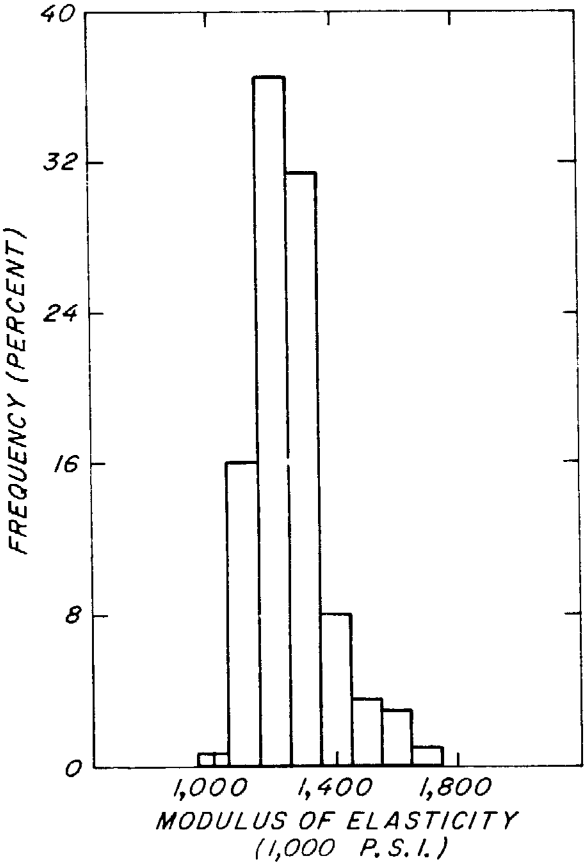

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Figure 6–6.—Histogram of modulus of elasticity observed in a single machine stress grade.

Strengths in shear parallel to the grain and in compression perpendicular to the grain have not been shown to be well related to modulus of elasticity. Therefore, in mechanical stress grading these properties are handled in relationship to clear wood properties and lumber visual characteristics.

Most commercial mechanical grading practice in the United States combines a modified strength ratio concept with the modulus of elasticity as a predictor of grade properties. Emphasis is placed on edge defects when deriving the limitations to visual characteristics of the grade. It has been shown that strength ratio and modulus of elasticity used together provide a somewhat more efficient strength prediction than either by itself.

In a fashion similar to visual grading, the properties derived from mechanical sorting criteria may be further modified for design use by consideration of moisture content and load duration.

ADJUSTING PROPERTIES FOR DESIGN USE

The mechanical properties associated with lumber quality, for the stress grading methods, are adjusted to give allowable unit stresses and an allowable modulus of elasticity suitable for most engineering uses.

A composite adjustment factor is applied to each strength property to adjust for an assumed 10-year duration of full design load. The composite factor includes a safety factor

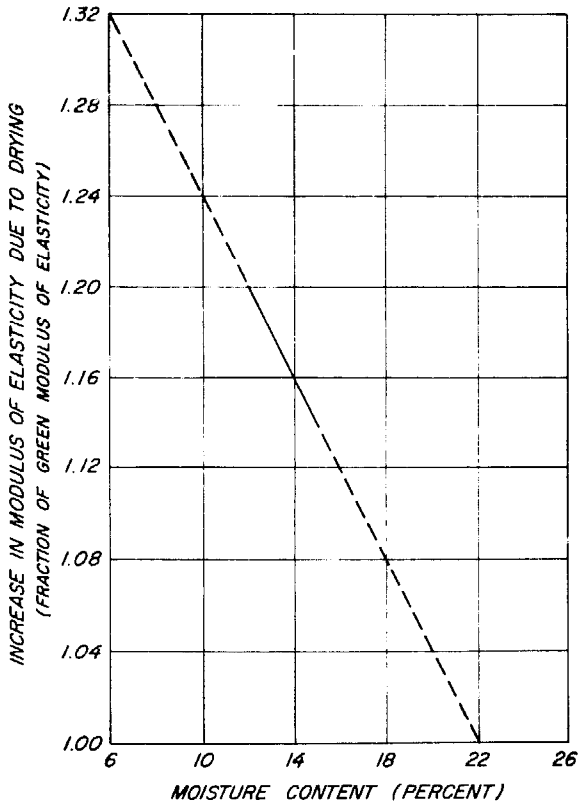

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Figure 6–7.—Modulus of elasticity as a function of moisture content for lumber. Solid line represents range of experimental data on which graph is based.

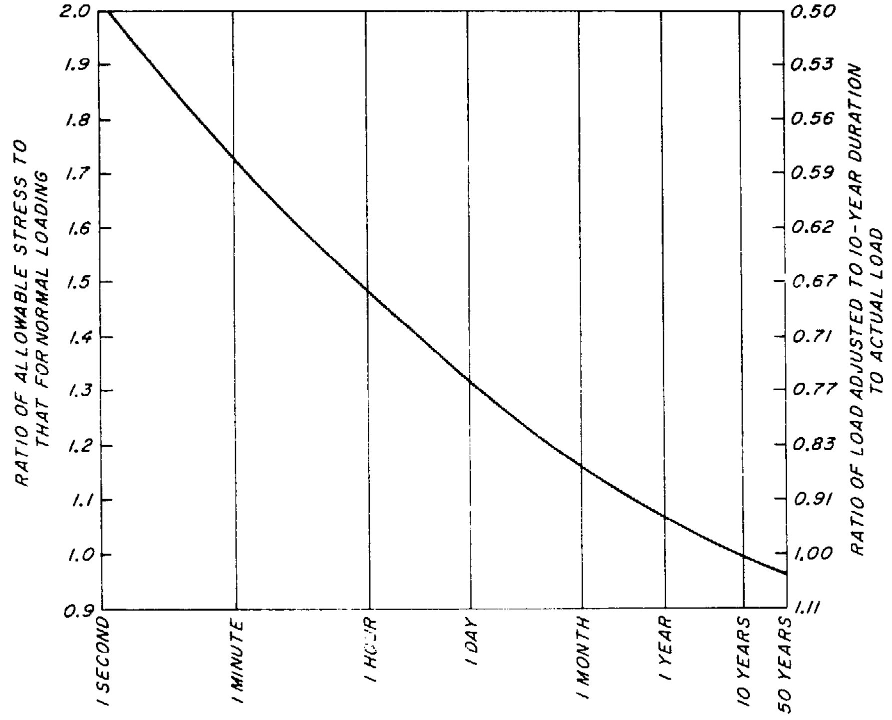

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Figure 6–8.—Relation of strength to duration of load.

of about 1.3. Additional adjustments are often made for size and moisture content. Discussion of these adjustment factors follows; specific adjustments are given in ASTM Designation D 245.

Size Factor

In bending, a size effect causes small members to have a greater unit strength than large members. If bending strength is known for one size of lumber, it can be approximated for another size by using formulas given in chapter 8. These formulas are used in the development of visual grades to convert from the sizes of standard small, clear specimens to lumber sizes.

Moisture Adjustments

For lumber 4 inches thick or less that has been dried, properties are related to moisture content. As an example, the relationship for modulus of elasticity is shown in figure 6–7, where the modulus at any moisture content is expressed as an increase above the modulus for green lumber.

For lumber thicker than 4 inches, often no adjustment for moisture content is made; most allowable properties are assigned on the basis of wood in the green condition. Lumber in large sizes is usually put in place without drying.

Duration of Load

If loading will not be for a 10-year period (called normal loading), allowable stress can be adjusted using figure 6–8. There is some evidence that an intermittent load causes a cumulative effect on strength, and that the total duration should be considered in establishing the duration of load effect.

In many design circumstances there are several loads on the structure, some acting simultaneously and each with a different duration. Each increment of time during which the total load is constant should be treated separately, and the most severe condition governs the design. Either the allowable stress or the total design load (but not both) can be adjusted using figure 6–8.

For example, suppose a structure is expected to support a load of 100 pounds per square foot (p.s.f.) off and on for a cumulative duration of 1 year. Also, it is expected to support its own dead load of 20 p.s.f. for the anticipated 50-year life of the structure. The adjustments to be made to arrive at a design load are listed below. The more critical design load is 112 p.s.f., and this load and the allowable stress for lumber based on normal loading would be used to pick members of suitable size. In this case, it was convenient to adjust the loads on the structure, although the same result can be obtained by adjusting the allowable stress.

Time	Total load	Load adjustment	Design load
(Yr.)	*(P.s.f.)*		*(P.s.f.)*
1	100 + 20 = 120	0.93	112
50	20	1.04	21

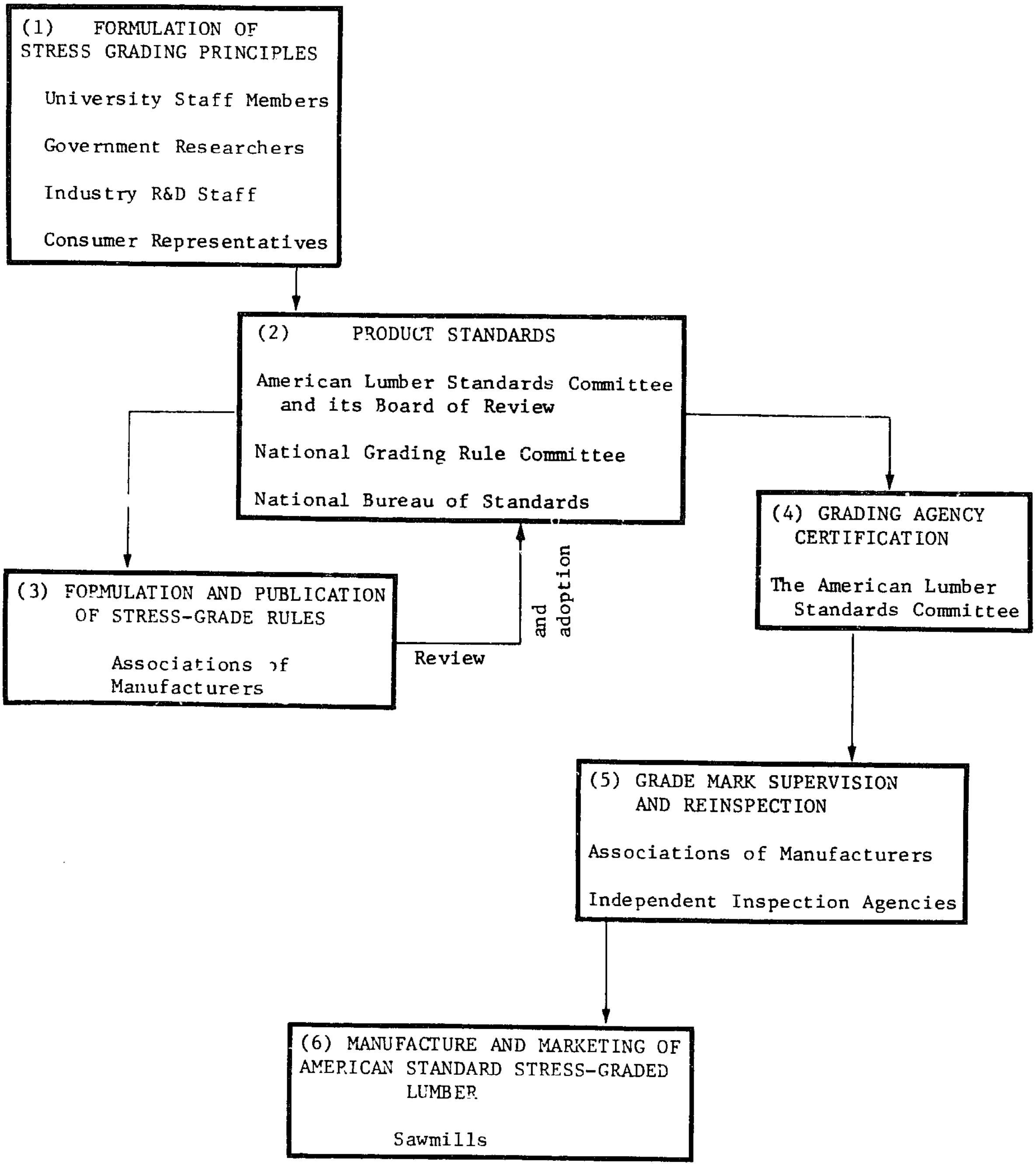

Figure 6–9.—Voluntary system of responsibilities for stress grading under the American Softwood Lumber Standard. M 139 117

Cumulative effects of repeated loads of the very short durations shown in figure 6–8 are called fatigue. For comments on fatigue, see chapter 4.

PRACTICE OF STRESS GRADING

An orderly, voluntary, but circuitous, system of responsibilities has evolved in the United States for the development, manufacture, and merchandising of most stress-graded lumber. The system is shown schematically in figure 6–9. Stress-grading principles are developed from research findings and engineering concepts, often within committees and subcommittees of the American Society for Testing and Materials.

The National Bureau of Standards cooperates with lumber producers, distributors, and users through an American Lumber Standards Committee (ALSC) to assemble a voluntary softwood standard of manufacture, called the American Softwood Lumber Standard (see ch. 5). The American Lumber Standard and the related National Grading Rule prescribe the ways in which stress-grading principles can be used to formulate grading rules said to be American Standard.

Organizations of lumber manufacturers publish grading rule books containing stress-grade descriptions. If an organization wants its published rules to be American Standard, it submits them to the ALSC's Board of Review for review of conformance with the American Softwood Lumber Standard (ALS).

Organizations that write grading rules, as well as independent agencies, can be certified by ALSC to issue grade marks corresponding to published stress-grade rules and provide grade marking supervision and reinspection services to individual lumber manufacturers. The performance of these organizations is then under the scrutiny of the Board of Review of the ALSC.

Most commercial softwoods are stress graded under standard practice in the United States. The principles of stress grading also can be applied to hardwoods; several are graded under provisions of the ALS.

Lumber found in the marketplace may be stress graded by methods approved by the American Lumber Standards Committee, by some other grading rule, or it may not be stress graded. Stress grades that meet the requirements of the voluntary American Lumber Standard are developed by the principles that have been described in this chapter, and only these stress grades are discussed here.

Stress grading under the auspices of the American Lumber Standards Committee is applied to many of the sizes and several of the patterns of lumber meeting the provisions of the American Lumber Standard. A majority of stress-graded lumber is dimension, however, and a uniform procedure, the National Grading Rule, is used for writing grading rules for this size lumber. Grade rules for other sizes may vary by grading agencies or species.

National Grading Rule

The American Softwood Lumber Standard, PS 20–70, provides for a National Grading Rule for lumber from 2 up to, but not including, 5 inches in nominal thickness (dimension lumber). All American Standard lumber in that size range is required to conform to the

Table 6–1.—*Visual grades described in the National Grading Rule*[1]

Lumber classification	Grade name	Bending strength ratio
		Pct.
Light framing (2 to 4 in. thick, 4 in. wide)[2]	Construction	34
	Standard	19
	Utility	9
Structural light framing (2 to 4 in. thick, 2 to 4 in. wide)	Select structural	67
	1	55
	2	45
	3	26
Studs (2 to 4 in. thick, 2 to 4 in. wide)	Stud	26
Structural joists and planks (2 to 4 in. thick, 6 in. and wider)	Select structural	65
	1	55
	2	45
	3	26
Appearance framing (2 to 4 in. thick, 2 to 4 in. wide)	Appearance	55

[1] Sizes shown are nominal.

[2] Widths narrower than 4 in. may have different strength ratio than shown. Contact rules-writing agencies for additional information.

National Grading Rule, except for special products such as scaffold planks.

The National Grading Rule establishes the lumber classifications and grade names for visually stress-graded lumber shown in table 6–1. The approximate minimum bending strength ratio is also shown to provide a comparative index of quality. The corresponding visual descriptions of the grades can be found in the grading rule books of most of the softwood rule-writing agencies listed in chapter 5. Grades of lumber that meet these requirements should have about the same appearance regardless of species. They will not have the same allowable properties. The allowable properties for each species and grade are given in the appropriate rule books and in the National Design Specification.

The National Grading Rule also establishes some limitations on sizes of permissible edge knots and other visual characteristics for American Standard lumber that is graded by a combination of mechanical and visual methods.

Grouping of Species

Some species have always been grouped together and the lumber from them treated as equivalent. This usually has been done for species that have about the same mechanical properties, for the wood of two or more species very similar in appearance, or for marketing convenience. For visual stress grades, ASTM D 2555 contains some rules for calculating clear wood properties for groups of species. The properties assigned to a group by such a procedure often will not be identical with any of the species that make up the group. The group will display a unique identity with nomenclature approved by the American Lumber Standards Committee. The grading association under whose auspices the lumber was graded should be contacted if the identities, properties, and characteristics of individual species of the group are desired.

In the case of mechanical stress grading, the inspection agency that supervises the grading certifies by test that the allowable properties in the grading rule are appropriate for the species or species group and the grading process.

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Chapter 7

FASTENINGS

FASTENINGS

The strength and stability of any structure depend heavily on the fastenings that hold its parts together. One prime advantage of wood as a structural material is the ease with which wood structural parts can be joined together with a wide variety of fastenings—nails, spikes, screws, bolts, lag screws, drift pins, staples, and metal connectors of various types. For utmost rigidity, strength, and service, each type of fastening requires joint designs adapted to the strength properties of wood along and across the grain, and to dimensional changes that may occur with changes in moisture content.

NAILS

Nails are the most common mechanical fastenings used in construction. There are many types, sizes, and forms of nails (fig. 7–1). The formulas presented in this chapter for loads apply for bright, smooth, common steel wire nails driven into wood when there is no visible splitting. For nails other than common wire nails, the loads can be adjusted by factors given later in the chapter.

Nails in use resist either withdrawal loads or lateral loads, or a combination of the two. Both withdrawal and lateral resistance are affected by the wood, the nail, and the condition of use. In general, however, any variation in these factors has a more pronounced effect on withdrawal resistance than on lateral resistance. The serviceability of joints with nails laterally loaded is not greatly dependent upon withdrawal resistance unless large joint distortion can be tolerated. Nails, as well as such other driven fasteners as staples and T-nails, should be used so that they are loaded laterally (perpendicular to the shank or direction of driving) rather than being loaded in direct withdrawal.

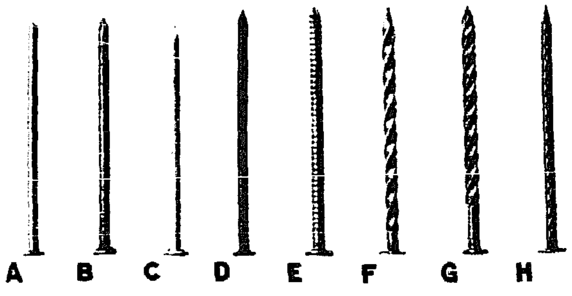

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Figure 7–1.—Various types of nails: A, bright, smooth wire nail; B, cement-coated; C, zinc-coated; D, chemically etched; E, annularly threaded; F, helically threaded; G, helically threaded and barbed; and H, barbed.

Withdrawal Resistance

The resistance of a nail shank to direct withdrawal from a piece of wood depends on the density of the wood, the diameter of the nail, and the depth of penetration. The surface condition of the nail at the time of driving also influences the initial withdrawal resistance.

For bright, common wire nails driven into the side grain of seasoned wood or unseasoned wood that remained wet, the results of many tests have shown that the maximum withdrawal load is given by the empirical formula:

$$p = 7{,}850 G^{5/2} D L \qquad (7\text{–}1)$$

where p is the maximum load in pounds; L, the depth, in inches, of penetration of the nail in the member holding the nail point; G, the specific gravity of the wood based on ovendry weight and volume at 12 percent moisture content (see table 4–2, ch. 4); and D, the diameter of the nail in inches.

The diameters of various penny or gage sizes of bright common nails are given in table 7–1. Bright box nails are generally of the same length but slightly smaller diameter (table 7–2), while cement-coated nails such as coolers, sinkers, and coated box nails are slightly shorter ($\frac{1}{8}$ in.) and of smaller diameter for the same penny size than common nails. Annularly and helically threaded nails generally have smaller diameters than common nails for the same penny size (table 7–3). The loads expressed by equation 7–1 represent average

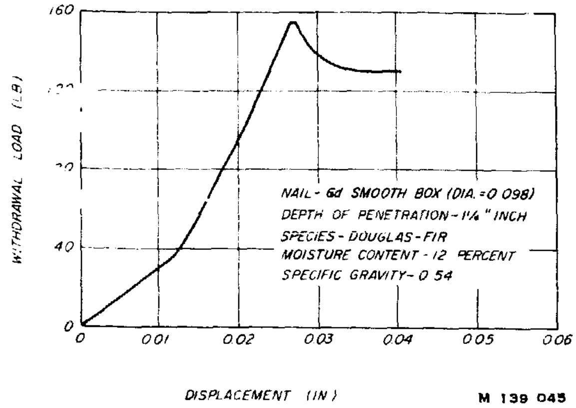

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Figure 7–2.—Typical load-displacement curve for direct withdrawal of a nail.

data. A typical load-displacement curve for nail withdrawal (fig. 7–2) shows that maximum load occurs at relatively small values of displacement.

Although the formula for nail-withdrawal resistance indicates that the dense, heavy woods offer greater resistance to nail withdrawal than the lighter weight ones, lighter species should not be disqualified for uses requiring high resistance to withdrawal. As a rule, the less dense species do not split so readily as the denser ones and thus offer an opportunity for increasing the diameter, length, and number of the nails to compensate for the wood's lower resistance to nail withdrawal.

Table 7–1.—*Sizes of bright, common wire nails*

Size	Gage	Length	Diameter
		In.	*In.*
6d	11½	2	0.113
8d	10¼	2½	.131
10d	9	3	.148
12d	9	3¼	.148
16d	8	3½	.162
20d	6	4	192
30d	5	4½	.207
40d	4	5	.225
50d	3	5½	.244
60d	2	6	.262

Table 7–2.—*Sizes of smooth box nails*

Size	Gage	Length	Diameter
		In.	*In.*
3d	14½	1¼	0.076
4d	14	1½	.080
5d	14	1¾	.080
6d	12½	2	.098
7d	12½	2¼	.098
8d	11½	2½	113
10d	10½	3	.128
16d	10	3½	.135
20d	9	4	.148

Table 7–3.—*Sizes of helically and annularly threaded nails*

Size	Length	Diameter
	In.	*In.*
6d	2	0.120
8d	2½	.120
10d	3	.135
12d	3¼	.135
16d	3½	.148
20d	4	.177
30d	4½	.177
40d	5	177
50d	5½	.177
60d	6	.177
70d	7	.207
80d	8	.207
90d	9	.207

The withdrawal resistance of nail shanks is greatly affected by such factors as type of nail point, type of shank, time the nail remains in the wood, surface coatings, and moisture content changes in the wood.

Effect of Seasoning

With practically all species, nails driven into green wood and pulled before any seasoning takes place offer about the same withdrawal resistance as nails driven into seasoned wood and pulled soon after driving. If, however, common smooth-shank nails are driven into green wood that is allowed to season, or into seasoned wood that is subjected to cycles of wetting and drying before the nails are pulled, they lose a major part of their initial withdrawal resistance. The withdrawal resistance for nails driven into wood that is subjected to changes in moisture content may be as low as 25 percent of the values for nails tested soon after driving. On the other hand if the wood fibers are affected or the nail corrodes under some conditions of moisture variation and time, withdrawal resistance is erratic; resistance may be regained or even increased over the immediate withdrawal resistance. However, such sustained performance should not be relied on in the design of a nailed joint.

In seasoned wood that is not subjected to appreciable moisture content changes, the withdrawal resistance of nails may also diminish with lapse of time. Under all these conditions of use, the withdrawal resistance of nails differs among species as well as within individual species, making it difficult to evaluate their behavior.

Effect of Nail Form

The surface condition of nails is frequently modified during the manufacturing process to improve withdrawal resistance. Such modification is usually done by surface coating, surface roughening, or mechanical deformation of the shank. Other factors that affect the surface condition of the nail are the oil film remaining on the shank after manufacture or corrosion resulting from storage under adverse conditions; but these factors are so variable that their influence on withdrawal resistance cannot be adequately evaluated.

A common surface treatment for nails is the so-called cement coating. Cement coatings, contrary to what the name implies, do not include cement as an ingredient; they generally are a composition of resin applied to the nail to increase the resistance to withdrawal by increasing the friction between the nail and the wood. If properly applied, they increase the resistance of nails to withdrawal immediately after the nails are driven into the softer woods. In the denser woods (such as hard maple, birch, or oak), however, cement-coated nails have practically no advantage over plain nails, because most of the coating is removed in driving. Some of the coating may also be removed in the cleat or facing member before the nail penetrates the foundation member.

Good-quality cement coatings are uniform, not sticky to the touch, and cannot be rubbed off easily. Different techniques of applying the cement coating and variations in its ingredients may cause large differences in the relative resistance to withdrawal of different lots of cement-coated nails. Some nails may show only a slight initial advantage over plain nails. The increase in withdrawal resistance of cement-coated nails is not permanent but drops off about one-half after a month or so for the softer woods. Cement-coated nails are used primarily in construction of boxes, crates, and other containers usually built for rough handling and relatively short service.

Nails that have special coatings, such as zinc, are intended primarily for uses where corrosion and staining are important factors in permanence and appearance. If the zinc coating is evenly applied, withdrawal resistance may be increased, but extreme irregularities of the coating may actually reduce it. The advantage that zinc-coated nails with a uniform coating may have over plain nails in resistance to initial withdrawal is usually reduced by repeated cycles of wetting and drying.

Nails have also been made with plastic coatings. The usefulness and characteristics of these coatings are influenced by the quality and type of coating, the effectiveness of the bond between the coating and base fastener, and the effectiveness of the bond between the coating and wood fibers. Some plastic coatings appear to resist corrosion or improve resistance to withdrawal, while others offer little improvement.

Fasteners with properly applied nylon coating tend to retain their initial resistance to withdrawal, as compared to other coatings which exhibit a marked decrease in withdrawal resistance within the first month after driving.

A chemically etched nail has somewhat higher withdrawal resistance than some coated nails, as the minutely pitted surface is an integral part of the nail shank. Under impact loading, however, the withdrawal resistance of etched nails is little different from that of plain or cement-coated nails under various moisture conditions.

Sand-blasted nails perform in much the same manner as do chemically etched nails.

Nail shanks may be varied from a smooth, circular form to give an increase in surface area without an increase in nail weight. Special nails with barbed, helically or annularly threaded, and other irregular shanks (fig. 7–1) are offered commercially.

The form and magnitude of the deformations along the shank influence the performance of the nails in the various wood species. The withdrawal resistance of these nails, except some types of barbed nails, is generally somewhat greater than that of common wire nails of the same diameter, in wood remaining at a uniform moisture content. For instance, annular shank nails have about 40 percent greater withdrawal resistance. Under conditions involving changes in the moisture content of the wood, however, some special nail forms provide considerably greater withdrawal resistance than the common wire nail—about four times greater for annular and helical shank nails of the same diameter. This is especially true of nails driven into green wood that subsequently dries. In general, annularly threaded nails sustain larger withdrawal loads, and helically threaded nails sustain greater impact withdrawal work values than the other nail forms.

A smooth, round shank nail with a long, sharp point will usually have a higher withdrawal resistance, particularly in the softer woods, than the common wire nail (which usually has a diamond point). Sharp points, however, accentuate splitting of certain species, which may reduce withdrawal resistance. A blunt or flat point without taper reduces splitting, but its destruction of the wood fibers when driven reduces withdrawal resistance to less than that of the common wire nail. A nail tapered at the end and terminating in a blunt point will cause less splitting. In the heavier woods, such a tapered, blunt-pointed nail will provide about the same withdrawal resistance, but in the less dense woods, its resistance to withdrawal is lower than the common nail.

Nailhead classifications include flat, oval, countersunk, deep-countersunk, and brad. Nails with all types of heads, except the deep-countersunk, brad, and some of the thin flathead nails, are sufficiently strong to withstand the force required to pull them from most woods in direct withdrawal. The deep-countersunk and brad nails are usually driven below the wood surface and are not intended to carry large withdrawal loads. In general, the thickness and diameter of the heads of the common wire nails increase as the size of the nail increases.

The development of some pneumatically operated portable nailers has introduced special headed nails such as T-nails and nails with a segment of the head cut off. Although the resistance of these heads to pulling through the wood might be less than for conventional nailheads, the performance of the modified heads appears adequate. It is preferable that the T-head be oriented so that the head is perpendicular to the grain of the adjoining wood.

Nails of copper alloys, aluminum alloys, stainless steel, and other alloys are used mainly where corrosion or staining is an important factor for appearance or permanence. Specially hardened nails are also frequently used where driving conditions are difficult, or to obtain improved performance, such as in pallet assembly. Sometimes even the mechanically deformed shank nails are given heat treatments. Hardened nails are brittle and care should be exercised to avoid injuries from fragments of nails broken during driving.

In general, the withdrawal resistance of copper and other alloy nails is somewhat comparable to that of common steel wire nails when pulled soon after driving.

Driving and Clinching

The resistance of nails to withdrawal is generally greatest when they are driven perpendicular to the grain of the wood. When the nail is driven parallel to the wood fibers—that is, into the end of the piece—withdrawal resistance in the softer woods drops to 75 or even 50 percent of the resistance obtained when the nail is driven perpendicular to the grain. The difference between side- and end-grain withdrawal loads is less for dense woods than for softer woods. With most species, the ratio between the end- and side-grain withdrawal loads of nails pulled after a time interval, or after moisture content changes have occurred, is usually somewhat higher than that of nails pulled immediately after driving.

Toenailing, a common method of joining wood framework, involves slant driving a nail or group of nails through the end or edge of an attached member and into a main member. Toenailing requires greater skill in assembly than does ordinary end nailing but provides joints of greater strength and stability. Tests show that the maximum strength of toenailed joints under lateral and uplift loads is obtained by (1) using the largest nail that will not cause excessive splitting, (2) allowing an end distance (distance from the end of the attached member to the point of initial nail entry) of approximately one-third the length of the nail, (3) driving the nail at a slope of 30° with the attached member, and (4) burying the full shank of the nail but avoiding excessive mutilation of the wood from hammer blows.

In tests of stud-to-sill assemblies with the number and size of nails frequently used in toenailed and end-nailed joints, a joint toenailed with four eightpenny common nails was superior to a joint end nailed with two sixteenpenny common nails. With such woods as Douglas-fir, toenailing with tenpenny common nails gave greater joint strength than the commonly used eightpenny nails.

The results of withdrawal tests with multiple nail joints in which the piece attached is pulled directly away from the main member show that slant driving is usually superior to straight driving when nails are driven into dry wood and pulled immediately, and decidedly superior when nails are driven into green or partially dry wood that is allowed to season for a month or more. However, the loss in depth of penetration due to slant driving may, in some types of joints, offset the advantages of slant nailing. Cross slant driving of groups of nails is usually somewhat more effective than parallel slant driving.

Nails driven into lead holes with a diameter slightly smaller than the nail have somewhat higher withdrawal resistance than nails driven without lead holes. Lead holes also prevent or reduce splitting of the wood, particularly for dense species.

The withdrawal resistance of smooth-shank, clinched nails is considerably higher than that of unclinched nails. The ratio between the loads for clinched and unclinched nails varies enormously, depending upon the moisture content of the wood when the nail is driven and withdrawn, the species of wood, the size of nail, and the direction of clinch with respect to the grain of the wood.

In dry or green wood, a clinched nail provides from 45 to 170 percent more withdrawal resistance than an unclinched nail when withdrawn soon after driving. In green wood that seasons after a nail is driven, a clinched nail gives from 250 to 460 percent greater withdrawal resistance than an unclinched nail. However, this improved strength of the clinched- over the unclinched-nail joint does not justify the use of green lumber, because the joints may loosen as the lumber seasons. Furthermore, laboratory tests were made with single nails, and the effects of drying, such as warping, twisting, and splitting, may reduce the efficiency of a joint that has more than one nail. Clinching of nails is generally confined to such construction as boxes and crates and other container applications.

Nails clinched across the grain have approximately 20 percent more resistance to withdrawal than nails clinched along the grain.

Plywood

The nailing characteristics of plywood are not greatly different from those of solid wood except for plywood's greater resistance to splitting when nails are driven near an edge. The nail shank withdrawal resistance of plywood is from 15 to 30 percent less than that of solid wood of the same thickness. The reason is that fiber distortion is less uniform in plywood than in solid wood. For plywood less than one-half inch thick, the high splitting resistance tends to offset the lower withdrawal resistance as compared to solid wood. The withdrawal resistance per inch of penetration decreases with increase in the number of plies. The direction of the grain of the face ply has little influence on the withdrawal resistance along the end or edge of a piece of plywood. The direction of the grain of the face ply may influence the pullthrough resistance of staples or nails with severely modified heads, such as T-heads. Fastener design information for plywood is available from the American Plywood Association.

Allowable Loads

The preceding discussion has dealt with maximum withdrawal loads obtained in short-time test conditions. For design, these loads must be reduced to account for variability and duration of load effects. A value of one-sixth the maximum load has usually been accepted as the allowable load for longtime loading conditions. For normal duration of load, this value may be increased by 10 percent.

Lateral Resistance

Test loads at joint slips of 0.015 inch for bright, common wire nails in lateral resistance driven into the side grain (perpendicular to the wood fibers) of seasoned wood were found to be expressed by the following empirical formula:

$$p = KD^{3/2} \qquad (7\text{–}2)$$

where p is the lateral load in pounds per nail at a joint slip of 0.015 inch (approximately proportional limit load); K is a coefficient; and D is the diameter of the nail in inches. Values of the coefficient K are listed in table 7–4 for ranges of specific gravity of hardwoods and softwoods.

The ultimate lateral nail loads for softwoods may approach 3½ times the loads expressed by the formula, and for hardwoods they may be seven times as great. The joint slip at maximum load, however, is over 20 times 0.015 inch. This is demonstrated by the typical load-slip curve shown in figure 7–3.

The loads obtained by the formula apply only for conditions where the side member and the member holding the nail point are of approximately the same density and where the nail penetrates into the member holding the point by not less than 10 times the nail

Table 7–4.—*Coefficients for computing loads for fasteners in seasoned wood*[1]

Specific gravity range[2]	Lateral load coefficient (K)		
	Nails[3]	Screws	Lag screws
	HARDWOODS		
0.33–0.47	1,440	3,360	3,820
.48– .56	2,000	4,640	4,280
.57– .74	2,720	6,400	4,950
	SOFTWOODS		
.29– .42	1,440	3,360	3,380
.43– .47	1,800	4,320	3,820
.48– .52	2,200	5,280	4,280

[1] Wood with a moisture content of 15 pct.

[2] Specific gravity based on ovendry weight and volume at 12 pct. moisture content.

[3] Coefficients based on load at joint slip of 0.015 in.

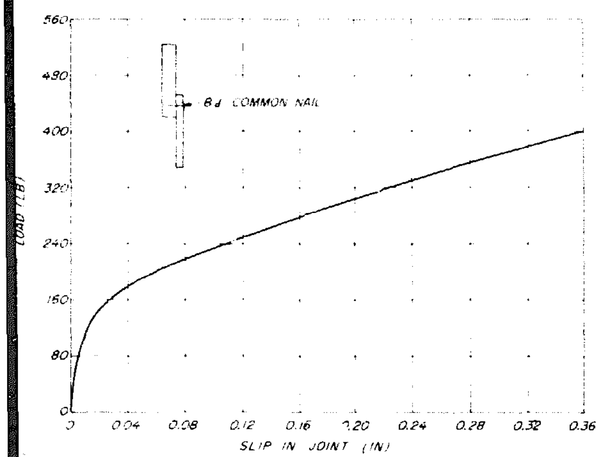

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Figure 7–3.—Typical relation between lateral load and slip in the joint.

diameter for dense woods and 14 times the diameter for lightweight woods. The thickness of the side member should be about one-half the depth of penetration of the nail in the member holding the point. End distance should be no less than 15 times the nail diameter if the end is stressed or 12 times the nail diameter if unstressed. Edge distance should be no less than 10 times the nail diameter. When the side member is steel, an increase of about 25 percent can be applied to the lateral nail load because initiation of failure is forced to occur in the wood member holding the nail point.

Theoretical Analysis

A considerable amount of work has been done to evaluate the lateral resistance of nailed joints. For the interested designer a theoretical approach is available for determining the lateral load of a joint having a single nail or bolt.[1]

Results of the theoretical analysis, which considers the nail to be a beam supported on an elastic foundation (the wood), show that the lateral load up to the proportional limit for a two-member joint with one nail bearing parallel to the grain is given approximately by the formula:

$$P = 0.354\ (k_0^{3/4})\ (E^{1/4})\ (I^{1/4})\ (D^{3/4})S \qquad (7\text{–}3)$$

where P is the lateral load, k_0 is the elastic bearing constant of the wood, E is the modulus of elasticity of the nail, I is the moment of inertia of the nail cross section, D is the nail size (cross-section dimension), and S is the joint slip. For a nail of circular cross section of diameter D, this formula reduces to

$$P = \frac{k_0^{3/4} E^{1/4} D^{7/4} S}{6} \qquad (7\text{–}4)$$

This equation has been shown, experimentally, to account for the different properties of the nail. The elastic bearing constant, k_0, is related to the average species specific gravity by the formula:

$$k_0 = 3{,}200{,}000G \qquad (7\text{–}5)$$

where G is the specific gravity based on volume at the moisture content at which the wood is used. This value of the elastic bearing constant is for smooth shank nails driven in prebored lead holes and loaded parallel to the grain.

Research Results

The lateral load for side-grain nailing given by the empirical formula $p = KD^{3/2}$ applies whether the load is in a direction parallel to the grain of the pieces joined or at right angles to it. When nails are driven into the end grain (parallel with the wood fibers), limited data on softwood species indicate that their maximum resistance to lateral displacement is about two-thirds that for nails driven into the side grain. Although the average proportional limit loads appear to be about the same for end- and side-grain nailing, the individual results are more erratic for end-grain nailing, and the minimum loads approach only 75 percent of corresponding values for side-grain nailing.

Nails driven into the side grain of unseasoned wood give maximum lateral resistance loads approximately equal to those obtained in seasoned wood, but the lateral resistance loads at 0.015-inch joint slip are somewhat less. To prevent excessive deformation, lateral loads obtained by the formula for seasoned wood should be reduced 25 percent for unseasoned wood that will remain wet or be loaded before seasoning takes place.

When nails are driven into green wood, their lateral proportional limit loads after the wood has seasoned are also less than when they are driven into seasoned wood and loaded. The erratic behavior of a nailed joint that has undergone one or more moisture content changes makes it difficult to establish a lateral load for a

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[1] In Bibliography at the end of this chapter see reports by Kuenzi and by Wilkinson.

nailed joint under these conditions. Structural joints should be inspected at intervals, and if it is apparent that a loosening of the joint has ocurred during drying, the joint should be reinforced with additional nails.

Deformed-shank nails carry somewhat higher maximum lateral loads than common wire nails, but both perform similarly at small distortions in the joint.

Allowable Loads

The value of the lateral load at proportional limit obtained from tests must be reduced (to account for variability and duration of load effects) to arrive at allowable values (see eq. 7–2). A reduction factor of 1.6 has been used to arrive at a value for longtime loading. For normal loading, this value may be increased by 10 percent.

SPIKES

Common wire spikes are manufactured in the same manner as common wire nails. They have either a chisel point or a diamond point and are made in lengths of 3 to 12 inches. For corresponding lengths (3 to 6 in.), they have larger diameters (table 7–5) than the common wire nails, and beyond the sixtypenny size they are usually designated by inches of length.

The withdrawal and lateral resistance formulas and limitations given for common wire nails are also applicable to spikes, except that in calculating the withdrawal load for spikes, the depth of penetration should be reduced by two-thirds the length of the point.

STAPLES

Different types of staples have been developed with various modifications in points, shank treatment and coatings, gage, crown width, and length. These fasteners are available in clips or magazines to permit their use in pneumatically operated portable staplers. Most of the factors that affect the withdrawal and lateral loads of nails similarly affect the loads on staples. The withdrawal resistances, for example, vary almost directly with the circumference and depth of penetration when the type of point and shank are similar. Thus, equation (7–1) may be used to predict the withdrawal load for staples, and the same factors used for nails may be used to arrive at an allowable load.

Table 7–5.—*Sizes of common wire spikes*

Size	Length	Diameter	Size	Length	Diameter
	In.	*In.*		*In.*	*In.*
10d	3	0.192	40d	5	0.263
12d	3¼	.192	50d	5½	.283
16d	3½	.207	60d	6	.283
20d	4	.225	5/16 inch	7	.312
30d	4½	.244	3/8 inch	8½	.375

The load in lateral resistance varies about as the $^{3}/_{2}$ power of the diameter when other factors, such as quality of metal, type of shank, and depth of penetration, are similar. The diameter of each leg of a two-legged staple must therefore be about two-thirds the diameter of a nail to provide a comparable load. Equation (7–2) may be used to predict the lateral resistance of staples and the same factors for nails may be used to arrive at allowable loads.

In addition to the immediate performance capability of staples and nails as determined by test, such factors as corrosion, sustained performance under service conditions, and durability in various uses should be considered in evaluating the relative usefulness of a connection.

DRIFT BOLTS

The ultimate withdrawal load of a round drift bolt or pin from the side grain of seasoned wood is given by the formula:

$$p = 6{,}600G^2DL \qquad (7\text{–}6)$$

where p is the ultimate withdrawal load in pounds, G is the specific gravity based on the ovendry weight and volume at 12 percent moisture content of the wood, D is the diameter of the drift bolt in inches, and L is the length of penetration of the bolt in inches.

This formula provides an average relationship for all species, and the withdrawal load of some species may be above or below the equation values. It also presumes that the bolts are driven into prebored holes having a diameter one-eighth inch less than the bolt diameter.

In lateral resistance, the load for a drift bolt driven into the side grain of wood should not exceed, and ordinarily should be taken as less than, that for a machine bolt of the same diameter. The drift bolt should normally be of greater length than the common bolt to compensate for the lack of washers and nut.

WOOD SCREWS

The common types of wood screws have flat, oval, or round heads. The flathead screw is most commonly used if a flush surface is desired. Ovalhead and roundhead screws are used for appearance, and roundhead screws are used when countersinking is objectionable. Besides the head, the principal parts of a screw are the shank, thread, and core (fig. 7-4). Wood screws are usually made of steel or brass or other metals, alloys, or with specific finishes such as nickel, blued, chromium, or cadmium. They are classified according to material, type, finish, shape of head, and diameter of the shank or gage.

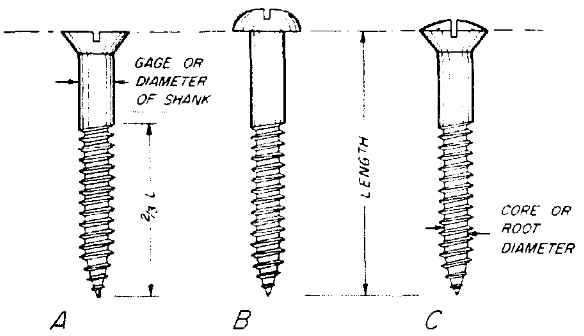

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Figure 7-4.—Common types of wood screws: A, flathead; B, roundhead; and C, ovalhead.

Current trends in fastenings for wood also include tapping screws. Tapping screws have threads the full length of the shank and thus may have some advantage for certain specific uses.

Withdrawal Resistance

Experimental Loads

The resistance of wood screw shanks to withdrawal from the side grain of seasoned wood varies directly with the square of the specific gravity of the wood. Within limits, the withdrawal load varies directly with the depth of penetration of the threaded portion and the diameter of the screw, provided the screw does not fail in tension. The limiting length to cause screw failure decreases as the density of the wood increases. The longer lengths of standard screws are therefore superfluous in dense hardwoods.

The withdrawal resistance of type A tapping screws, commonly called sheet metal screws, is in general about 10 percent higher than for wood screws of comparable diameter and length of threaded portion. The ratio between the withdrawal resistance of tapping screws and wood screws is somewhat higher in the denser woods than in the lighter woods.

Ultimate test values for withdrawal loads of wood screws inserted into the side grain of seasoned wood may be expressed as:

$$p = 15{,}700 G^2 D L \qquad (7\text{-}7)$$

where p is the maximum withdrawal load in pounds, G is the specific gravity based on oven-dry weight and volume at 12 percent moisture content, D is the shank diameter of the screw in inches, and L is the length of penetration of the threaded part of the screw in inches.

This formula is applicable when screw lead holes in softwoods have a diameter of about 70 percent of the root diameter of the threads, and in hardwoods about 90 percent. The root diameter for most sizes of screws averages about two-thirds of the shank diameter.

The equation values are applicable to the following sizes of screws:

Screw length	*Gage limits*
Inches	
½	1 to 6
¾	2 to 11
1	3 to 12
1½	5 to 14
2	7 to 16
2½	9 to 18
3	12 to 20

For lengths and gages outside these limits, the actual values are likely to be less than the equation values. The withdrawal loads of screws inserted into the end grain of wood are somewhat erratic; but, when splitting is avoided, they should average 75 percent of the load sustained by screws inserted into the side grain.

Lubricating the surface of a screw is recommended to facilitate insertion, especially in the dense woods. It will have little effect on ultimate withdrawal resistance.

Allowable Loads

For allowable values, the practice has been to use one-sixth the ultimate load for longtime loading conditions. This also accounts for variability in test data. For normal duration of load, the allowable load may be increased 10 percent.

Lateral Resistance

Experimental Loads

The test proportional limit loads in lateral resistance for wood screws in the side grain of seasoned wood is given by the empirical formula:

$$p = KD^2 \qquad (7\text{–}8)$$

where p is the lateral load in pounds, D is the diameter of the screw shank in inches, and K is a coefficient depending on the inherent characteristics of the wood species. Values of screw shank diameters for various screw gages are:

Screw number or gage	Diameter
	Inches
4	0.112
5	.125
6	.138
7	.151
8	.164
9	.177
10	.190
11	.203
12	.216
14	.242
16	.268
18	.294
20	.320
24	.372

Values of K are based on ranges of specific gravity of hardwoods and softwoods and are given in table 7–4. They apply to wood at about 15 percent moisture content. Loads computed by substituting these constants in the equation are expected to allow a slip of 0.007 to 0.010 inch, depending somewhat on the species and density of the wood.

Formula (7–8) applies when the depth of penetration of the screw into the block receiving the point is not less than seven times the shank diameter and when the cleat (member not receiving point) and the block holding the point are approximately of the same density. The thickness of the side member should be about one-half the depth of penetration of the screw in the member holding the point. The end distance should be no less than the side member thickness, and the edge distances no less than one-half the side member thickness.

This depth of penetration (seven times shank diameter) gives an ultimate load of about four times the load obtained by the formula. For a depth of penetration of less than seven times the shank diameter, the ultimate load is reduced about in proportion to the reduction in penetration and the load at the proportional limit is reduced somewhat less rapidly. When the depth of penetration of the screw in the holding block is four times the shank diameter, the maximum load will be less than three times the load expressed by the formula, and the proportional limit load will be approximately equal to that given by the formula. When the screw holds metal to wood, the load can be increased by about 25 percent.

For these lateral loads, the part of the lead hole receiving the shank should be the same diameter or slightly smaller than the shank, and that receiving the threaded part the same diameter or slightly smaller than the root of the thread. The size of the lead hole may have to be varied with the density of the wood, the smaller lead holes being used with the lower density species.

Screws should always be turned in. They should never be started or driven with a hammer because this practice tears the wood fibers and injures the screw threads, seriously reducing the loadcarrying capacity of the screw.

Allowable Loads

For allowable values, the practice has been to reduce the proportional limit load by a factor of 1.6 to account for variability in test data and reduce the load to a longtime loading condition. For normal duration of load, the allowable load may be increased by 10 percent.

LAG SCREWS

Lag screws are commonly used because of their convenience, particularly where it would be difficult to fasten a bolt or where a nut on the surface would be objectionable. Commonly available lag screws range from about 0.2 to 1 inch in diameter and from 1 to 16 inches in length. The length of the threaded part varies with the length of the screw and ranges from three-fourths inch with the 1- and 1¼-inch screws to half the length for all lengths greater than 10 inches. The equations given here for withdrawal and lateral loads are based on lag screws having a base metal average tensile yield strength of about 45,000 pounds per square inch (p.s.i.) and an average ultimate tensile strength of 77,000 p.s.i. For metal lag screws having greater or lower yield and tensile strengths, the withdrawal loads should be adjusted in proportion to the tensile strength and the lateral loads in proportion to the square root of the yield-point stresses.

Withdrawal Resistance

Experimental Loads

The results of withdrawal tests have shown that the maximum load in direct withdrawal of lag screws from seasoned wood may be computed from the equation:

$$p = 8{,}100G^{3/2}D^{3/4}L \qquad (7\text{–}9)$$

where p is the maximum withdrawal load in pounds, D is the shank diameter in inches, G is the specific gravity of the wood based on ovendry weight and volume at 12 percent moisture content, and L is the length, in inches, of penetration of the threaded part.

Lag screws, like wood screws, require prebored holes of the proper size (fig. 7–5). The lead hole for the shank should be the same diameter as the shank. The diameter of the lead hole for the threaded part varies with the density of the wood: For the lightweight softwoods, such as the cedars and white pines, 40 to 70 percent of the shank diameter; for Douglas-fir and southern pine, 60 to 75 percent; and for dense hardwoods, such as the oaks, 65 to 85 percent. The smaller percentage in each range applies to lag screws of the smaller diameters, and the larger percentage to lag screws of larger diameters. Soap or similar lubricants should be used on the screws to facilitate turning, and lead holes slightly larger than those recommended for maximum efficiency should be used with lag screws of excessive length.

In determining the withdrawal resistance, the allowable tensile strength of the lag screw at the net (root) section should not be exceeded. Penetration of the threaded part to a distance about seven times the shank diameter in the denser species and 10 to 12 times the shank diameter in the less dense species will develop approximately the ultimate tensile strength of the lag screw.

The resistance to withdrawal of a lag screw from the end-grain surface of a piece of wood is about three-fourths as great as its resistance to withdrawal from the side-grain surface of the same piece.

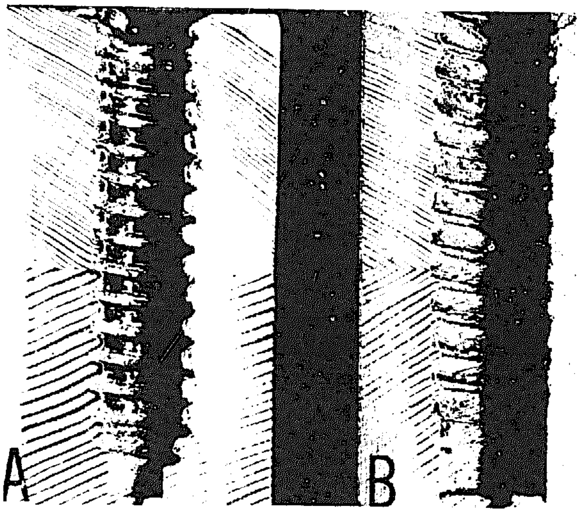

Figure 7–5.—A, clean-cut, deep penetration of thread made by lag screw turned into a lead hole of proper size, and B, rough, shallow penetration of thread made by lag screw turned into over-sized lead hole.

Allowable Loads

For allowable values, the practice has been to use one-fifth the ultimate load to account for variability in test data and reduce the load to a longtime loading condition. For normal duration of load, the allowable load may be increased by 10 percent.

Lateral Resistance

Experimental Loads

The experimentally determined lateral loads for lag screws inserted in the side grain and loaded parallel to the grain of a piece of seasoned wood can be computed from the equation:

$$p = KD^2 \qquad (7\text{–}10)$$

where p is the proportional limit lateral load in pounds parallel to the grain, K is a coefficient depending on the species specific gravity, and D is the shank diameter of the lag screw in inches. Values for K for a number of specific gravity ranges can be found in table 7–4. These coefficients are based on average results for several ranges of specific gravity for hardwoods and softwoods. The loads given by this formula apply when the thickness of the attached member is 3.5 times the shank diameter of the lag screw, and the depth of penetration in the main member is seven times the diameter in the harder woods and 11 times the diameter in the softer woods. For other thicknesses, the computed loads should be multiplied by the following factors:

Ratio of thickness of attached member to shank diameter of lag screw	Factor
2	0.62
2½	.77
3	.93
3½	1.00
4	1.07
4½	1.13
5	1.18
5½	1.21
6	1.22
6½	1.22

The thickness of a solid wood side member should be about one-half the depth of penetration in the member holding the point.

When the lag screw is inserted into the side grain of wood and the load is applied perpendicular to the grain, the load given by the lateral resistance formula should be multiplied by the following factors:

Shank diameter of lag screw	Factor
Inches	
3/16	1.00
¼	.97
5/16	.85
⅜	.76
7/16	.70
½	.65
⅝	.60
¾	.55
⅞	.52
1	.50

For other angles of loading, the loads may be computed from the parallel and perpendicular values by the use of the Scholten nomograph for determining the bearing strength of wood at various angles to the grain (fig. 7–6). The nomograph provides values comparable to those given by the Hankinson formula:

$$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta} \qquad (7\text{–}11)$$

where P represents the load or stress parallel to the grain. Q, the load or stress perpendicular to the grain; and N, the load or stress at an inclination θ with the direction of the grain.

Example: P, the load parallel to grain is 6,000 pounds (lb.), and *Q*, the load perpendicular to the grain is 2,000 lb. *N*, the load at an angle of 40° to grain is found as follows: Connect with a straight line 6,000 lb. (a) on line *OX* of the nomograph with the intersection (b) on line *OY* of a vertical line through 2,000 lb. The point where this line (*ab*) intersects the line representing the given angle 40° is directly above the load, 3,285 lb.

Values for lateral resistance as computed by the preceding methods are based on complete penetration of the shank into the attached member but not into the foundation member. When the unthreaded portion of the shank penetrates the foundation member, the following increases in loads are permitted:

Ratio of penetration of shank into foundation member to shank diameter	Increase in load
	Percent
1	8
2	17
3	26
4	33
5	36
6	38
7	39

When lag screws are used with metal plates, the lateral loads parallel to the grain may be increased 25 percent, but no increase should be made in the loads when the applied load is perpendicular to the grain.

Lag screws should not be used in end grain, because splitting may develop under lateral load. If lag screws are so used, however, the loads should be taken as two-thirds those for lateral resistance when lag screws are inserted into side grain and the loads act perpendicular to the grain.

The spacings, end and edge distances, and net section for lag screw joints should be the same as those for joints with bolts of a diameter equal to the shank diameter of the lag screw.

Lag screws should always be inserted by turning with a wrench, not by driving with a hammer. Soap, beeswax, or other lubricants applied to the screw, particularly with the denser wood species, will facilitate insertion and prevent damage to the threads but will not affect the lag screw's performance.

Allowable Loads

For allowable loads, the accepted practice has been to reduce the proportional limit load by a factor of 2.25 to account for variability in test data and reduce the load to a longtime loading condition. For normal duration of load, the allowable load may be increased by 10 percent.

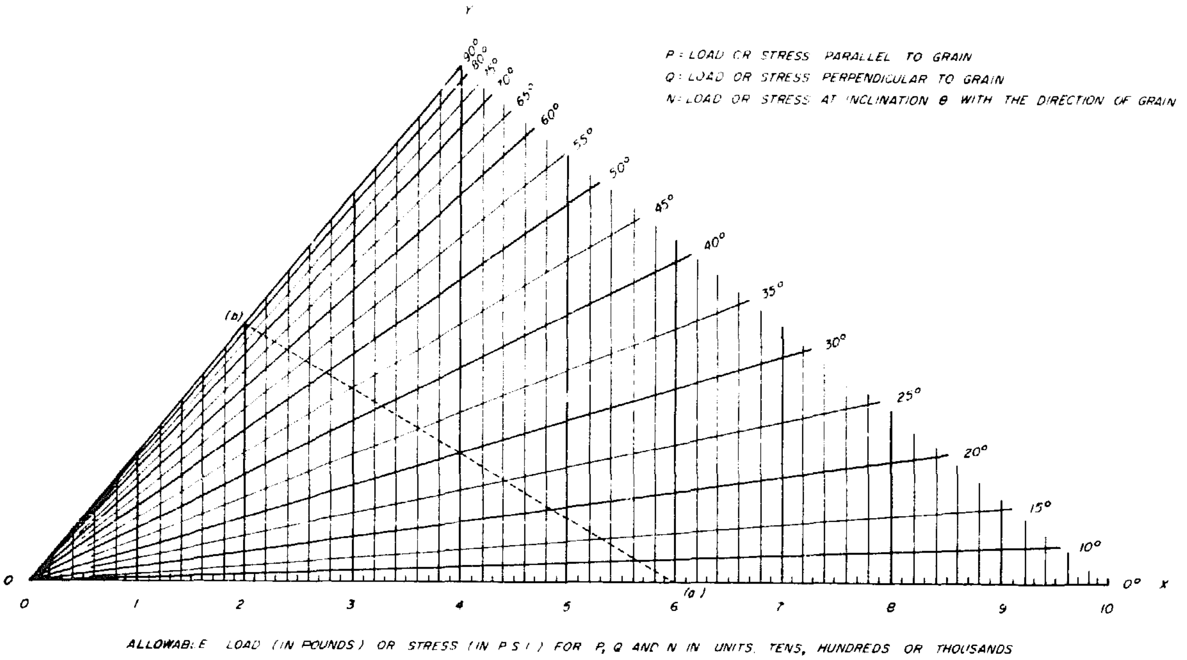

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Figure 7–6.—Scholten nomograph for determining the bearing stress of wood at various angles to the grain. The dotted line ab refers to the example given in the text.

BOLTS

Bearing Stress of Wood Under Bolts

The bearing stress under a bolt, computed by dividing the load by the product *LD* where *L* is length of bolt in main member and *D* is bolt diameter, is largest when the bolt does not bend, i.e. for joints with small *L/D* values.

The results of many tests of joints having a seasoned wood member and two steel splice plates show that bearing stress parallel to the grain at proportional limit loads approached 60 percent of the crushing strength of conifers and 80 percent of the crushing strength of hardwoods, where the crushing strengths are those obtained for clear, straight-grained specimens (table 4–2, ch. 4). The curve of figure 7–7 shows the reduction in bearing stress as *L/D* ratio increases. Thus the bolt-bearing stress parallel to the grain can be obtained for the crushing strength of small clear specimens, which is reduced by the above-mentioned factor for conifers or hardwoods, and an additional factor for *L/D* ratio. When wood splice plates were used, each splice plate half as thick as the center member, the bearing stresses were about 80 percent of those obtained with steel splice plates.

For bearing stresses perpendicular to the grain in seasoned wood, the stresses for short bolts (small *L/D* ratios) depend upon bolt diameter. Small bolts had higher proportional limit values than large bolts. The effect is presented in figure 7–8, wherein the ratio of proportional limit bearing stress to compression perpendicular to the grain pro-

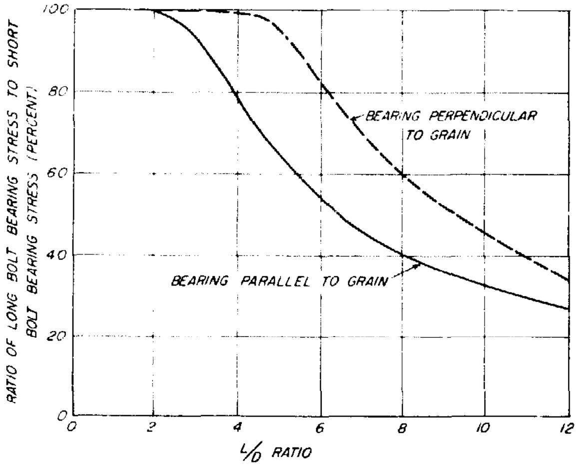

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Figure 7–7.—Variation in the proportional limit bolt-bearing stress with L/D ratio.

portional limit stress is plotted as a function of bolt diameter. The variation with bolt length (*L*/*D* ratio) is given by the appropriate curve in figure 7–7. Thus, the bolt-bearing stress perpendicular to the grain can be obtained from the proportional limit stress perpendicular to grain of small clear specimens (table 4–2, ch. 4), this is increased by the factor given in figure 7–8 and then reduced by the factor given in figure 7–7. The same data were obtained with steel splice plates and wood splice plates, each half as thick as the main center member. Bearing was parallel to the grain in the splice plates.

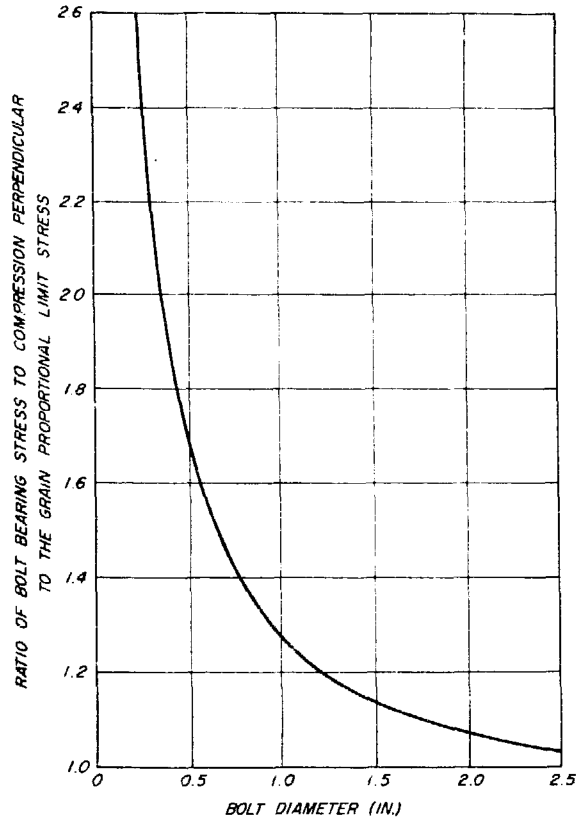

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Figure 7–8.—Bearing stress perpendicular to the grain as affected by bolt diameter.

For loads applied at an angle intermediate between those parallel to the grain and perpendicular to the grain, the bolt bearing stress may be obtained from the nomograph in figure 7–6.

Effect of Bolt Quality on Joint Strength

Both the properties of the wood and the quality of the bolt are factors in determining the proportional limit strength of a bolted joint. The percentages of stresses given in figure 7–7 for calculating bearing stresses apply to steel machine bolts used in building construction. For high-strength bolts, such as aircraft bolts, the factors given in figure 7–7 would be conservative for the larger *L*/*D* ratios.

Design Details

The details of design required in the application of the loads for bolts may be summarized as follows:

(1) A load applied to only one end of a bolt, perpendicular to its axis, may be taken as one-half the symmetrical two-end load.

(2) The center-to-center distance along the grain between bolts acting parallel to the grain should be at least four times the bolt diameter. When a joint is in tension, the bolt nearest the end of a timber should be at a distance from the end of at least seven times the bolt diameter for softwoods and five times for hardwoods. When the joint is in compression, the end margin may be four times the bolt diameter for both softwoods and hardwoods. Any decrease in these spacings and margins will decrease the load in about the same ratio.

(3) For bolts bearing parallel to the grain, the distance from the edge of a timber to the center of a bolt should be at least 1.5 times the bolt diameter. This margin, however, will usually be controlled by (a) the common practice of having an edge margin equal to one-half the distance between bolt rows and (b) the area requirements at the critical section. (The critical section is that section of the member taken at right angles to the direction of load, which gives the maximum stress in the member based on the net area remaining after reductions are made for bolt holes at that section.) For parallel-to-grain loading in softwoods, the net area remaining at the critical section should be at least 80 percent of the total area in bearing under all the bolts in the particular joint under consideration; in hardwoods it should be 100 percent.

(4) For bolts bearing perpendicular to the grain, the margin between the edge toward which the bolt pressure is acting and the center of the bolt or bolts nearest this edge should be at least four times the bolt diameter. The

margin at the opposite edge is relatively unimportant. The minimum center-to-center spacing of bolts in the across-the-grain direction for loads acting through metal side plates need only be sufficient to permit the tightening of the nuts. For wood side plates, the spacing is controlled by the rules applying to loads acting parallel to grain if the design load approaches the bolt-bearing capacity of the side plates. When the design load is less than the bolt-bearing capacity of the side plates, the spacing may be reduced below that required to develop their maximum capacity.

Effect of Bolt Holes

The bearing strength of wood under bolts is affected considerably by the size and type of bolt hole into which the bolts are inserted. A bolt hole that is too large causes nonuniform bearing of the bolt; if the bolt hole is too small, the wood will split when the bolt is driven. Normally, bolts should fit neatly, so that they can be inserted by tapping lightly with a wood mallet. In general, the smoother the hole, the higher the bearing values will be (fig. 7-9). Deformations accompanying the load also increase with increase in the unevenness of the bolt-hole surface (fig. 7-10).

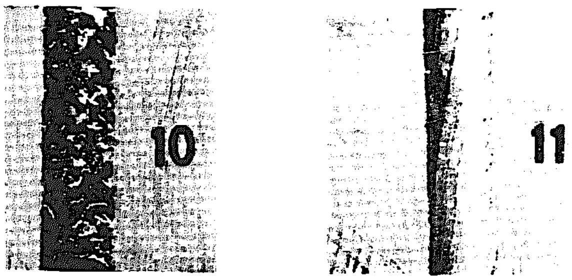

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Figure 7-9.—Effect of rate of feed and drill speed on the surface condition of bolt holes drilled in Sitka spruce. The hole on the left was bored with a twist drill rotating at a peripheral speed of 300 inches per minute; the feed rate was 60 inches per minute. The hole on the right was bored with the same drill at a peripheral speed of 1,250 inches per minute; the feed rate was 2 inches per minute.

Rough holes are caused by using dull bits and improper rates of feed and drill speed. A twist drill operated at a peripheral speed of approximately 1,500 inches per minute produces uniform smooth holes at moderate feed rates. The rate of feed depends upon the diameter of the drill and the speed of rotation but should enable the drill to cut rather than tear the wood. The drill should produce shavings, not chips.

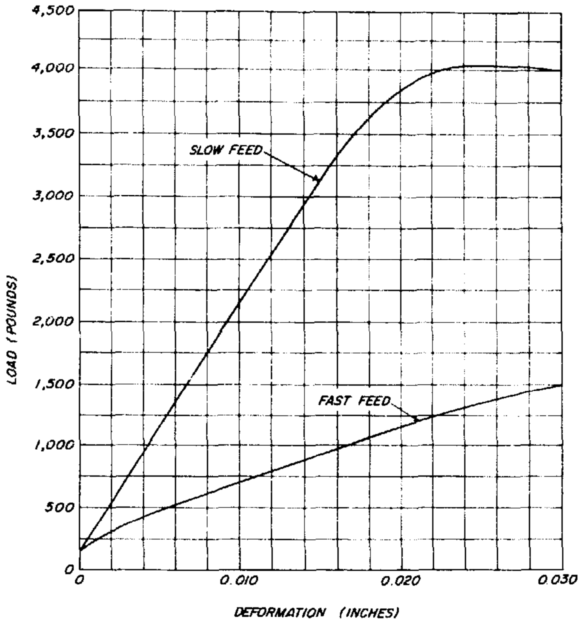

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Figure 7-10.—Typical load-deformation curves showing the effects of surface condition of bolt holes, resulting from a slow feed rate and a fast feed rate, on the deformation in a joint when subjected to loading under bolts. The surface conditions of the bolt holes were similar to those illustrated in figure 7-9.

Multiple-Bolt Joints

Joints containing six or more bolts in a row have an uneven distribution of bolt loads. The two end bolts together usually carry over 50 percent of the load. More than six bolts in a row do not substantially increase the elastic strength of the joint, in that the additional bolts only tend to reduce the load on the less heavily loaded interior bolts.

A small misalinement of bolt holes may cause large shifts in bolt loads. Therefore, in field-fabricated joints, the exact distribution of bolt loads would be difficult to predict. The most even distribution of bolt loads occurs in a joint in which the extensional stiffness of the main member is equal to that of both splice plates.

A simplified method of analysis that closely predicts the load distribution among the bolts in a timber tension joint has been developed by Cramer (see Bibliography).

CONNECTOR JOINTS

Several types of connectors have been devised that increase joint bearing and shear areas by utilizing rings or plates around bolts holding joint members together. The primary load-carrying portions of these joints are the connectors; the bolts usually serve to prevent sideways separation of the members, but do contribute some load-carrying capacity.

The strength of the connector joint depends on the type and size of the connector, the species of wood, the thickness and width of the member, the distance of the connector from the end of the member, the spacing of the connectors, the direction of application of the load with respect to the direction of the grain of the wood, and other factors. Loads for wood joints with steel connectors—split-ring (fig. 7–11), toothed-ring (fig. 7–12), and shear-plate (fig. 7–13)—are discussed in this section. The split-ring and shear-plate connectors require closely fitting machined portions in the wood members. The toothed-ring connector is pressed into the wood.

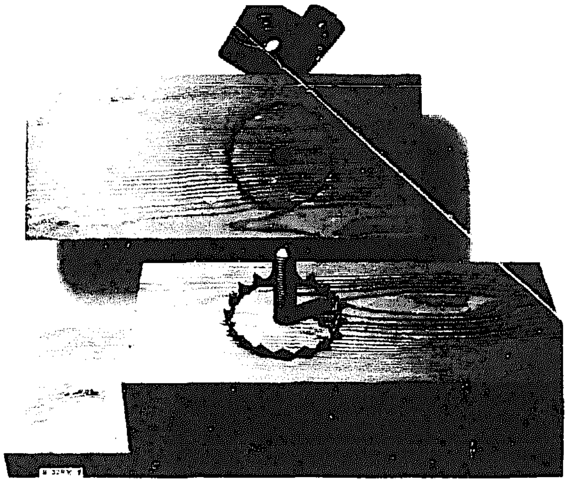

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Figure 7–12.—Joint with toothed-ring connector.

Connector Joints Under Permanent Load

Allowable loads for the split-ring, shear-plate, and toothed-ring connectors provided in table 7–6 were derived from the results of tests of joints made from several wood species. The species were classified into four groups in accordance with their strength in connector joints. In establishing the loads, particular consideration was given to (1) the effect of long-continued loading as against the brief loading period involved in the test of joints and (2) allowance for variability in timber quality (ASTM 1761).

Since adequate data are not available on the effect of duration of stress on the strength of connector joints, insofar as the wood is considered, the relation between the load at failure in a standard bending test of a few minutes' duration and the load that will cause failure under longtime loading was assumed to apply. Under constant load a beam will fail at a load only about nine-sixteenths as great as the breaking load found in the standard bending test (see ch. 6).

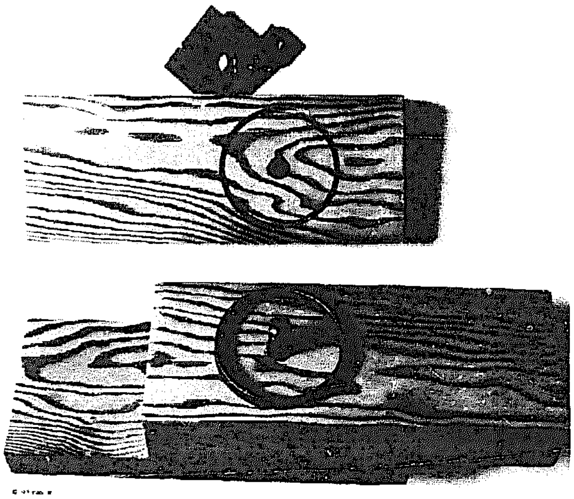

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Figure 7–11.—Joint with split-ring connector showing connector, precut groove, bolt, washer, and nut.

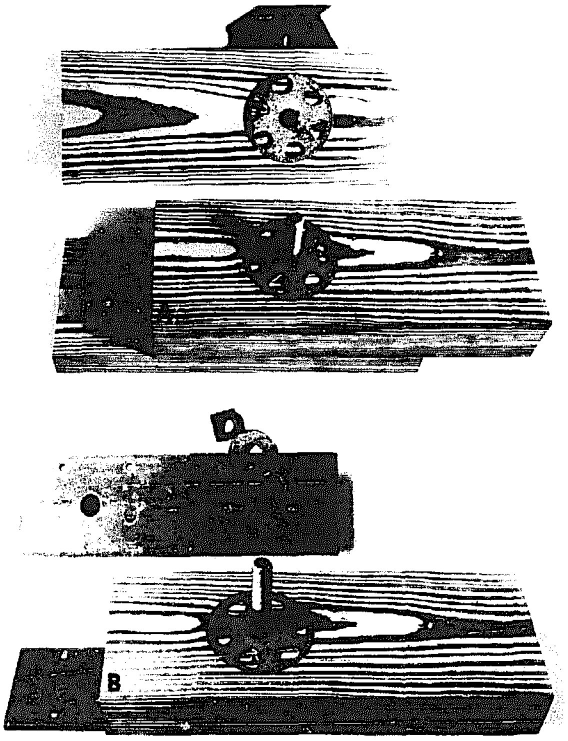

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Figure 7–13.—Joints with shear-plate connectors with A, wood side plates; and B, steel side plates.

Table 7–7.—*Species groupings for connector loads*

Connector load group	Species or species group		
Group 1	Aspen	Basswood	Cottonwood
	Western redcedar	Balsam fir	White fir
	Eastern hemlock	Eastern white pine	Ponderosa pine
	Sugar pine	Western white pine	Engelmann spruce
Group 2	Chestnut	Yellow-poplar	Baldcypress
	Alaska-cedar	Port-Orford-cedar	Western hemlock
	Red pine	Redwood	Red spruce
	Sitka spruce	White spruce	
Group 3	Elm, American	Elm, slippery	Maple, soft
	Sweetgum	Sycamore	Tupelo
	Douglas-fir	Larch, western	Southern pine
Group 4	Ash, white	Beech	Birch
	Elm, rock	Hickory	Maple, hard
	Oak		

Tests have demonstrated that the density of the wood is a controlling factor in determining the strength of a joint. Consequently, the load carried by a connector in the laboratory test employing wood of average quality for a species was adjusted to allow for the lower than average material that might be in service.

The values listed in table 7–6 for connectors loaded parallel to the grain were derived by applying a reduction factor to the ultimate test load. For split-ring and shear-plate connectors, a reduction factor of 4 gave values that would not exceed five-eighths of the proportional limit test load. Because load-slip curves for joints with toothed connectors do not exhibit a well-defined proportional limit, a reduction factor of $4\frac{1}{2}$ was applied to their ultimate loads.

Tests of connector joints under loads bearing perpendicular to grain, although less extensive than those for parallel bearing, have been sufficient to establish a generally applicable relationship between the two directions. This relationship was used in deriving loads for perpendicular bearing. Ultimate load was given less consideration for perpendicular than for parallel bearing, and greater dependence was placed on other factors, such as the load at proportional limit and at given slips of the joint.

The figures quoted as the ratios between tabulated loads and the loads found in tests are in no instance true factors of safety. For example, the reduction factor of 4 for split-ring and shear-plate connectors includes allowances for duration of stress and for variability as well as a margin for safety. Thus, after the values from test are multiplied by a factor of $\frac{9}{16}$ as an allowance for a long-continued load and by $\frac{3}{4}$ to cover variability of the wood, the actual factor of safety for a connector joint is on the order of $1\frac{3}{4}$ ($4 \times \frac{9}{16} \times \frac{3}{4} = 1\frac{11}{16}$) if the load acts over a long period. The tests from which loads were derived were on specimens carefully made from seasoned material, under favorable conditions, and by experienced workmen.

For any joint assembly in which more than one connector is used in the contact faces with the same bolt axis, the total load is the sum of the loads of each connector. For example, in table 7–6 minimum actual thickness of the members is given for a joint assembly of three members employing two connectors in opposite faces with a common bolt; this assembly is equivalent to two connectors; therefore, the load will be twice the corresponding value shown for a one-connector assembly. The loads given apply only when the joints are properly designed with respect to such features as centering of connectors on the member axis, adequate end distances, and suitable spacing of connectors.

Modifications

Some of the factors that affect the loads of connectors were taken into account in deriving the tabular values. Other varied and extreme conditions require modification of the values.

Table 7–6.—*Allowable loads [1] for one connector in a joint*

Connector	Minimum thickness of wood member		Minimum width all members	Group 1 woods [2]		Group 2 woods [2]		Group 3 woods [2]		Group 4 woods [2]	
	With one connector only	With two connectors in opposite faces, one bolt [3]		Load at 0° angle to grain	Load at 90° angle to grain	Load at 0° angle to grain	Load at 90° angle to grain	Load at 0° angle to grain	Load at 90° angle to grain	Load at 0° angle to grain	Load at 90° angle to grain
	In.	*In.*	*In.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
Split Ring:											
2½-in. diameter, ¾-in. wide with ½-in. bolt	1	2	3½	1,785	1,055	2,085	1,230	2,480	1,475	2,875	1,725
4-in. diameter, 1-in. wide, with ¾-in. bolt	1½	3	5½	3,445	1,995	3,985	2,310	4,780	2,775	5,580	3,235
Toothed Ring:											
2-in. diameter, 0.94 in. wide with ½-in. bolt	1⅛	2	2½	860	[4] 570	990	[4] 660	1,100	[4] 735	1,210	[4] 805
2⅝-in. diameter, 0.94 in. wide with ⅝-in. bolt	1⅜	2½	3½	1,460	[4] 976	1,690	[4] 1,125	1,875	[4] 1,250	2,060	[4] 1,375
3⅜-in. diameter, 0.94 in. wide with ¾-in. bolt	1½	3	4⅝	2,055	[4] 1,370	2,370	[4] 1,580	2,630	[4] 1,755	2,895	[4] 1,930
4-in. diameter, 0.94 in. wide with ¾-in. bolt	1½	3	5½	2,385	[4] 1,590	2,750	[4] 1,835	3,055	[4] 2,035	3,360	[4] 2,240
Shear Plate:											
2⅝-in. diameter, 0.42 in. wide with ¾-in. bolt	1½	2⅝	3½	1,890	1,095	2,190	1,270	2,630	1,525	2,665	1,780
4-in. diameter, 0.64 in. wide with ¾- or ⅞-in. bolt	1¾	3⅝	5½	2,850	1,655	3,305	1,915	3,965	2,300	4,625	2,685

[1] The loads apply to seasoned timbers in dry, inside locations for a long-continued load. It is assumed also that the joints are properly designed with respect to such features as centering of connectors, adequate end distance, and suitable spacing.

[2] Group 1 woods provide the weakest connector joints, and group 4 woods the strongest. Groupings are given in table 7–7.

[3] A 3-member assembly with 2 connectors takes double the loads indicated in fifth to twelfth columns.

[4] These loads are for any angle from 45° to 90° to the grain.

Wind or Earthquake Loads

In designing for wind or earthquake forces acting alone, or acting in conjunction with dead and live loads, the loads for the various connectors may be increased by the following percentages, provided the number and size of connectors are not less than required for the combination of dead and live loads alone:

	Increase
	Percent [2]
Split-ring connector, any size, bearing in any direction	50
Shear-plate connector, any size, bearing parallel to grain	33½
Shear-plate connector. any size, bearing perpendicular to grain	50
Toothed-ring connector, 2-inch, bearing in any direction	50
Tooth-ring connector, 4-inch, bearing in any direction	25

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[2] Percentages for shear-plate connectors bearing at intermediate angles and for toothed-ring connectors of other sizes can be obtained by interpolation.

Impact Forces

Impact may be disregarded up to the following percentage of the static effect of the live load producing the impact:

	Impact allowances
	Percent [3]
Split-ring connector, any size, bearing in any direction	100
Shear-plate connector, any size, bearing parallel to grain	66⅔
Shear-plate connector, any size, bearing perpendicular to grain	100
Toothed-ring connector, 2-inch, bearing in any direction	100
Toothed-ring connector, 4-inch, bearing in any direction	50

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[3] One-half of any impact load that remains after disregarding the percentages indicated should be included with the other dead and live loads in obtaining the total force to be considered in designing the joint.

Factor of Safety Not Reduced

The procedures described for increasing the loads on connectors for forces suddenly applied and forces of short duration do not reduce the actual factor of safety of the joint but are realistic because of the favorable behavior of wood under suddenly applied forces. The differentiation among types and sizes of connector and directions of bearing is due to variations in the extent to which distortion of the metal, as well as the strength of the wood, affects the ultimate strength of the joint.

Exposure and Moisture Condition of Wood

The loads listed in table 7–6 apply to seasoned members used where they will remain dry. If the wood will be more or less continuously damp or wet in use, two-thirds of the tabulated values should be used. The amount by which the loads should be reduced to adapt them to other conditions of use depends upon the extent to which the exposure favors decay, the required life of the structure or part, the frequency and thoroughness of inspection, the original cost and the cost of replacements, the proportion of sapwood and the durability of the heartwood of the species, if untreated, and the character and efficiency of any treatment. These factors should be evaluated for each individual design. Industry recommendations for the use of connectors when the condition of the lumber is other than continuously wet or continuously dry are given in the National Design Specification for Stress-Grade Lumber and Its Fastenings.

Ordinarily, before fabrication of connector joints, members should be seasoned to a moisture content corresponding as nearly as practical to that which they will attain in service. This is particularly desirable for lumber for roof trusses and other structural units used in dry locations and in which shrinkage is an important factor. Urgent construction needs sometimes result in the erection of structures and structural units employing green or inadequately sesoned lumber with connectors. Since such lumber subsequently dries out in most buildings, causing shrinkage and opening the joints, it is essential that adequate maintenance measures be adopted. The maintenance for connector joints in green lumber should include inspection of the structural units and tightening of all bolts as needed during the time the units are coming to moisture equilibrium, which is normally during the first year.

Grade and Quality of Lumber

The lumber for which the loads for connectors are applicable should conform to the general requirements in regard to the quality of structural lumber given in the grading rule books of lumber manufacturers' associations for the various commercial species.

The loads for connectors were obtained for wood at the joints that were clear and free from checks, shakes, and splits. Cross grain at the joint should not be steeper than a slope of 1 in 10, and knots in the connector area should be accounted for as explained under "Net Section."

Loads at Angle With Grain

The loads for the split-ring and shear-plate connectors for angles of 0° to 90° between direction of load and grain may be obtained by Hankinson's formula (eq. 7–11) or by the nomograph in figure 7–6. With the toothed connectors, the load at an inclination to the grain of 0° to 45° may be obtained with the previously mentioned formula, but from 45° to 90° it is equal to the load perpendicular to the grain.

Thickness of Member

The relationship between the loads for the different thicknesses of lumber is based on test results for connector joints. The least thickness of member given in table 7–6 for the various sizes of connectors is the minimum to obtain optimum load. The loads listed for each type and size of connector are the maximum loads to be used for all thicker lumber. The loads for wood members of thicknesses less than those listed can be obtained by the percentage reductions indicated in figure 7–14. Thicknesses below those indicated by the curves should not be used.

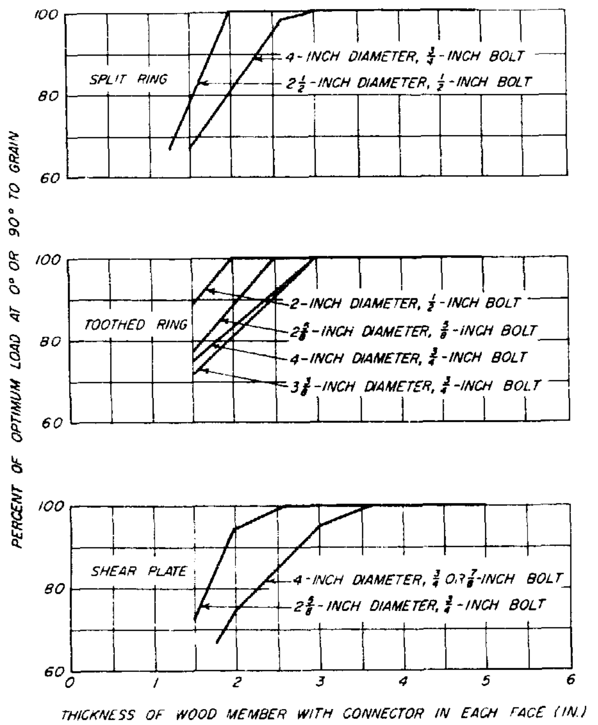

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Figure 7–14.—Effect of thickness of wood member on the optimum load capacity of a timber connector.

Thicknesses of members containing one connector only are equal to half the thickness of a member containing one connector in each face plus one-eighth inch for split-ring and toothed-ring connectors. For split-ring connectors, the reduction in load for other thicknesses of members containing one connector only may be obtained by following the same rules as for shear plate and toothed-ring connectors.

Width of Member

The width of member listed for each type and size of connector is the minimum that should be used. When the connectors are bearing parallel to the grain, no increase in load occurs with an increase in width. When they are bearing perpendicular to the grain, the load increases about 10 percent for each 1-inch increase in width of member over the minimum widths required for each type and size of connector, up to twice the diameter of the connectors. When the connector is placed off center and the load is applied continuously in one direction only, the proper load can be determined by considering the width of member as equal to twice the edge distance (the distance between the center of the connector and the edge of the member toward which the load is acting). But the distance between the center of the connector and the opposite edge should not be less than one-half the permissible minimum width of the member.

Net Section

The net section is the area remaining at the critical section after subtracting the projected area of the connectors and bolt from the full cross-sectional area of the member. For sawed timbers, the stress in the net area (whether in tension or compression) should not exceed the stress for clear wood in compression parallel to the grain. In using this stress, it is assumed that knots do not occur within a length of one-half the diameter of the connector from the net section. If knots are present in the longitudinal projection of the net section within a length from the critical section of one-half the diameter of the connector, the area of the knots should be subtracted from the area of the critical section.

In laminated timbers, knots may occur in the inner laminations at the connector location without being apparent from the outside of the member. It is impractical to assure that there are no knots at or near the connector. In laminated construction, therefore, the stress at the net section is limited to the compressive stress for the member, accounting for the effect of knots.

End Distance and Spacing

The load values in table 7–6 apply when the distance of the connector from the end of the member (end distance *e*) and the spacing (*s*) between connectors in multiple joints are not factors affecting the strength of the joint (fig. 7–15, *A*). When the end distance or spacing for connectors bearing parallel to the grain is less than that required to develop the full load, the proper reduced load may be obtained by multiplying the loads in table 7–6 by the appropriate strength ratio given in table 7–8. For example, the load for a 4-inch split-ring connector bearing parallel to the grain, when placed 7 or more inches from the end of a Douglas-fir tension member that is 1½ inches thick, is 4,780 pounds. When the end distance is only 5¼ inches, the strength ratio obtained by direct interpolation from the values given in table 7–8 is 0.81, and the load equals 0.81 times 4,780 or 3,870 pounds.

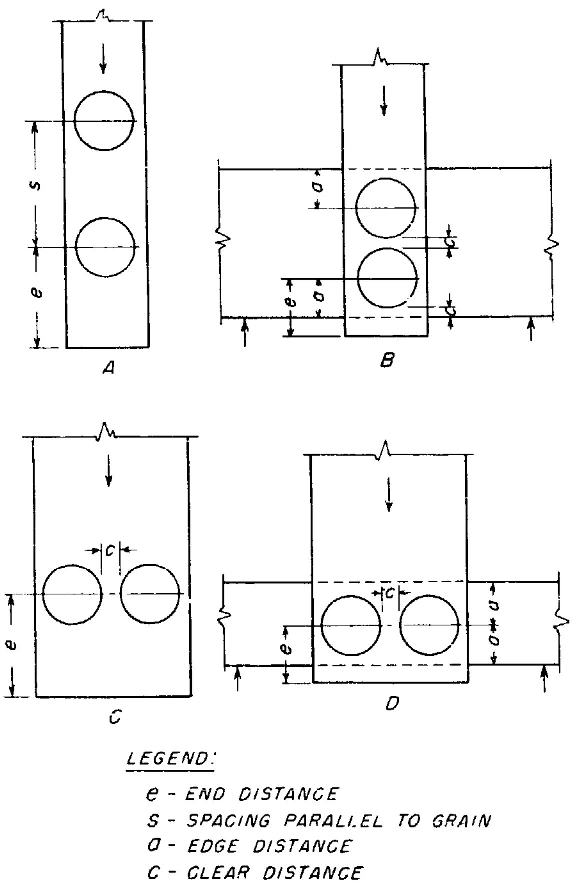

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Figure 7–15.—Types of multiple-connector joints: *A*, joint strength dependent on end distance *e* and connector spacing *s*; *B*, joint strength dependent on end *e*, clear *c*, and edge *a* distances; *C*, joint strength dependent on end *e* and clear *c* distances; *D*, joint strength dependent on end *e*, clear *c*, and edge *a* distances.

Placement of Multiple Connectors

Preliminary investigations of the placement of connectors in a multiple joint, together with the observed behavior of single connector joints tested with variables that simulate those in a multiple joint, furnish a basis for some suggested design practices.

When two or more connectors in the same face of a member are in a line at right angles to the grain of the member and are bearing parallel to the grain (fig. 7–15, *C*), the clear distance (*c*) between the connectors should not be less than one-half inch.

When two or more connectors are acting perpendicular to the grain and are spaced on a line at right angles to the length of the member (fig. 7–15, *B*), the rules for the width of member and edge distances used with one connector are applicable to the edge distances for multiple connectors. The clear distance between the connectors (*c*) should be equal to the clear distance from the edge of the member toward which the load is acting to the connector nearest this edge (*c*).

In a joint with two or more connectors spaced on a line parallel to the grain and with the load acting perpendicular to the grain (fig. 7–15, D), the available data indicate that the load for multiple connectors is not equal to the sum of the loads for individual connectors. Somewhat more favorable results can be obtained if the connectors are staggered so that they do not act along the same line with respect to the grain of the transverse member. Industry recommendations for various angle-to-grain loadings and spacings are given in National Design Specifications.

Table 7-8.—*Strength ratio for connectors for various longitudinal spacings and end distances*[1]

Connector diameter	Spacing[2]	Spacing strength ratio	End distance[3]		End distance strength ratio
			Tension member	Compression member	
In.	*In.*	*Pct.*	*In.*	*In.*	*Pct.*
SPLIT-RING					
2½	6¾+	100	5½+	4+	100
2½	3⅜	50	2¾	2½	62
4	9+	100	7+	5½+	100
4	4⅞	50	3½	3¼	62
SHEAR-PLATE					
2⅝	6¾+	100	5½+	4+	100
2⅝	3⅜	50	2¾	2½	62
4	9+	100	7+	5½+	100
4	4½	50	3½	3¼	62
TOOTHED-RING					
2	4+	100	3½+	2+	100
2	2	50	2	....	67
2⅝	5¼+	100	4⅝+	2⅝+	100
2⅝	2⅝	50	2⅝	....	67
3⅜	6¾+	100	5⅞+	3⅜+	100
3⅜	3⅜	50	3⅜	....	67
4	8+	100	7+	4+	100
4	4	50	4	....	67

[1] Strength ratio for spacings and end distances intermediate to those listed may be obtained by interpolation, and multiplied by the loads in table 7-6 to obtain design load. The strength ratio applies only to those connector units affected by the respective spacings or end distances. The spacings and end distances should not be less than the minimum shown.

[2] Spacing is distance from center to center of connectors (fig. 7-15, *A*).

[3] End distance is distance from center of connector to end of member (fig. 7-15, *A*).

Cross Bolts

Cross bolts or stitch bolts placed at or near the end of members joined with connectors or at points between connectors will provide additional safety. They may also be used to reinforce members that have, through change in moisture content in service, developed splits to an undesirable degree.

Examples of Connector-Joint Design

(1) Calculate the load of a tension joint of seasoned Douglas-fir in which two pieces 3½ inches thick and 5½ inches wide are joined end to end by side plates 1½ inches thick, 5½ inches wide, and 28 inches long, when four 4-inch split-ring connectors and two ¾-inch bolts are used. In this arrangement, two connectors and a concentric bolt are placed symmetrically on either side of the butt joint at a distance of 7 inches from the ends of the members and side plates. This end distance, as shown in table 7-8, is adequate to develop the full load.

The load given in table 7-6 for one 4-inch split-ring connector, when used in one face of a Douglas-fir member 1½ inches thick or as one of two connectors used in opposite faces of a member 3 inches thick, is 4,780 lb. The load of the joint for two connectors is twice 4,780 or 9,560 lb.

(2) Calculate the load of the joint in example (1) when the side plates are 16 inches instead of 28 inches long. By placing the connectors halfway between the ends of the side plates and the butt joint, the end distance is 4 inches. The strength ratio as interpolated from values given in table 7-8 for a 4-inch end distance is 0.68, and the load accordingly equals 0.68 times 9,560 or 6,500 lb.

(3) Calculate the load of a joint of seasoned southern pine in which two tension side members 1½ inches thick and 5½ inches wide are joined at right angles to opposite faces of a center timber 3½ inches thick and 5½ inches wide by means of two 4-inch split-ring connectors and a ¾-inch bolt.

The load for one of two 4-inch split-ring connectors used in opposite faces of a member 3 inches thick and 5½ inches wide and bearing perpendicular to the grain is 2,775 lb. (table 7-6). The load for one connector bearing parallel to the grain in one face of a side member 1½ inches thick and with an end distance of 7 inches is 4,780 lb. (table 7–6). The load of the joint, which is governed by the center member, is twice 2,775 or 5,550 lb.

(4) Calculate the load of the joint in example (3) when the distance from the end of the side plates overlapping the center member to the center of the bolt hole is 3½ instead of 7 inches.

The strength ratio for an end distance of 3½ inches is 0.62 (table 7–8). The load for one 4-inch split-ring connector in the side member, hence, equals 0.62 times 4,780 or 2,964 lb. This is larger than the load for one connector in the center member. The strength of the joint, therefore, is still governed by the center member and, as before, is 5,550 lb.

FASTENER HEAD EMBEDMENT

The bearing strength of wood under fastener heads is important in such applications as the anchorage of building framework to foundation structures. When pressure tends to pull the framing member away from the foundation, the fastening loads could cause tensile failure of the fastenings, withdrawal of the fastenings from the framing member, or embedment of the fastener heads into the member. Possibly the fastener head could even be pulled completely through.

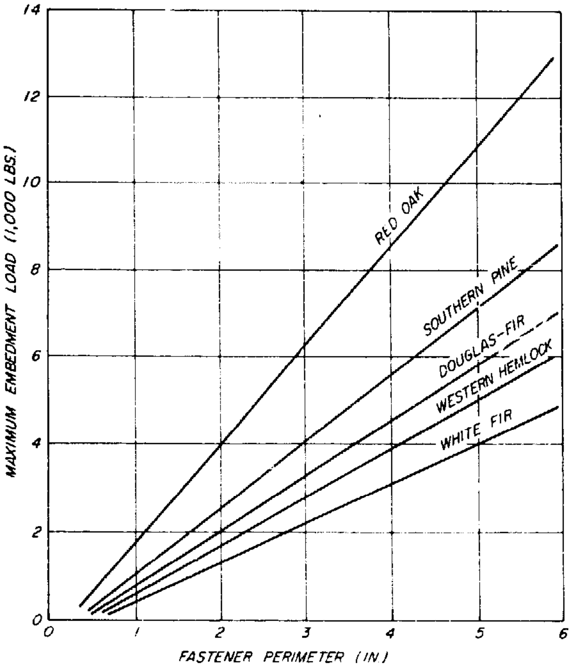

Figure 7–16.—Relation between maximum embedment load and fastener perimeter for several species of wood.

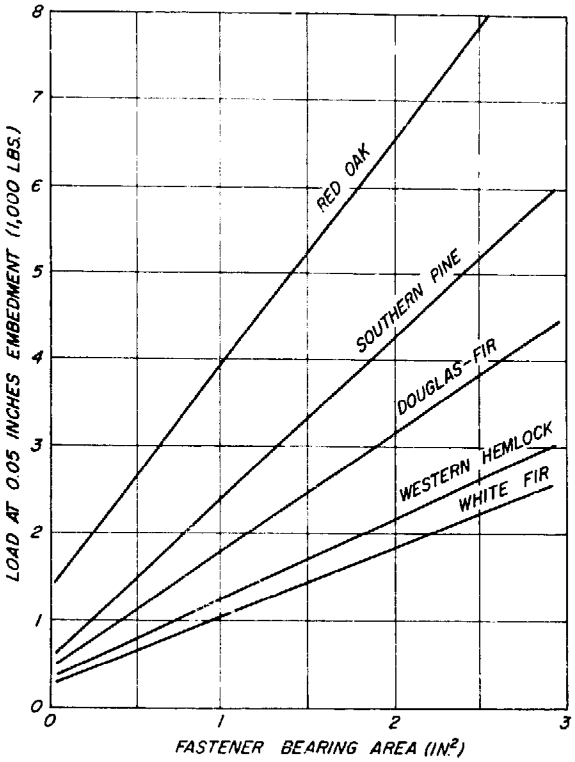

Figure 7–17.—Relation between load at 0.05 inch embedment and fastener bearing area for several species.

The maximum resistance to fastener head embedment is related to the fastener perimeter, while loads of low embedments (0.05 in.) are related to the fastener bearing area. These relations for several species at 10 percent moisture content are shown in figures 7–16 and 7–17.

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Chapter 8

WOOD STRUCTURAL MEMBERS

WOOD STRUCTURAL MEMBERS

This chapter deals with fundamental considerations related to the simpler structural members, such as beams and columns. Members of several parts assembled with mechanical fastenings are included but details regarding glued structural members are discussed in chapter 10.

BEAMS

Wood beams are usually of rectangular cross section and of constant depth and width throughout their span. They should be large enough so that their deflection under load will not exceed the limit fixed by the intended use of the structure. Beams should also be large enough so that the following stresses do not exceed allowable values: Flexural stresses of compression on the concave portion and tension on the convex portion caused by bending moment, shear stresses caused by shear load, and compression across the grain at the end bearings. The actual, not nominal, sizes of the lumber must be used when computing the deflections and stresses.

Formulas for determining deflections and stresses in beams of sawn timber, of glued or mechanically fastened laminations at right angles to the neutral plane, or of glued laminations parallel to the neutral plane are given in this chapter. The property values, modulus of elasticity, and stresses for various wood species are given in chapter 4. Values of coefficients of variation are included in chapter 4 to indicate the variability and reliability of the data as an aid in selection of allowable property values.

Beam Deflections

The deflection of beams is often limited to 1/360 of the span of framing over plastered ceilings and 1/240 of the span over unplastered ceilings. Deflection of highway bridge stringers is often limited to 1/200 of the span and stringers for railroad bridges and trestles to 1/300 of the span.

Straight Beam Deflection

The deflection of straight beams (or long, slightly curved beams with the radius of curvature in the plane of bending), elasticially stressed, and having a constant cross section throughout their length is given by the formula:

$$y = \frac{k_b W L^3}{EI} + \frac{k_s W L}{GA'} \qquad (8\text{–}1)$$

where y is deflection, W is total beam load acting perpendicular to beam neutral axis, L is beam span, k_b and k_s are constants dependent upon beam loading and location of point whose deflection is to be calculated, I is beam moment of inertia, A' is a modified beam area, E is beam modulus of elasticity (for beams having straight grain parallel to their axis $E = E_L$), and G is beam shear modulus (for beams with flat-grained vertical faces $G = G_{LT}$ and for beams with edge-grained vertical faces $G = G_{LR}$). Elastic property values are given in chapter 4.

The first term on the right side of formula (8–1) gives the bending deflection and the

Table 8–1.—*Values of k_b and k_s for several beam loadings*

Loading	Beam ends	Deflection at—	k_b	k_s
Uniformly distributed	Both simply supported	Midspan	5/384	1/8
	Both clamped	do	1/384	1/8
Concentrated at midspan	Both simply supported	do	1/48	1/4
	Both clamped	do	1/192	1/4
Concentrated at outer quarter span points	Both simply supported	do	11/768	1/8
	do	Load point	1/96	1/8
Uniformly distributed	Cantilever, 1 free, 1 clamped	Free end	1/8	1/2
Concentrated at free end	Cantilever, 1 free, 1 clamped	do	1/3	1

second term the shear deflection. Values of k_b and k_s for several beam loadings are given in table 8–1.

The moment of inertia, I, of the beams is given by the formulas:

$$I = \frac{bh^3}{12} \text{ for beam of rectangular cross section} \tag{8–2}$$

$$I = \frac{\pi d^4}{64} \text{ for beam of circular cross section}$$

where b is beam width, h is beam depth, and d is beam diameter. The modified area A' is given by the formulas:

$$A' = \frac{5}{6}bh \text{ for beam of rectangular cross section} \tag{8–3}$$

$$A' = \frac{9}{40}\pi d^2 \text{ for beam of circular cross section}$$

Tapered Beam Deflection

The bending deflection of beams tapering in depth but of constant width throughout their length can be determined from the nondimensional ordinates of the graphs given in figures 8–1 and 8–2. The graph axes are chosen so that the ordinate contains data usually known in a design such as elastic properties, deflection, span, and difference in beam height $(h_c - h_o)$, as required by roof slope or architectural effect. Then the value of the abscissa γ can be determined as shown by the example line on the graph to thus eventually compute the smallest beam depth, h_o. The graphs can also be used to determine maximum bending deflections if the abscissa is known. Tapered beams deflect due to shear distortion in addition to bending deflections and this shear deflection Δ_s can be closely approximated by the formulas:

$$\Delta_s = \frac{3WL}{20Gbh_o} \text{ for load uniformly distributed} \tag{8–4}$$

$$\Delta_s = \frac{3PL}{10Gbh_o} \text{ for midspan concentrated load}$$

The final beam design should include shear as well as bending deflection and it may be necessary to iterate to arrive at final beam dimensions.

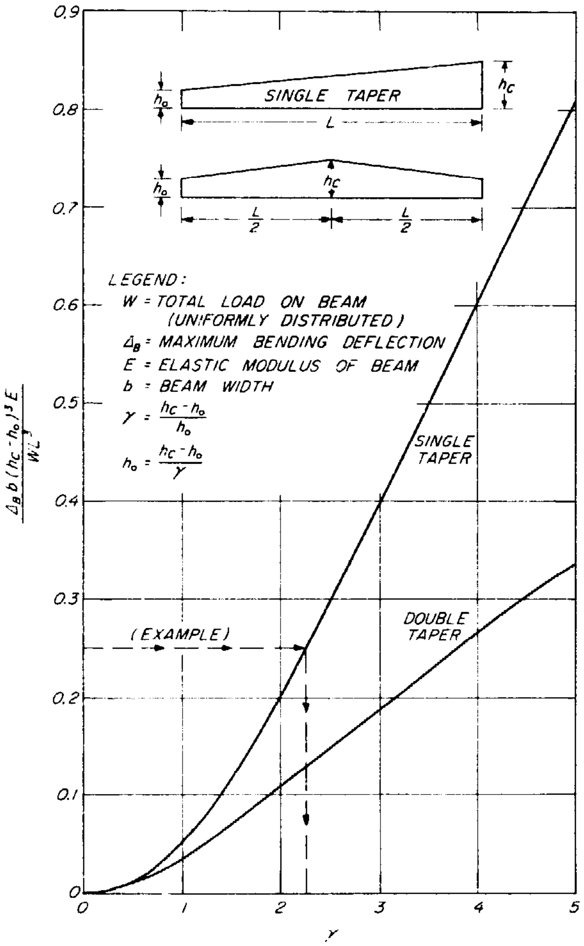

Figure 8–1.—Graph for determining tapered beam size based on deflection under uniformly distributed load.

Effects of Notches and Holes

The deflection of beams is increased if reductions in cross section dimensions occur such as are caused by holes or notches. The deflection of such beams can be determined by considering them of variable cross section along their length and appropriately solving the general differential equations of the elastic curves, $EI\frac{d^2y}{dx^2} = M$, to obtain deflection expressions or by the often simpler theorem of least work implicity in Castigliano's theorem. (These procedures are given in most texts on strength of materials.) If notches occur, their effective dimension along the beam axis for use in determining beam deflection is approximately equal to the length of the notch plus twice the depth of the notch.

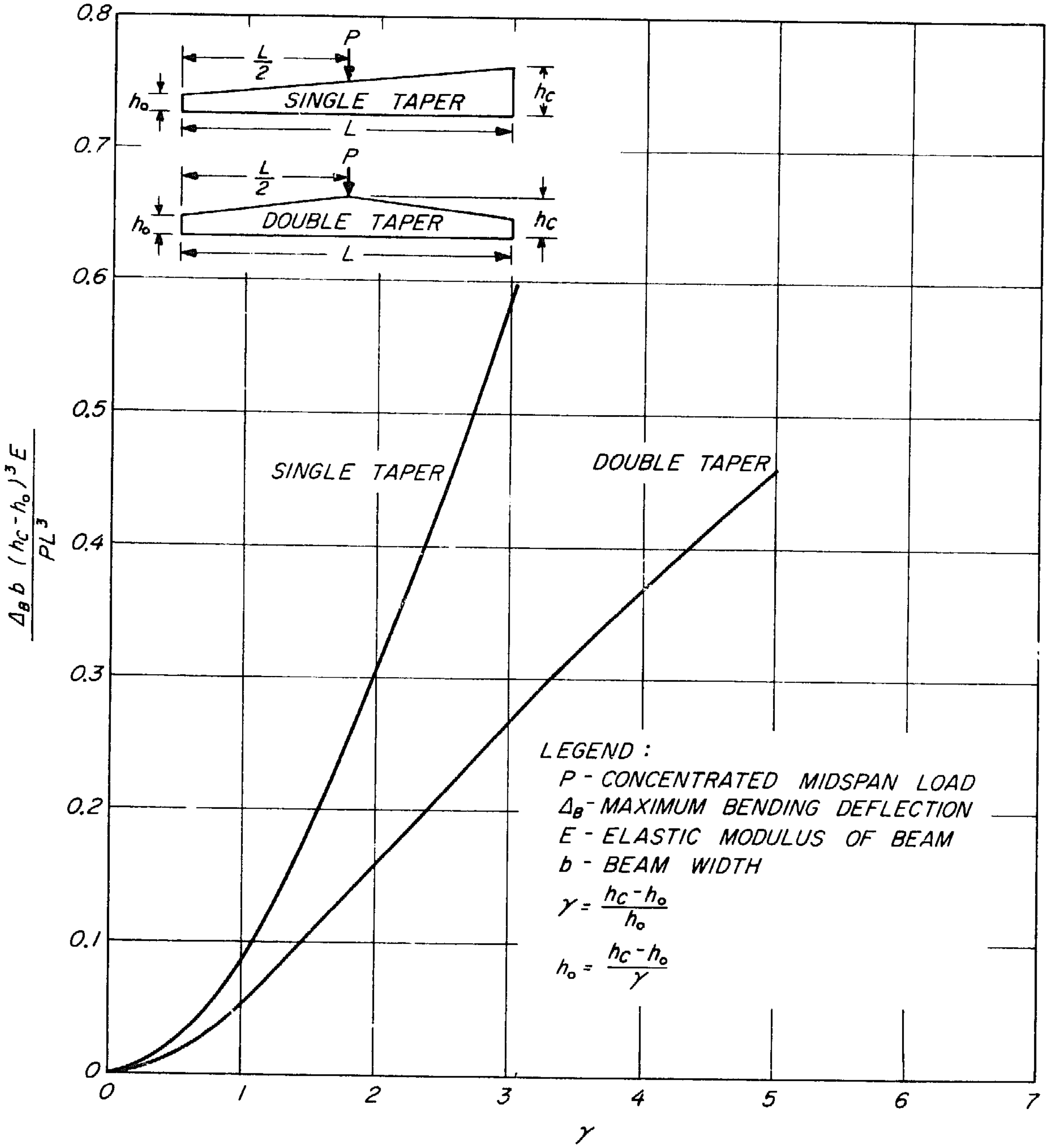

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Figure 8–2.—Graph for determining tapered beam size based on deflection under concentrated midspan load.

Effect of Ponding Water

Ponding of water on roofs already deflected under normal loads can cause large increases in deflection. The deflection of a simply supported, uniformly loaded beam under ponding water can be estimated closely by multiplying deflection under design loading without ponding, by the following magnification factor:

$$\frac{1}{1 - \frac{W'L^3}{\pi^4 EI}} \qquad (8\text{–}5)$$

where W' is total load of 1 inch depth of water on the roof area supported by the beam; L is beam span; E is beam modulus of elasticity; and I is beam moment of inertia. As the second term in the denominator of formula (8–5) becomes unity, the magnification becomes infinite, thus denoting complete collapse of the beam.

The deflections of a beam with fixed ends under concentrated midspan load P plus ponding water can be estimated closely by multiplying deflection under design load without ponding, by the following magnification factor:

$$\frac{1}{1 - \frac{3W'L^3}{16\pi^4 EI}} \qquad (8\text{–}6)$$

Effect of End Loading

Addition of end loading (in a direction parallel to the beam length) to a beam under loads acting perpendicular to the beam neutral axis causes increase in deflection for added end compression and decrease in deflection for added end tension. The deflection under combined loading can be estimated closely by the formula:

$$\Delta = \frac{\Delta_0}{1 \pm \frac{P}{P_{cr}}} \qquad (8\text{–}7)$$

where the plus sign is chosen if the end load is tension and the minus sign is chosen if the end load is compression; Δ is deflection under combined loading; Δ_0 is beam deflection without end load; P is end load; and P_{cr} is buckling load of beam under end compressive load only (see section on Columns), based on beam stiffness about the neutral axis perpendicular to the direction of bending loads. P must be less than P_{cr} in order to avoid collapse if P is compression.

Deflection With Time

In addition to the elastic deflections previously discussed, wood beams usually sag in time; that is, the deflection increases beyond what it was immediately after the load was first applied. Green timbers, especially, will sag if allowed to dry under load, although partially dried material will also sag to some extent. In thoroughly dried beams, there are small changes in deflection with changes in moisture content but little permanent increase in deflection. If deflection under longtime load is to be limited, it has been customary to design for an initial deflection of about one-half the value permitted for longtime deflection. This can be done by doubling the longtime load value when calculating deflection, by using one-half of the usual value for modulus of elasticity or any equivalent method.

Beam Strength

The strength of beams is determined by flexural stresses caused by bending moment, shear stresses caused by shear load, and compression across the grain at the end bearings.

Bending Moment

The bending moment capacity of a beam is given by the formula:

$$M = fS \qquad (8\text{–}8)$$

where M is bending moment, S is beam section modulus (for a beam of rectangular cross section $S = \frac{bh^2}{6}$ and for a circular cross section $S = \frac{\pi d^3}{32}$), and f is stress. The significance of M in denoting allowable moment or maximum moment is dependent upon choice of the stress f at an allowable value or a modulus of rupture value.

Size Effect

It has been found that the modulus of rupture (maximum bending stress) of wood beams depends on beam size and method of loading and that the strength of clear, straight-grained beams decreases as size increases.[1] These effects were found to be describable by statistical strength theory involving "weakest link" hy-

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[1] For further information see report by Bohannan in Bibliography.

potheses and can be summarized as: For two beams under two equal concentrated loads applied symmetrical to the midspan points, the ratio of the modulus of rupture of beam 1 to the modulus of rupture of beam 2 is given by the formula:

$$\frac{R_1}{R_2} = \left[\frac{h_2 L_2 \left(1 + \frac{m a_2}{L_2}\right)}{h_1 L_1 \left(1 + \frac{m a_1}{L_1}\right)} \right]^{1/m} \qquad (8\text{–}9)$$

where subscripts 1 and 2 refer to beam 1 and beam 2; R is modulus of rupture; h is beam depth; L is beam span; a is distance between loads placed $\frac{a}{2}$ each side of midspan; and m is a constant. For clear, straight-grained Douglas-fir beams $m = 18$. If formula (8–9) is used for beam 2 of standard size (see ch. 4), loaded at midspan then $h_2 = 2$ inches, $L_2 = 28$ inches, and $a_2 = 0$ and formula (8–9) becomes

$$\frac{R_1}{R_2} = \left[\frac{56}{h_1 L_1 \left(1 + \frac{m a_1}{L_1}\right)} \right]^{1/m} \qquad (8\text{–}10)$$

Example: Determine modulus of rupture for a beam 10 inches deep, spanning 18 feet, and loaded at one-third span points compared with a beam 2 inches deep, spanning 28 inches, and loaded at midspan that had a modulus of rupture of 10,000 pounds per square inch. Assume $m = 18$. Substitution of the dimensions into formula (8–10) produces:

$$R_1 = 10{,}000 \left[\frac{56}{2{,}160(1 + 6)} \right]^{1/18}$$

$= 7{,}340$ pounds per square inch

Extrapolation of the theory of reference to beams under uniformly distributed load resulted in the following relationship between modulus of rupture of beams under uniformly distributed load and modulus of rupture of beams under concentrated loads:

$$\frac{R_u}{R_c} = \left[\frac{\left(1 + 18 \frac{a_c}{L_c}\right) h_c L_c}{3.876 h_u L_u} \right]^{1/18} \qquad (8\text{–}11)$$

where subscripts u and c refer to beams under uniformly distributed and concentrated loads, respectively, and other symbols are as previously defined.

Effects of Notches and Holes

In beams having changes in cross sectional dimensions because of holes or notches, bending stresses can be calculated at the hole or notch by dividing the bending moment there by the section modulus of the material remaining. Values of this bending stress are not useful in design because the change in cross section also causes shear stresses and stresses perpendicular to the beam neutral axis; the combination of these stresses with the bending stress can cause failure at low load. It is not known how to compute these stresses and therefore it would be wise to avoid notches in beams.

Effect of Ponding Water

Ponding of water on roofs can cause increases in bending stresses that can be computed by using the same magnification factors, formulas (8–5 and 8–6), as determined for deflection.

Compressive End Loading

Addition of compressive end loading to a beam under loads acting perpendicular to the beam's neutral axis increases compressive stress and decreases tensile stress; the stress due to combined loading can be estimated closely by the formulas:

$$\text{Compressive stress, } f_c = \frac{f_o}{1 - \frac{P}{P_{cr}}} + \frac{P}{A} \qquad (8\text{–}12)$$

$$\text{Tensile stress, } f_t = \frac{f_o}{1 - \frac{P}{P_{cr}}} - \frac{P}{A} \qquad (8\text{–}13)$$

where f_o is bending stress without end load, P is compressive end load, A is area of beam cross section; and P_{cr} is buckling load of beam under end compressive load only, based on beam stiffness about the neutral axis perpendicular to the direction of bending loads. P must be less than P_{cr} in order to avoid collapse.

Tensile End Loading

Addition of tensile end loading to a beam under loads acting perpendicular to the beam's neutral axis increases tensile stress and decreases compressive stress; the stress due to combined loading can be estimated closely by the formulas:

$$\text{Compressive stress, } f_c = \frac{f_o}{1 + \frac{P'}{P_{cr}}} - \frac{P'}{A} \quad (8\text{–}14)$$

$$\text{Tensile stress, } f_t = \frac{f_o}{1 + \frac{P'}{P_{cr}}} + \frac{P'}{A} \quad (8\text{–}15)$$

where P' is the tensile end load and the other symbols are as previously defined.

Shear Capacity

The shear capacity of a beam is given by the formula:

$$V = f_s A \qquad (8\text{–}16)$$

where V is shear load perpendicular to beam neutral axis, A is effective beam shear area (for a beam of rectangular cross section $A = \frac{2bh}{3}$ and for a beam of circular cross section $A = 3\pi\frac{d^2}{16}$), and f_s is shear stress at the neutral axis. The significance of V in denoting allowable shear or maximum shear depends on choice of the stress f_s at an allowable value or a strength value.

Increases in shear stresses caused by ponding of water on roofs can be computed by using the same magnification factors, formulas (8–5) and (8–6), as determined for deflection.

For beams that taper in depth but are of constant width, the shear stress can be a maximum at the tapered edge as well as at the neutral axis of the beam. The shear stress distribution for a beam of rectangular cross section, of constant width, tapering in depth linearly with spanwise distance, and loaded with concentrated loads to produce a reaction V, is shown in figure 8–3. For other loadings, the basic theory derived by Maki and Kuenzi can be used to determine shear stress distributions. The shear stress at the tapered edge can reach a maximum value as great as that at the neutral axis at a reaction. For the beam shown in figure 8–3, this maximum stress occurs at the cross section which is double the depth of the beam at the reaction. For other loadings, the location of the cross section with maximum shear stress at the tapered edge will be somewhat different.

For the beam shown in figure 8–3, the bending stress is also a maximum at the same cross section where the shear stress is maximum at the tapered edge. This stress situation also causes a stress in the direction perpendicular to the neutral axis that is maximum at the tapered edge. The effect of combined stresses at a point can be approximately accounted for by an interaction formula based on the Henky-von Mises theory of energy due to the change of shape. This theory applied to wood by Norris results in the formula:

$$\frac{f_x^2}{F_x^2} + \frac{f_{xy}^2}{F_{xy}^2} + \frac{f_y^2}{F_y^2} = 1 \qquad (8\text{–}17)$$

where f_x is the bending stress, f_y is the stress perpendicular to the neutral axis, and f_{xy} is the shear stress. Values of F_x, F_y, and F_{xy} are cor-

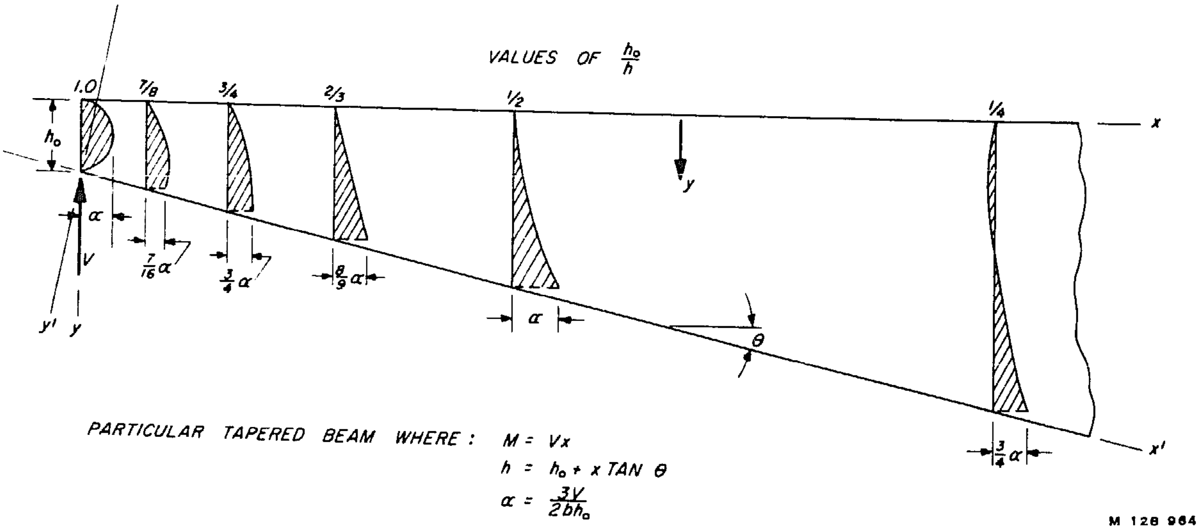

Figure 8–3.—Shear stress distributions for a tapered beam.

responding stresses chosen at design allowable values or maximum values in accordance with allowable or maximum values being determined for the tapered beam. Maximum stresses in the beam shown in figure 8–3 are given by the formulas:

$$f_x = \frac{3M}{2bh_o^2} \qquad (8\text{–}18)$$

$$f_{xy} = f_x \tan\theta \qquad (8\text{–}19)$$

$$f_y = f_x \tan^2\theta \qquad (8\text{–}20)$$

Substitution of these formulas into the interaction formula (8–17) will result in an expression for the moment capacity M of the beam. If the taper is on the beam tension edge, the values of f_x and f_y are tensile stresses.

Example: Determine the moment capacity of a tapered beam of width $b = 5$ inches, depth $h_o = 10$ inches, and taper $\tan\theta = \frac{1}{10}$. Substitution of these dimensions into formulas (8–18), (8–19), and (8–20) results in:

$$f_x = \frac{3M}{1{,}000}$$

$$f_{xy} = \frac{3M}{10{,}000}$$

$$f_y = \frac{3M}{100{,}000}$$

and substitution of these expressions into formula (8–17) and solving for M results finally in:

$$M = \frac{10^5}{3\left[\frac{10^4}{F_x^2} + \frac{10^2}{F_{xy}^2} + \frac{1}{F_y^2}\right]^{1/2}}$$

where appropriate allowable or maximum values of the F stresses are chosen.

End Bearing Area

The end bearing area of all beams as well as bearing areas of concentrated loads along the beam should be large enough to prevent stresses perpendicular to the grain in the beam from reaching chosen allowable or maximum values.

Lateral Buckling

The lateral buckling of beams can occur at low bending stresses and result in beam collapse if the flexural rigidity of the beam in the plane of bending is very large in comparison with its lateral rigidity and the beam is fairly long. Thus beam strength may be governed by lateral buckling rather than material strength per se. Lateral buckling depends on beam torsional rigidity as well as lateral rigidity, beam length, and manner of loading. The critical bending moment or load for beams of rectangular cross section have been derived for

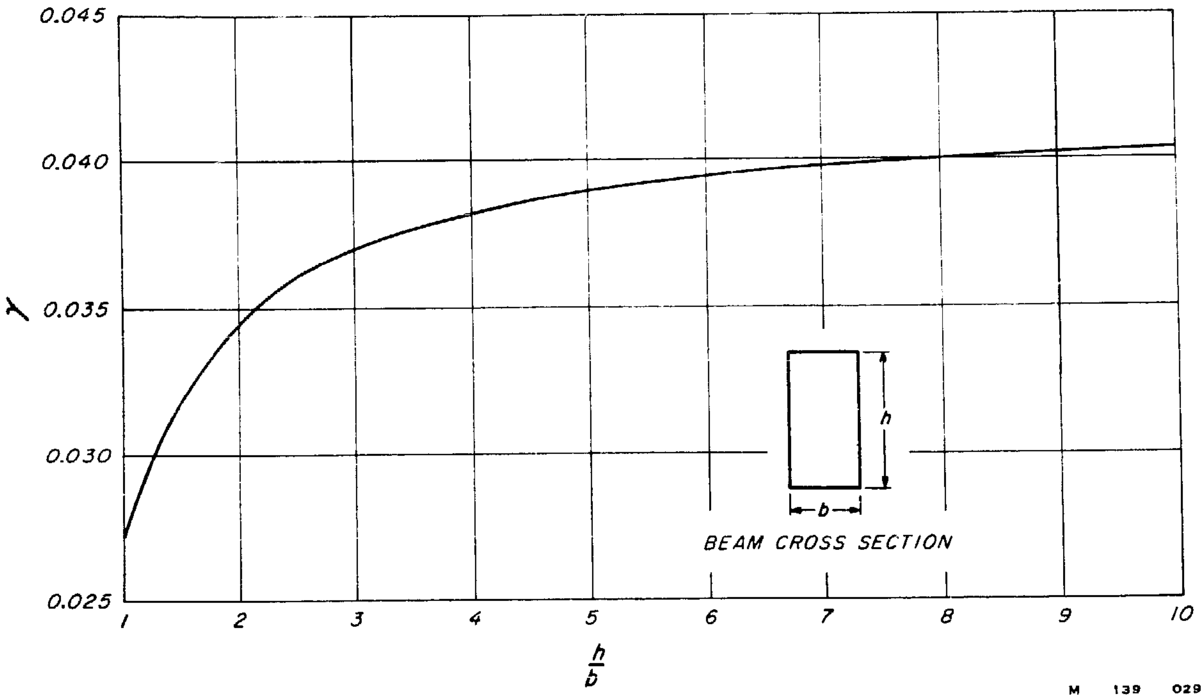

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Figure 8–4.—Constant γ for determining lateral buckling and twist of wood beams of rectangular cross section.

several loadings by Trayer and March and Zahn. The results are summarized in the following formula:

$$P_{cr} \text{ or } W_{cr} \text{ or } \frac{M_{cr}}{L} = \beta\gamma E_L \frac{(hb^3)}{L^2} \qquad (8\text{–}21)$$

where P_{cr} is total concentrated load; W_{cr} is total uniformly distributed load; M_{cr} is bending moment; E_L is beam modulus of elasticity; h is beam depth; b is beam width; L is beam span length; γ is beam torsion rigidity coefficient determined from the curve of figure 8–4 for a beam of rectangular cross section (assuming beam shear modulus is one-sixteenth of beam modulus of elasticity); and β is lateral buckling coefficient given in the following:

For a beam simply supported at the ends and under constant bending moment, $\beta = \pi$.

For a beam simply supported at the ends and under concentrated midspan load, $\beta = 16.9$.

For a beam simply supported at the ends and under uniformly distributed load, $\beta = 28.3$.

For a cantilever beam under concentrated end load, $\beta = 4$.

For a cantilever beam under uniformly distributed load, $\beta = 12.9$.

For beams laterally supported by sheathing, values of the coefficient β also depend on the parameter:

$$\frac{12CSL^2}{E_L hb^3} \qquad (8\text{–}22)$$

where S is beam spacing and C is effective inplane shearing rigidity of the sheathing and its connections to the beams. This rigidity is determined as the ratio of a shearing force per unit length of sheathing edge to angular shearing distortion of the sheathing-beam diaphragm. Curves giving values of β for several beam loadings are given in figure 8–5.

Twist

The twist of wood beams of rectangular cross section can be computed by the formula:

$$\theta = \frac{TL}{12\gamma^2 hb^3 E_L} \qquad (8\text{–}23)$$

where θ is angle of twist in radians; T is applied twisting torque; L is beam length; h is beam depth (larger cross section dimension); b is beam width (smaller cross section dimension); E_L is beam modulus of elasticity; and γ is a coefficient determined from figure 8–4. In computing values of γ it was assumed that the beam shear modulus was one-sixteenth of the beam modulus of elasticity.

COLUMNS

Columns should be designed so that stresses do not exceed allowable values and that buckling does not occur. This section contains formulas and graphs for determining buckling loads and stresses in wood columns of sawn timber, of glued or mechanically fastened laminations at right angles to the neutral plane having the smaller moment of inertia, or of glued laminations parallel to the neutral plane having the smaller moment of inertia. The property values for use in the formulas—modulus of elasticity and stresses for various wood species—are given in chapter 4. Values of coefficients of variation are included in chapter 4 to indicate the variability and reliability of the data as an aid in selecting allowable property values.

Concentrically Loaded Columns

A concentrically loaded column is stressed primarily in compression and, if this column is long, buckling can occur. The critical elas-

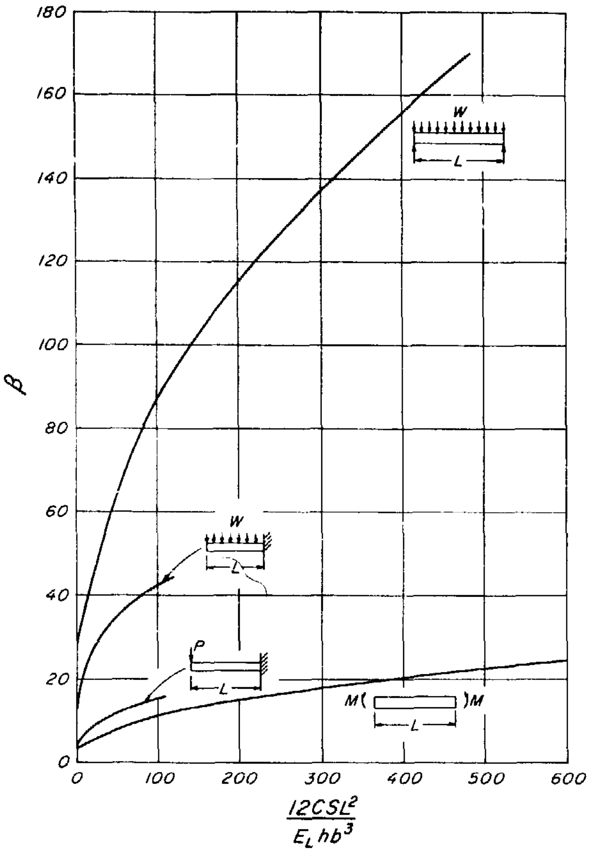

Figure 8–5.—Coefficients for determining lateral buckling loads of beams.

tic buckling stress is closely predictable by the Euler column formula for a hinge-ended column of uniform cross section throughout its length:

$$\left(f_{cr}\right)_A = \frac{\pi^2 E_L}{\left(\frac{L}{r}\right)^2} \qquad (8\text{–}24)$$

where E_L is the modulus of elasticity of the column, $\left(\frac{L}{r}\right)$ is the column slenderness ratio determined by the unsupported length L and the lesser radius of gyration (for a rectangular cross section with b as its smaller dimension $r = \frac{b}{2\sqrt{3}}$ and for a circular cross section $r = \frac{d}{4}$).

Short wood columns will not buckle elastically as predicted by formula (8–24) because they can be stressed beyond proportional limit values. Usually the short column range is explored empirically and appropriate formulas derived to extend for compressive strength values to the long column range. Material of this nature is presented in USDA Technical Bulletin 167. The final formula is a fourth-power parabolic function which can be written as:

$$\left(f_{cr}\right)_B = F_c \left\{1 - \frac{1}{3}\left[\frac{\left(\frac{L}{r}\right)}{\left(\frac{L}{r}\right)'}\right]^4\right\} \qquad (8\text{–}25)$$

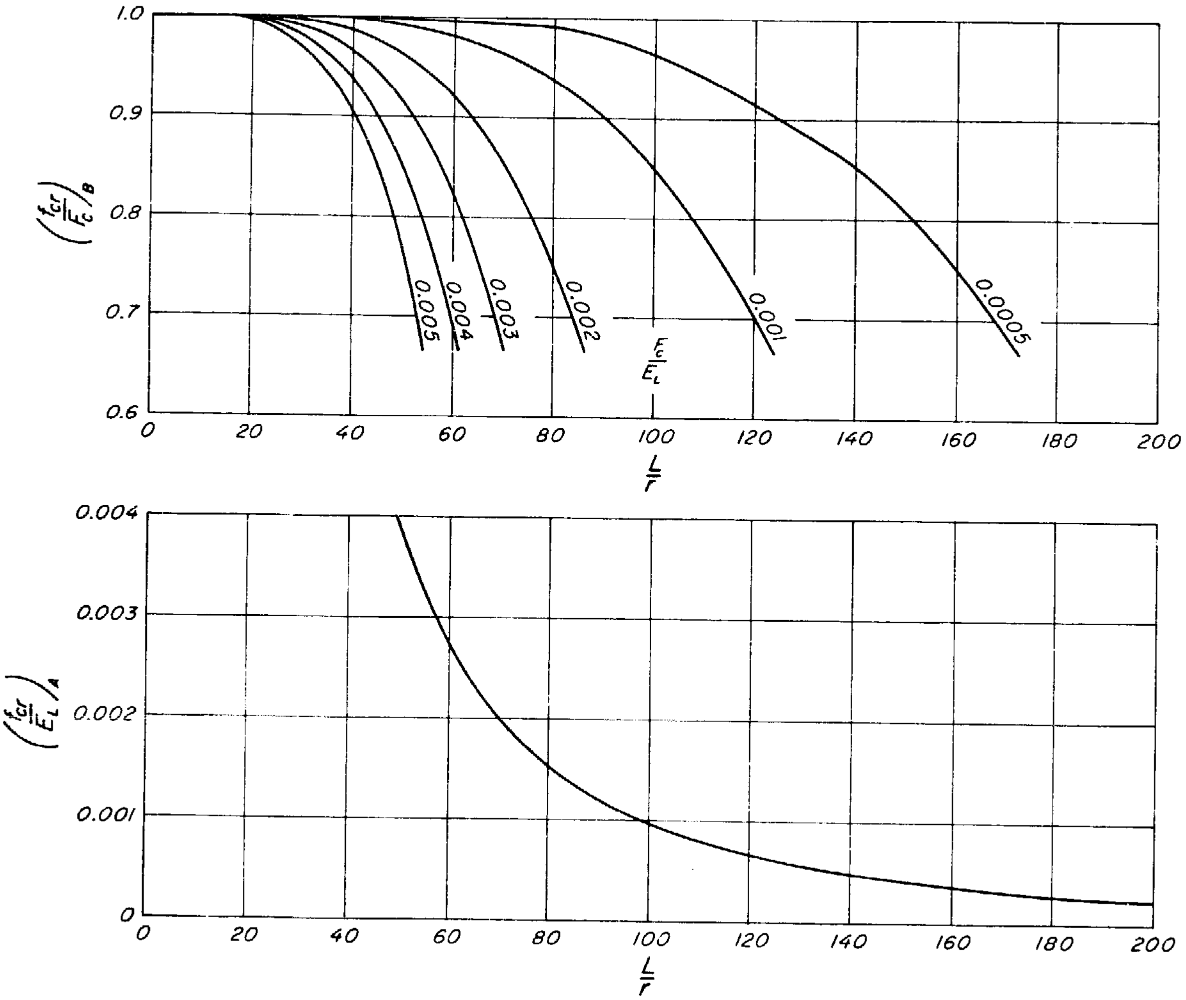

Figure 8–6.—Graphs for determining critical stresses of wood columns. Top, FPL fourth-power parabolic formula for short wood columns; bottom, hinged Euler column formula.

where F_c is compressive strength; $\left(\frac{L}{r}\right)$ is column slenderness ratio; and $\left(\frac{L}{r}\right)'$ is the slenderness ratio at which the Euler column buckling stress is two-thirds of F_c. A graphical presentation of formulas (8–24) and (8–25) is given in figure 8–6. These graphs may be used for any wood species by introducing the appropriate property values for modulus of elasticity and compressive stress. After entering the column slenderness ratio on the graphs of figure 8–6, the lesser values of f_{cr} as determined from the graphs is the critical stress. The curves in the top graph do not extend below $\left(\frac{f_{cr}}{F_c}\right)_B = 2/3$.

Example: Determine critical stresses for columns of a wood species for which $\frac{F_c}{E} = 0.002$.

For a column of slenderness ratio $\left(\frac{L}{r}\right) = 100$, the bottom graph gives a value of $\left(\frac{f_{cr}}{E}\right)_A = 0.001$ and the top graph has no solution at $\left(\frac{L}{r}\right) = 100$; therefore $f_{cr} = 0.001E$ for $\left(\frac{L}{r}\right) = 100$.

For a column of slenderness ratio $\frac{L}{r} = 60$, the bottom graph gives a value of $\left(\frac{f_{cr}}{E}\right)_A = 0.00276$ and top graph gives $\left(\frac{f_{cr}}{F_c}\right)_B = 0.92$ which, for $\frac{F_c}{E} = 0.002$, can be written as $\left(\frac{f_{cr}}{E}\right)_B = 0.00184$. Thus the lesser value of f_{cr} is given by the top graph as $f_{cr} = 0.00184E$.

Eccentrically Loaded Columns

An eccentrically loaded column is stressed in compression and bending. The eccentricity and end load determine the amount of bending stress induced and this must be added to the compressive stress caused by direct compression. The eccentrically loaded column does not buckle but continues to bend from the onset of loading. The maximum stress produced in a hinge-ended column is given by the formula:

$$f_{c\,\text{max.}} = \frac{P}{A}\left\{1 + \frac{ec}{r^2}\sec\left[\frac{P}{4EA}\left(\frac{L}{r}\right)^2\right]^{1/2}\right\} \qquad (8\text{–}26)$$

where P is end load; e is eccentricity (distance from neutral axis to point of application of load); c is distance from neutral axis to extreme fiber nearest the point of load application; r is radius of gyration of section about neutral axis; L is column length; A is area of cross section; and E is modulus of elasticity. For a column of circular cross section, $c = \frac{d}{2}$ and $r = \frac{d}{4}$ and for a rectangular cross section $c = \frac{b}{2}$ and $r = \frac{b}{2\sqrt{3}}$ or $c = \frac{h}{2}$ and $r = \frac{h}{2\sqrt{3}}$ for eccentricities about axes parallel to side h and b, respectively.

Stresses and deflections of columns with side loads are included in the previous section as beams with end loads.

Columns With Flanges

Columns with thin, outstanding flanges can fail by elastic instability of the outstanding flange, causing wrinkling of the flange and twisting of the column at stresses less than those for general column instability as given by formulas (8–24) and (8–25). For outstanding flanges of sections such as I, H, +, and L the flange instability stress can be estimated by the formula:

$$f_{cr} = 0.044E\,\frac{t^2}{b^2} \qquad (8\text{–}27)$$

where E is the column modulus of elasticity; t is the thickness of the outstanding flange; and b is the width of the outstanding flange. If the joints between the column members are glued and reinforced with glued fillets, the instability stress increases to as much as 1.6 times that given by formula (8–27).

Built-Up Columns

Build-up columns of nearly square cross section will not support as high loads if the lumber is nailed together as if it were glued together. The reason is that shear distortions can occur in the nailed joints. The shearing resistance of the column can be improved, so that previously presented formulas may be used, by nailing cover plates of lumber to the edges of the built-up layers. If the built-up column is of several spaced pieces, the spacer blocks should be placed close enough together, lengthwise in the column, so the unsupported portion of the spaced member will not buckle at the same or lower stress than that of the complete member. "Spaced columns" are designed with previously presented column formulas, considering each compression member as an unsupported simple column; the sum of column loads for all the members is taken as the column load for the spaced column. Sufficient net area should be provided in short columns so that compression failure does not occur. The net area is, of course, that area remaining after subtracting portions for connectors or bolts used to fasten the members together at the spacer blocks.

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Chapter 9

GLUING OF WOOD

GLUING OF WOOD

More and more gluing is done with wood in producing laminated wood and other built-up wood products, plywood, and sandwich materials. Modern adhesives, processes, and techniques vary as widely as the glued-wood products made with them, and many developments have been made in recent years. In general, however, the quality and serviceability of a glued-wood joint depends upon (1) kind of wood and its preparation for use, (2) kind and quality of the adhesive, (3) control exercised over the gluing process, (4) types of joints or construction, and (5) moisture-excluding effectiveness of the finish or protective treatment applied to the glued product. Besides these factors, conditions in use affect the performance of the joint.

GLUING PROPERTIES OF DIFFERENT WOODS

Table 9–1 broadly classifies the gluing properties of the woods most widely used for glued products. The classifications are based on the average quality of side-grain joints of lumber that is approximately average in density for the species, when glued with animal, casein, starch, urea-resin, and resorcinolresin adhesives at normal room temperatures.

A species is considered to be bonded satisfactorily when the strength of side-grain to side-grain joints is approximately equal to the strength of the wood. This criterion is considered reasonable for the conventional rigid wood adhesives. Whether it will be easy or difficult to obtain a satisfactory joint by this

Table 9–1.—*Classification of various hardwood and softwood species according to gluing properties*

Group 1	Group 2	Group 3	Group 4
(Glue very easily with glues of wide range in properties and under wide range of gluing conditions)	(Glue well with glues of fairly wide range in properties under a moderately wide range of gluing conditions)	(Glue satisfactorily with good quality glue, under well-controlled gluing conditions)	(Require very close control of glue and gluing conditions, or special treatment to obtain best results)
	HARDWOODS		
Aspen Chestnut, American Cottonwood Willow, black Yellow-poplar	Alder, red Basswood [1] Butternut [1] [2] Elm: American [2] Rock [1] [2] Hackberry Magnolia [1] [2] Mahogany [2] Sweetgum [1]	Ash, white [2] Cherry, black [1] [2] Dogwood [2] Maple, soft [1] [2] Oak: Red [2] White Pecan Sycamore [1] [2] Tupelo: Black [1] Water [1] [2] Walnut, black	Beech, American Birch, sweet and yellow [2] Hickory [2] Maple, hard Osage-orange Persimmon
	SOFTWOODS		
Baldcypress Fir: White Grand Noble Pacific silver California red Larch, western Redcedar, western [3] Redwood Spruce, Sitka	Douglas-fir Hemlock Western [2] Pine: Eastern white [3] Southern [1] Ponderosa Redcedar, eastern [2]	Alaska-cedar [2]	

[1] Species is more subject to starved joints, particularly with animal glue, than the classification would otherwise indicate.

[2] Bonds more easily with resin adhesives than with nonresins.

[3] Bonds more easily with nonresin adhesives than with resin.

criterion depends on the density of the wood, its structure, moisture content during gluing, the presence of extractives or infiltrated materials, and the kind and quality of the adhesive.

In general, heavy woods require adhesives of superior quality and better control of bonding conditions than lightweight woods; hardwoods—particularly the denser ones—are generally more difficult to glue than softwoods, and heartwood is usually more difficult to glue than sapwood. Several species vary considerably in their gluing characteristics with different glues (table 9–1).

As a general rule, the gluability of tropical species can be estimated by comparison with a domestic species of similar density. Species high in resinous or oily extractives can be glued satisfactorily by freshly machining the surfaces just before gluing and carefully controlling the conditions used for bonding.

ADHESIVES

For Bonding Wood

The term "glue" was first applied to bonding materials of natural origin, while "adhesive" has been used to describe those of synthetic composition. Today the terms are often used interchangeably, but adhesive better covers all types of materials.

Table 9–2 describes briefly the characteristics, preparation and application, and uses of the adhesives most commonly used for bonding wood. The choice of the proper adhesive for a job will depend mainly on (1) species and type of joint (particularly on the kind and amount of stress likely to be encountered in service), (2) working properties of the adhesive (as dictated by the conditions under which gluing must be done), (3) degree of permanence required in service, and (4) cost.

Animal glues were long used extensively in wood bonding. Casein glue and vegetable protein glues, of which soybean is the most widely used, gained commercial importance during World War I for gluing lumber and veneer into products that required moderate water resistance. Glues of natural origin continue to hold an important place in bonding wood. Blood proteins are used by themselves, or in combination with soybean protein, or with small amounts of phenol resins for making interior-type softwood plywood. Some ready-to-use liquid glues, based on either animal glue or fish glue, are still sold for use in home repair or small shop fabrication work. Casein glues, to be used after mixing with water, are also available for shop fabrication.

Synthetic resin adhesives were introduced before World War II, and now surpass most of the older glues in importance for wood bonding. Phenol-resin adhesives are widely used to produce softwood plywood for severe service conditions. Urea-resin adhesives are used extensively in producing hardwood plywood for furniture and interior paneling and for furniture assembly. Resorcinol and phenol-resorcinol resin adhesives are used mainly for gluing lumber into products that must withstand exposure to the weather. Polyvinyl-resin-emulsion adhesives are used in assembly joints of furniture. They are sometimes combined with urea resins to provide faster setting at normal shop temperatures. Thermosetting or modified polyvinyl-resin-emulsion adhesives are used for assembly of interior woodwork, doors, furniture, and nonstructural finger joints, bonding decorative wall paneling to framing in mobile homes, and are being considered for applying cellulosic overlays to lumber and plywood.

Melamine resins are used primarily to improve the durability of urea-resin adhesives. Synthetic resin adhesives available for shop use include a moisture-resistant type based on urea resins and a waterproof type based on resorcinol resins.

Use of epoxy adhesives for bonding wood products has evolved slowly because of the high cost of materials when epoxies were first developed. Their potential properties, especially for gap filling, have led to specialty applications. Thus the epoxies find uses such as filling voids and cracks in timbers and panels, and for bonding other materials to wood.

Contact adhesives are essentially emulsions or solutions of natural or synthetic rubbers that are applied to both mating surfaces, partially dried either at room temperature or under forced-air heating, and then assembled carefully (because the joined pieces cannot be realined after they have come in contact) and pressed momentarily. These are used mainly for on-the-job bonding of plastic laminates or metal sheets to wood bases, or for continuous

Table 9-2.—Characteristics, preparation, and uses of the adhesives most commonly used for bonding wood

Class [1]	Form	Properties	Preparation and application	Typical uses for wood bonding
Animal	Many grades sold in dry form; liquid glues available.	High dry strength; low resistance to moisture and damp conditions.	Dry form mixed with water, soaked, and melted; solution kept warm during application; liquid forms applied as received; both pressed at room temperatures; adjustments in gluing procedures must be made for even minor changes in temperature.	Furniture assembly, use is declining.
Blood protein [2]	Primarily, dry soluble whole blood. Commonly now handled and used like soybean glues.	Moderate resistance to water and damp atmospheres. Moderate resistance to intermediate temperatures and to micro-organisms.	Mixed with cold water, lime, caustic soda, and other chemicals; applied at room temperature; and pressed either at room temperature or in hot presses at 240° F. or higher.	Primarily for interior-type softwood plywood. Sometimes in combination with soybean protein.
Casein	Several brands sold in dry powder form; may also be prepared from raw materials by user.	Moderately high dry strength; moderate resistance to water, damp atmospheres, and intermediate temperatures; not suitable for exterior uses.	Mixed with water; applied and generally pressed at room temperature.	Laminated timbers for interior use.
Vegetable protein [3] (mainly soybean).	Protein sold in dry powder form (generally with small amounts of dry chemicals added) to be prepared for use by user.	Moderate to low dry strength; moderate to low resistance to water and damp atmospheres; moderate resistance to intermediate temperatures.	Mixed with cold water, lime, caustic soda, and other chemicals; applied and pressed at room temperatures, but more frequently hot-pressed.	Bonding softwood plywood for interior use.
Urea resin	Many brands sold as dry powders, others as liquids; may be blended with melamine or other resins.	High in both wet and dry strength; moderately durable under damp conditions; moderate to low resistance to temperatures in excess of 120° F.; white or tan.	Dry form mixed with water; hardeners, fillers, and extenders may be added by user to either dry or liquid form; applied at room temperatures, some formulas cure at room temperatures, others require hot pressing at about 250° F.	Hardwood plywood for interior use and furniture; interior particleboard; flush doors.
Melamine resin	Comparatively few	High in both wet and dry	Mixed with water and applied at	Primarily as fortifier

Phenol resin	Many brands available, some dry powders, others as liquids, and at least one as dry film. Most commonly sold as aqueous, alkaline dispersions.	High in both wet and dry strength; very resistant to moisture and damp conditions, more resistant than wood to high temperatures; dark red; often combined with neoprene, polyvinyl butyral, nitrile rubber, or epoxy resins for bonding metals.	Film form used as received; powder form mixed with solvent, often alcohol and water, at room temperature; with liquid forms, modifiers and fillers are added by users; most common types require hot pressing at about 260° to 300° F.[4]	Exterior softwood plywood and particleboard.
Resorcinol resin and phenol-resorcinol resins.	Several brands available in liquid form; hardener supplied separately; some brands are combinations of phenol and resorcinol resins.	High in both wet and dry strength; very resistant to moisture and damp conditions; more resistant than wood to high temperatures; dark red.	Mixed with hardener and applied at room temperatures; resorcinol glues cure at room temperatures on most species; phenol-resorcinols cure at temperatures from 70° F. to 150° F., depending on curing period and species.	Primarily for laminated timbers and assembly joints that must withstand severe service conditions.
Polyvinyl acetate resin emulsions.	Several brands are available, varying to some extent in properties; marketed in liquid form ready to use.	Generally high in dry strength; low resistance to moisture and elevated temperatures; joints tend to yield under continued stress; white.	Marketed as a liquid ready to use; applied and pressed at room temperatures.[5]	Furniture assembly, flush doors, bonding plastic laminates. Assembly of panel systems (mobile homes).
Rubber-base adhesives A. Contact adhesives.	Typically a neoprene rubber base in organic solvents or water emulsion. Other elastomer systems are also available.	Initial joint strength develops immediately upon pressing, increases slowly over a period of weeks; dry strengths generally lower than those of conventional woodworking glues; water resistance and resistance to severe conditions variable.	Used as received; both surfaces spread and partially dried before pressing. Commonly used in roller presses for instantaneous bonding.	For some nonstructural bonds, as on-the-job bonding of decorative tops to kitchen counters. Useful for low-strength metal and some plastic bonding.
B. Mastics (elastomeric construction adhesives).	Puttylike consistency. Synthetic or natural rubber base usually in organic solvents; others solvent-free.	Gap filling. Develop strength slowly over several weeks. Water resistance and resistance to severe conditions variable.	Used as received. Extruded by calking guns in beads and ribbons, with and without supplemental nailing.	Lumber and plywood to floor joist and wall studs; laminating gypsum board, styrene and urethane foams, and other materials; assembly of panel systems.
Thermoplastic synthetic resins.	Solid chunks, pellets, ribbons, rods, or films; solvent-free.	Rapid bonding; gap filling; lower strength than conventional wood adhesives; minimal penetration; moisture resistant.	Melted for spreading; bond formation by cooling and solidification; requires special equipment for controlling bonding conditions.	Edge banding of panels; plastic lamination; patching; films and paper overlays.

Table 9–2.—*Characteristics, preparation, and uses of the adhesives most commonly used for bonding wood*—(cont.)

Class [1]	Form	Properties	Preparation and application	Typical uses for wood bonding
Epoxy resins	Several different chemical polymers of the general type available or possible; usually in 2 parts, both liquid, most common use in combination with other resins for bonding of metal and materials other than wood.	Completely reactive; no solvent or other volatiles in the liquid adhesives or evolved in curing; good adhesion to metals, glass, certain plastics, and wood products, permanence in wood joints not adequately established; most common use in combination with other resins for bonding metals, plastics, and materials other than wood, can be formulated for curing at either room or elevated temperatures.	Marketed in 2 parts, resin and curing agent, both liquid; mixed at the point of use; applied at room temperatures; cured at room or elevated temperatures, depending on formulation. Potlife and cure conditions vary widely with composition.	For bonding metals, certain plastics, and some masonry materials to themselves and to wood. Bonding wood-to-wood specialty items.

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[1] Although starch (or vegetable) glues still are used in the United States, apparently little use is made of these glues in the wood industry. They have been replaced by urea-resin adhesives in gluing interior-type hardwood plywood and furniture.

[2] The older glues, referred to as "blood albumin glues" and dispersed in ammoniacal water solutions for use as hot-pressed plywood glues, are apparently no longer extensively used in the United States.

[3] Another principal type is a protein blend, primarily of blood and soybean proteins. These are mixed and used like the hot-press blood glues.

[4] Most types used in the United States are alkaline-catalyzed. The general statements refer to this type. Acid-catalyzed systems are also available, primarily for use at curing temperatures of 70° to 140° F., but are little used in the United States. Their principal limitation is the possible damage to wood by the acid catalyst.

[5] Modified vinyl-resin emulsions are available which involve addition of a curing agent at time of use, resulting in greatly improved resistance to heat and moisture.

bonding of such materials with a roller press. Their relatively low strength, and the creep and deformability of the glueline, make these contact adhesives suitable for nonstructural joints, but generally inadequate for highly stressed joints.

The elastomeric construction adhesives, extrudable from calking guns, are used in building construction to bond plywood to floor joists, a decorative wall paneling to studs, and in a variety of sealing and calking applications. They add strength, stiffness, and resiliency to the structure, and reduce the number of nails required. The adhesive fills the gaps between the members being joined. Construction adhesives are used in both factory and on-site building construction.

The thermoplastic synthetic resin adhesives, known as hot melts, are used for high-speed bonding in automatic production machines for edge-banding panels with lumber, veneer, plastic laminates, or film. Close control of melt temperature, amount spread, and time of assembly is essential, for bonding depends upon cooling and solidification of the melted adhesive after application and assembly of the joint. The adhesives are based upon various polymers such as polyolefins, vinyl acetate-olefin copolymers, polyamides, and polyurethanes.

Generally, the same adhesives that are suitable for wood-to-wood gluing may also be used for gluing wood-base materials, such as particleboard, hardboard, or fiberboard, to themselves or to wood. When such wood-base materials are produced in a hot press, as is much of the plywood, the heated surfaces are modified and adhesion is often impaired. This can usually be corrected by light sanding of such surfaces before bonding. Only a small amount of surface material need be removed.

For Bonding Wood to Metal

Adhesives capable of producing bonds of high strength and durability between wood and metal are comparatively new.

The contact-pressure adhesives mentioned previously may be used for moderate-strength joints between metal and wood, as in metal-faced plywood. Casein-latex adhesives are still used for this purpose, but to a lesser extent. When higher strength joints are required in structural applications, at least two types of adhesive systems are available—one-stage and two-stage. Neither type is yet highly developed for wood-to-metal bonding. They are essentially variations of systems originally developed for bonding metal to metal in aircraft.

Of the two types, one-stage systems are the most convenient. These involve applying a single adhesive to both metal and wood surfaces, force drying to remove solvent, and assembling and pressing the joint, usually at platen temperatures of 300° F. or higher. Typical adhesives used are combinations of phenol resins with thermoplastic resins or synthetic rubbers. More recently, adhesives curing at 200° to 250° F. have been offered. Some special epoxy formulations will cure and develop strength adequately at normal room temperatures, while others require hot-pressing at temperatures of 180° F. or more. A polyurethane adhesive system can be used to bond metal to wood in a one-stage process with room-temperature cure.

Two-stage systems are useful in bonding dissimilar materials where differences in material properties limit the bonding conditions or the adhesive formulations that may be used. For example, a two-stage system has advantages in bonding a metal-to-wood panel with metal on only one face. When this type of panel is bonded at high temperatures, the metal will contract far more than the wood as the panel cools; the result is an unbalanced panel. The two-stage system minimizes this effect. First, an adhesive primer, often an adhesive used for one-stage bonding, is applied to the metal surface. This primer is cured with heat and the primed material cooled to room temperature. Second, the primed metal surface is glued to the wood with a conventional room-temperature-setting wood glue, such as a resorcinol resin.

In bonding metal the surface must be specially prepared. Such surface preparation involves primarily the removal of rust and surface contamination to provide the necessary initial adhesion, but may also provide corrosion resistance or otherwise modify the surface so the resultant bond will be more durable in service. Instructions for cleaning metal surfaces are usually supplied by the adhesive manufacturer, and should be followed.

Because metal is impervious to moisture and solvent vapors, more care must be taken to remove volatile solvents from the adhesive layer before assembly and pressing of metal-to-wood joints than is necessary for wood-to-wood joints. Failure to remove solvents may result in excessive blisters or low-quality, frothy gluelines.

For Special Purposes

Various wood-base facing materials may be bonded to paper honeycomb and other types of cores for sandwich panels with conventional wood glues. Metal facings can usually be bonded to paper and other woodbase cores with some of the same adhesives described for metal-to-wood bonding.

A variety of plastic sheets and films may be bonded to wood or wood-base materials with specially selected adhesives. In some cases, such as with melamine- and phenol-resin-based paper laminates, conventional urea-resin, phenol-resin, polyvinyl-resin emulsion, or contact-setting adhesives may be used, depending upon the levels of strength and durability required. Other plastics, such as polyvinyl fluoride or polyvinyl chloride films, may require specially formulated adhesives to provide the necessary adhesion to the plastic surfaces, as well as to the wood.

PREPARATIONS FOR GLUING

Drying and Conditioning Wood for Gluing

The moisture content of wood at the time of gluing has much to do with the final strength of joints, the development of checks in the wood, and the dimensional stability of the glued members. Large changes in the moisture content of the wood after gluing cause shrinking or swelling stresses that may seriously weaken both the wood and the joints and cause warping, twisting, and other undesirable effects. It is generally impractical to glue green wood or wood at high moisture content, particularly the higher density hardwoods that have high coefficients of shrinkage due to changes in moisture content.

Essentially, the wood should be dry enough so that, even after some moisture is added in gluing, the moisture content is at about the level desired for service.

The choice of moisture content conditions for gluing according to this principle depends heavily on whether the gluing process involves heating, as in hot-pressing, or merely pressing at room temperature. In gluing 1-inch boards or thicker pieces at room temperature, the desired relationship can be attained by proper seasoning. In gluing veneer or other thin pieces pressed at room temperature, however, the moisture added by the glue frequently exceeds the moisture content of the wood in service. Under these conditions, the wood cannot be dried enough before gluing to achieve the desired moisture content and thus avoid redrying after gluing. The amount of moisture added to wood in room-temperature gluing varies from less than 1 percent in some lumber gluing to 45 percent or more in gluing plywood having thin veneers. Thickness of the wood, number of plies, density of the wood, glue mixture, quantity of glue spread, and gluing procedure (hot-pressing or cold-pressing) all affect the change in moisture content of the wood. In hot-pressing a significant proportion of water is volatilized, thus reducing the moisture content of the product when removed from the press.

In practice, adjustments cannot be made for all these widely varying factors, and it is seldom necessary to dry lumber to a moisture content below the 6 to 12 percent range. Lumber with a moisture content of 6 to 7 percent is generally satisfactory for cold-press gluing into furniture, interior millwork, and similar items. Lumber for outside use should generally contain 10 to 12 percent moisture before gluing. A moisture content of 3 to 5 percent in veneer at the time of gluing by hot pressing is satisfactory for thin plywood to be used in furniture, interior millwork, softwood plywood for construction and industrial uses, and similar products. For such uses as plywood for boxes, veneer at a moisture content of about 8 to 10 percent is acceptable for cold pressing.

Lumber that has been dried to the approximate average moisture content desired for gluing may still show moisture content differences between various boards and between the interior and the surfaces of individual pieces. Large differences in the moisture content of pieces that are glued together result eventually in considerable stress on glue joints and may result in delamination and warping of the product. Lumber that is to be glued should also be free from casehardening, warp, checks, and splits, to produce the highest quality bonded product.

Machining Lumber for Gluing

Wood surfaces that are to be glued should be smooth and true, free from machine marks, and have no chipped or loosened grain or other surface irregularities. Preferably, machining should be done just before gluing, so moisture changes cannot induce distortions in the surfaces before they are bonded. For uniform distribution of gluing pressure, each lamination or ply should be uniformly thick. A small variation in thickness in each lamination or ply may cause a considerable variation in the thickness of the assembly.

Surfaces made by saws are usually rougher than those made by planers, jointers, and other machines equipped with cutterheads. Some saws, however, produce a smoother cut than other types. Such saws save both labor and material by making it possible to glue sawed lumber for certain products. Joints approximately equal in strength to those between planed surfaces can be made between smoothly sawed surfaces. Joint quality in panels produced by edge gluing lumber direct from a straight-line ripsaw is considered quite satisfactory when properly controlled. Unless the saws are very well maintained, however, joints between sawed surfaces are generally weaker and less uniform in quality than those between well-planed or jointed surfaces.

Abrasive planing can also produce surfaces satisfactory for gluing when fine grit sizes are used, abrasive belts are kept clean and well maintained, and sander dust is thoroughly removed.

In the past, wood surfaces were intentionally roughened by some operators by tooth planing, scratching, or sanding with coarse sandpaper in the belief that rough surfaces were better for gluing. Tests of joints made using good gluing practices, however, generally show no benefit from roughening the surfaces.

Preparing Veneer for Gluing

Veneer is cut by rotary processes, slicing, or sawing. Sawed veneer is produced in long narrow strips, usually from flitches selected for figure and grain. The two sides of the sawn sheet are equally firm and strong, and either surface may be glued or exposed to view with the same results.

Sliced veneer is also cut in the form of long strips by moving a flitch or block against a heavy knife. Because the veneer is forced abruptly away from the flitch by the knife, it tends to have fine checks or breaks on the knife side. This checked surface is likely to show imperfections in finishing and therefore should be the glue side whenever possible. For matching face stock, where the checked side of part of the sheets must be the finish side, the veneer must be well cut. Fancy hardwood face veneers are generally sliced.

The rotary process produces continuous sheets of flat-grained veneer by revolving a log against a knife. When rotary-cut veneer is used for faces, the knife or checked side should be the glue side.

Because veneer usually is not resurfaced before it is glued, it must be carefully cut and dried. Well-cut veneer from any of the three processes will yield products with no appreciable difference in any property except appearance. Veneer selected to be glued should be (1) uniform in thickness, (2) smooth and flat, (3) free from large checks, decay, or other quality-reducing features, and (4) have grain suitable for the intended product. For plywood of the lower grades, however, some of these requirements may be modified.

Veneers are normally dried rapidly after cutting, using continuous high-temperature dryers, heated either with steam or with hot air from oil- or gas-fired burners. Drying temperatures are usually from 340° to 400° F. for limited periods of time. Prolonged use of high drying temperatures is known to change the characteristics of the wood surfaces and interfere with subsequent gluing.

PROPER GLUING CONDITIONS

To produce a strong joint in wood with liquid glue, the glue must wet the wood surfaces completely and give a film of uniform thickness, free of foreign matter. Because different wood species vary in their absorptivity, a given glue mixture may penetrate into one wood more than into another under the same gluing conditions. A moderate amount of such penetration is not objectionable, and may even be desirable, if the wood surfaces tend to be somewhat torn and damaged. Excessive penetration, however, wastes glue and may result in starved gluelines.

Making strong joints with glues applied as liquids depends primarily upon a proper correlation between gluing pressure and glue consistency during pressing. Consistency of the glue mixture, once it is spread on wood, may vary appreciably. It depends upon such factors as the kind of glue; glue-water proportion of the mixture; age of the mixed glue; quantity of glue spread; moisture content and species of the wood; temperature of the glue, room, and wood; time elapsed after spreading; and the extent to which the glue-coated surfaces are exposed to the air. Room-temperature-setting glues usually thicken and harden steadily after spreading until they are fully cured. Hot-press glues often thin out during the initial heating period and then thicken and harden as curing progresses.

With dense species that are difficult to glue satisfactorily, a viscous glue generally gives the best results, as viscosity influences penetration of glue into the cell structure of the wood. Because glues are generally formulated for a variety of species, longer assembly periods (time between spreading and pressing) are usually required with dense than with light woods to allow the glue to thicken more before pressure is applied. Dense woods may also require longer assembly periods because they are less absorptive than light woods. Optimum penetration of glue for a specific species can also be influenced by proper selection of adhesive and its formulation.

Pressure is used to squeeze the glue into a thin continuous film between the wood layers, to force air from the joint, to bring the wood surfaces into intimate contact with the glue, and to hold them in this position during the setting or curing of the glue. Conversion of liquid to a strong solid film is achieved by physical action, by drying out of solvent, or by chemical action. During chemical action the individual molecules in the glue film become larger and more completely joined together. Chemical action is accelerated by increases in glueline temperature. This may be accomplished by applying external heat through use of hot air or hot platens or by high-frequency dielectric heating.

Light pressure should be used with a thin (low viscosity) glue or one that becomes thin during curing, heavy pressure with a thick glue, and corresponding variations in pressure with glues of intermediate consistency. The strongest joints usually result when the consistency of the glue permits the use of moderately high pressures (100 to 250 p.s.i.) to bring mating surfaces into close contact. Small areas with flat well-planed surfaces can be bonded satisfactorily at much lower pressures.

Lumber joints should be kept under pressure at least until they have enough strength to withstand the interior stresses that tend to separate the wood pieces. In cold-pressing operations, under favorable gluing conditions, this stage will be reached in 1 to 7 hours; time depends upon temperature of the glue room and the wood, upon curing characteristics of the glue, and upon the thickness, density, and absorptive characteristics of the wood. A longer pressing period is advisable, as a precautionary measure, when operating conditions permit. Cold-pressed softwood plywood, however, is usually kept under pressure for only 15 minutes.

In hot-pressing operations the time required varies with temperature of platens, thickness and kind of material being pressed, and glue formulation. In actual practice the variation is from about 2 minutes to as much as 30 minutes. The time under pressure may be reduced to a few seconds by heating the glue joint with high-frequency electrical energy, because it is possible to raise the glueline temperature very rapidly. High-frequency gluing is often used when bonding lumber joints but not in the production of softwood plywood.

Adhesives are sometimes supplied as dry films, which eliminates mixing and spreading operations. Because they add no moisture to the glueline and do not "bleed" through veneers, film glues are particularly suitable for gluing thin, figured, fragile veneers. Bonding these veneers requires special conditions that vary somewhat with the glue and the product, particularly as far as the moisture content of the wood is concerned.

GLUING TREATED WOOD

The advent of durable adhesives that will outlast wood itself under severe conditions has made it possible to glue wood treated with wood preservatives and fire retardants. Perhaps the most important applications have been in laminated beams in which the lumber was treated with preservatives before gluing, and in gluing fire-retardant-treated veneers and lumber for fire doors. Experience has shown that many types of preservative-treated lumber can be glued successfully with phenol-resorcinol-, resorcinol-, and melamine-resin adhesives under properly controlled gluing conditions. Generally, the preservative-treated wood surfaces should be resurfaced just before gluing to reduce interferences by oily solvents or other exudation of preservative material. Fire-retardant-treated material should also be resurfaced just before bonding to reduce interference by treating chemicals on the wood surfaces. It is usually necessary to control the gluing conditions more carefully in gluing treated wood than untreated wood of the same species; it may also be desirable to use a somewhat higher curing temperature, or a longer curing period, with the treated wood.

TYPES OF GLUED JOINTS

Side-Grain Surfaces

With most species of wood, straight, plain joints between side-grain surfaces (fig. 9–1, *A*) can be made substantially as strong as the wood itself in shear parallel to the grain, tension across the grain, and cleavage. The tongued-and-grooved joint (fig. 9–1, *B*) and other shaped joints have the theoretical advantage of larger gluing surfaces than the straight joints, but in practice they do not give higher strength with most woods. The theoretical advantage is often lost, wholly or partly, because the shaped joints are difficult to machine to obtain a perfect fit of the parts. Because of poor contact, the effective bonding area and strength may actually be less on a shaped joint than on a flat surface. The principal advantage of the tongued-and-grooved and other shaped joints is that the parts can be more quickly alined in the clamps or press. A shallow tongue-and groove is usually as useful in this respect as a deeper cut and is less wasteful of wood.

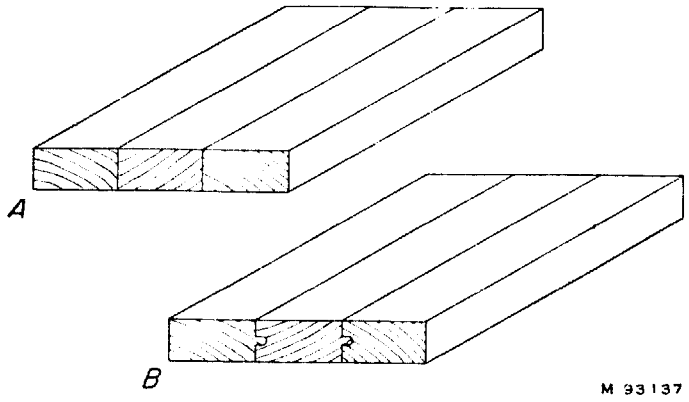

Figure 9–1.—Side-to-side-grain joints: *A*, plain; *B*, tongued-and-grooved.

End-Grain Surfaces

It is practically impossible with present water-based glues and techniques to make end-butt joints (fig. 9–2, *A*) sufficiently strong or permanent to meet the requirements of ordinary service. With the most careful gluing possible, not more than about 25 percent of the tensile strength of the wood parallel with the grain can be obtained in butt joints using conventional water-based adhesives. To approximate the tensile strength of various species, a scarf, finger, or other type of joint that approaches a side grain surface must be used. This side-grain area should be at least 10 times as large as the cross sectional area of the piece, because wood is approximately 10 times stronger in tension than in shear. In plywood scarfs and finger joints, a slope of 1 in 8 has been found adequate. For nonstructural, low-strength joints these requirements need not necessarily be met.

Finger joints may be cut with the profile showing either on the edge (horizontal joint)

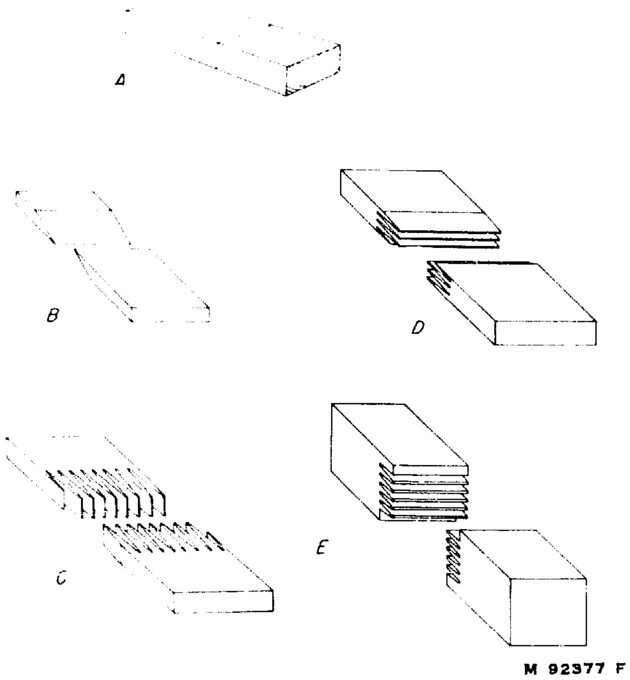

Figure 9–2.— End-to-end-grain joints: *A*, end butt; *B*, plain scarf; *C*, vertical structural finger joint; *D*, horizontal structural finger joint; *E*, nonstructural finger joint.

(fig. 9–2, *D*) or on the wide face (vertical joint) (fig. 9–2, *C*) of boards. There is greater leeway in design of a finger joint when a vertical joint is used, but a longer cutting head with more knives is needed. When the curing is done by high-frequency electrical energy, it can generally be done more rapidly with the vertical joint than with the horizontal joint.

The efficiencies of scarf joints of different slopes are discussed in chapter 10. Slopes 1:12 or flatter generally give the highest strength. This also holds true for finger joints, but in these the tip thickness also has to be as small as practical.

A well-manufactured glue joint (scarf, finger, or lap joint) exhibits fatigue behavior much like the wood that is joined. Curves showing stress versus cycles to failures are similar to those for unjointed wood when repeated stresses are expressed as a percent of static strength.

End-to-Side-Grain Surfaces

Plain end-to-side-grain glued joints (fig. 9–3, *A*) are difficult to design so they can carry an appreciable load. Also, joints in service face severe internal stresses in the members from unequal dimensional changes as moisture content changes; such stresses may be high enough to cause failure. It is therefore necessary to use joints of irregular shapes, dowels, tenons, rabbets, or other devices to reinforce a plain joint and bring side grain into contact with side grain or to secure larger gluing surfaces (fig. 9–3). All end-to-side-grain joints should be carefully protected from appreciable changes in moisture content in service.

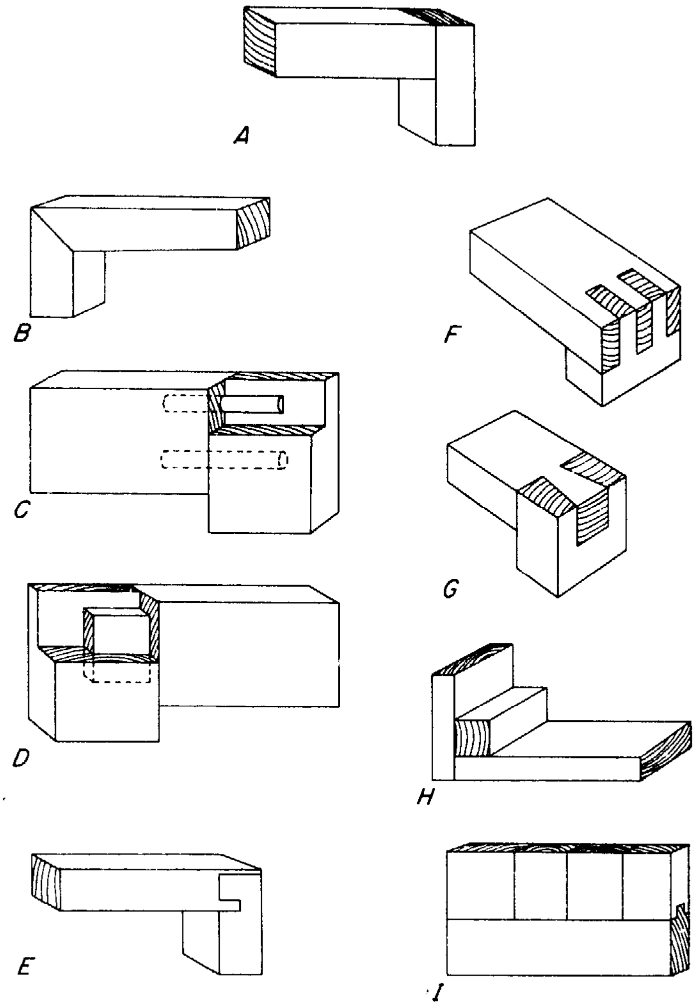

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Figure 9–3.—End-to-side-grain joints; *A*, plain, *B*, miter; *C*, dowels; *D*, mortise and tenon; *E*, dado tongue and rabbet; *F*, slip or lock corner; *G*, dovetail; *H*, blocked; *I*, tongued-and-grooved.

CONDITIONING GLUED JOINTS

When boards are glued edge to edge, the wood at the joint absorbs moisture from the glue and swells. If the glued assembly is surfaced before this excess moisture is dried out or distributed, more wood is removed along the swollen joints than elsewhere. Later, when the joints dry and shrink, permanent depressions are formed that may be very conspicuous in a finished product. This is particularly important when using glues that contain large amounts of water, such as casein.

As pieces of lumber are glued edge to edge or face to face, the moisture added by the glue need not be dried out but simply allowed to distribute itself uniformly throughout the wood. Approximately uniform distribution of such moisture can usually be obtained by conditioning the stock after gluing for 24 hours at 160° F., 4 days at 120° F., or at least 7 days at room temperature; in each case the relative humidity must be adjusted to prevent significant drying.

In plywood, veneered panels, and other constructions made by gluing together thin layers of wood, it is advisable to condition the panels to the average moisture content they are likely to encounter in service. In room-temperature gluing operations, it is frequently necessary to dry out at least a part of the moisture added in gluing. The drying is most advantageously done under controlled conditions and time schedules. Drying room-temperature-glued products to excessively low moisture content materially increases warping, opening of joints, and checking. Panels will often be very dry after hot-press operations. In such instances, it may be desirable to replace moisture by spraying the panels lightly with water and tightly stacking them to allow moisture to distribute uniformly. However, this is not common practice in softwood plywood plants.

DURABILITY OF GLUED PRODUCTS

The durability of glued joints in wood members depends upon the type of glue, gluing technique, service conditions, finish or surface coating, and design and construction of the joints. Moisture conditions are particularly important, not only because of the effect of moisture on the glue itself, but because changes in moisture content affect the internal stresses developed on the glue joint. These internal stresses, and consequently the behavior of the joints in service, also depend upon the design of the joint, the thickness of the plies or laminations, and the density and shrinkage characteristics of the species used.

Available evidence indicates that joints well designed and well made with any of the commonly used woodworking glues will retain their strength indefinitely if the moisture content of the wood does not exceed approximately 15 percent and the temperature remains within the range of human comfort.

Low temperatures seem to have no significant effect on strength of glued joints, but some glues have shown evidence of deterioration when exposed either intermittently or continuously to temperatures much above 100° F. for long periods. Joints that were well made with phenol resin, resorcinol resin, or phenol-resorcinol resin adhesives have proved more durable than the normal unglued wood when exposed to water, to warmth and dampness, to alternate wetting and drying, and to temperatures sufficiently high to char the wood. These glues are entirely adequate for use in products that are exposed indefinitely to the weather.

High-temperature-setting, uncatalyzed melamine-resin adhesives have shown excellent durability for two decades in Douglas-fir lumber joints. Tests have shown that joints made with urea-resin adhesives are highly resistant to water and to wetting and drying at room temperatures. Significant decreases in joint quality have been noted with some urea-resin adhesives exposed at 140° and 158° F. even when the relative humidity of the atmosphere is as low as 20 to 25 percent. Joints with casein and soybeam glue will withstand short exposure to dampness or water without permanent loss in strength, but if the moisture content of the wood continuously or repeatedly exceeds about 18 percent, they will lose strength and eventually fail. The rate of strength loss may vary, depending on species and construction as well as the glue formulation; strength loss is generally more rapid with denser species, and more rapid with soybean than with casein glues.

Joints made with polyvinyl-resin-emulsion adhesives have moderate resistance to dampness, but low resistance to water; the tendency of the joints to yield under stress generally increases as the temperature and moisture content increase. Joints made with animal glue are not suited to damp service conditions. No general pattern has yet been established for the durability characteristics of epoxy resin and contact-pressure adhesives in wood joints, partly because of the wide variety of formulations available. At present it appears that at least some epoxy resin joints might be durable enough to use on lower density species even under exterior conditions. Joints made with contact adhesives tend to creep when subjected to dimensional movement of the wood, but at present seem promising for nonstructural service conditions.

Treatments that can be used to increase the durability of glued products include: (1) Coatings that reduce the moisture content changes in the wood, and (2) impregnation of the wood with preservatives. Moisture-excluding coatings reduce the shrinking and swelling stresses that occur during varying exposure conditions; the coatings do not protect wood effectively, however, during prolonged exposure to damp conditions. By impregnating glued members with preservatives, particularly those that will also prevent rapid moisture changes, the deteriorating effects of prolonged exposure to outdoor or damp conditions can be greatly reduced. Preservatives can reduce the rate of moisture exchange with the atmosphere and protect against attack by micro-organisms.

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Chapter 10

GLUED STRUCTURAL MEMBERS

GLUED STRUCTURAL MEMBERS

Glued structural members are of two types—glued-laminated timbers and glued wood-plywood members of built-up cross sections. Both types offer certain advantages.

GLUED-LAMINATED TIMBERS

Glued-laminated timbers in this chapter (fig. 10–1) refer to two or more layers of wood glued together with the grain of all layers or laminations approximately parallel. The laminations may vary as to species, number, size, shape, and thickness. Laminated wood was first used in the United States for furniture parts, cores of veneered panels, and sporting goods, but is now widely used for structural timbers in building.

The first use of glued-laminated timbers was in Europe, where as early as 1893 laminated arches (probably glued with casein glue) were erected for an auditorium in Basel, Switzerland. Improvements in casein glue during World War I aroused further interest in the manufacture of glued-laminated structural members, at first for aircraft and later as framing members of buildings. In the United States one of the early examples of glued-laminated arches designed according to engineering principles is in a building erected in 1934 at the Forest Products Laboratory. This installation was followed by many others in gymnasiums, churches, halls, factories, hangars, and barns. The development of very durable synthetic-resin glues during World War II permitted the

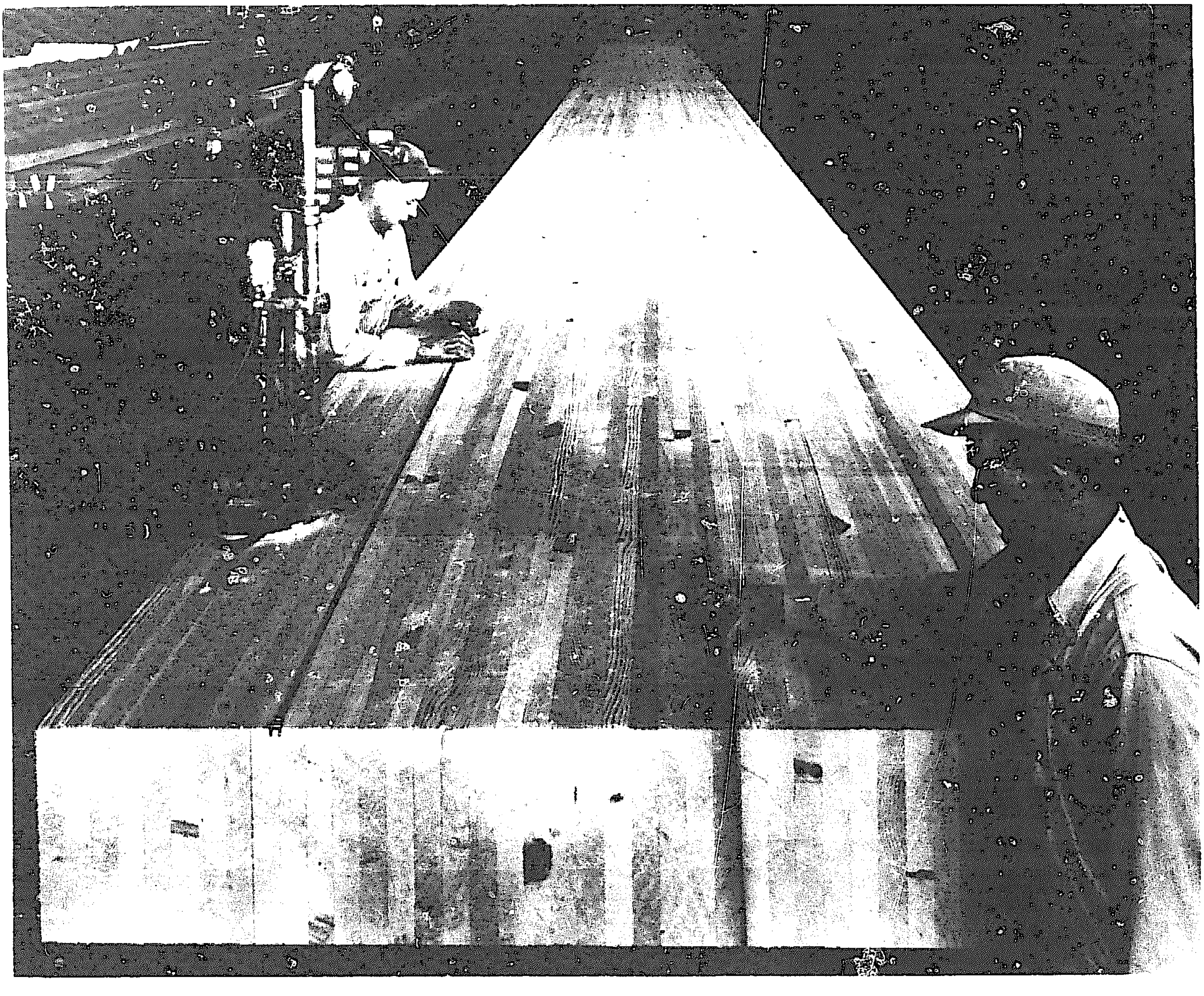
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Figure 10–1.—Heavy laminated timber, glued from 44 nominal 2-inch laminations.

use of glued-laminated members in bridges, trucks, and marine construction where a high degree of resistance to severe service conditions is required. With growing public acceptance of glued-laminated construction, laminating has increased steadily until it now forms an important segment of the woodworking industry.

Glued structural timbers may be straight or curved. Curved arches have been used to span more than 300 feet in structures. Straight members spanning up to 100 feet are not uncommon, and some span up to 130 feet. Sections deeper than 7 feet have been used. Straight beams can be designed and manufactured with horizontal laminations (lamination parallel to neutral plane) or vertical laminations (laminations perpendicular to neutral plane). The horizontally laminated timbers are the most widely used. Curved members are horizontally laminated to permit bending of laminations during gluing.

Advantages of Glued-Laminated Timbers

The advantages of glued-laminated wood construction are many and significant. They include the following:

1. Ease of manufacturing large structural elements from standard commercial sizes of lumber.
2. Achievement of excellent architectural effects and the possibility of individualistic decorative styling in interiors, as nearly unlimited curved shapes are possible.
3. Minimization of checking or other seasoning defects associated with large one-piece wood members, in that the laminations are thin enough to be readily seasoned before manufacture of members.
4. The opportunity of designing on the basis of the strength of seasoned wood, for dry service conditions, inasmuch as the individual laminations can be dried to provide members thoroughly seasoned throughout.
5. The opportunity to design structural elements that vary in cross section along their length in accordance with strength requirements.
6. The possible use of lower grade material for less highly stressed laminations, without adversely affecting the structural integrity of the member.
7. The manufacture of large laminated structural members from smaller pieces is increasingly adaptable to future timber economy, as more lumber comes in smaller sizes and in lower grades.

Certain factors involved in the production of laminated timbers are not encountered, however, in producing solid timbers:

1. Preparation of lumber for gluing and the gluing operation usually raise the cost of the final laminated product above that of solid sawn timbers in sizes that are reasonably available.
2. As the strength of a laminated product depends upon the quality of the glue joints, the laminating process requires special equipment, plant facilities, and manufacturing skills not needed to produce solid sawn timbers.
3. Because several extra manufacturing operations are involved in manufacturing laminated members, as compared with solid members, greater care must be exercised in each operation to insure a product of high quality.
4. Large curved members are awkward to handle and ship by the usual carriers.

Avoiding Internal Stresses

For best results in manufacturing glued-laminated timbers, it is important to avoid the development of appreciable internal stresses when the member is exposed to conditions that change its moisture content. Differences in shrinking and swelling are the fundamental causes of internal stresses. Therefore laminations should be of such character that they shrink or swell similar amounts in the same direction. If laminations are of the same species or of species with similar shrinkage characteristics, if they are all flat-grained or all edge-grained material, and if they are of the same moisture content, the assembly will be reasonably free from internal stresses and have little tendency to change shape or to check. Laminations that have an abnormal tendency to shrink longitudinally because they have excessive cross grain or compression wood should not be included.

While observance of these principles is desirable, practical considerations may prevent exact conformance. In softwood structural timbers for interior use, for example, segregation of flat-grained from edge-grained material is generally unnecessary, and a range in moisture content of no greater than 5 percent among the laminations in the same assembly may be permitted without significant effect on serviceability. The average moisture content, however, should be the same or slightly lower than that which the timber will attain in service. A slight increase in moisture content generally causes no harm but rapid drying could result in checking.

Preservative Treatment

If the laminated timber is to be used under conditions that raise its moisture content to more than 20 percent, either the heartwood of durable species should be used or the wood should be treated with approved preservative chemicals and only waterproof glues should be used. Experience has shown that some oil-borne preservatives, besides providing protection from fungi and insects, also retard moisture changes at the surface of the wood, and thus inhibit checking. If the size and shape of the timbers permit, laminated timbers can be treated with preservatives after gluing, but penetration perpendicular to the planes of the glue joints will be distinctly retarded at the first glueline.

Laminated timbers treated with preservatives after gluing and fabrication have given excellent service in bridges and similar installations. Laminations also can be treated and then glued if suitable precautions are observed. The treated laminations should be conditioned and must be resurfaced just before gluing. Not all preservative-treated wood can be glued with all glues, but, if suitable glues and treatments are selected and the gluing is carefully done, laminated timbers can be produced that are entirely serviceable under moist, warm conditions that favor decay.

Species for Laminating

Softwoods, principally Douglas-fir and southern pine, are most commonly used for laminated timbers. Other softwoods used include western hemlock, larch, and redwood. Boat timbers, on the other hand, are often made of white oak because it is moderately durable under wet conditions. Red oak, treated with preservative, has also been laminated for ship and boat use. Other species can also be used, of course, when their mechanical and physical properties are suited for the purpose.

Quality of Glue Joints

The quality of glue joints in laminated timbers intended for service under dry conditions is usually evaluated by the block shear test. Acceptance criteria are often based on unit shear strength and percentage of wood failure considered satisfactory for the species being used. For laminated members that must withstand severe service conditions, however, the block shear test alone does not provide an adequate evaluation. To serve satisfactorily under severe conditions, the glue joints should be capable of withstanding, without significant delamination, high internal stresses that develop as a result of rapid wetting and drying. Standards covering the design and manufacture of glued structural laminated wood are available (see Bibliography) and at least two military specifications cover structural glued-laminated items for specific uses.

Strength and Stiffness

The bending strength of horizontally laminated timbers depends on the position of various grades of laminations. High-grade laminations may be placed in the outer portions of the member, where their high strength may be effectively used, and lower grade laminations in the inner portion, where their low strength will not greatly affect the overall strength of the member. By selective placement of the laminations, the knots can be scattered and improved strength can be obtained. Even with random assembly of laminations, studies have indicated that knots are unlikely to occur one above another in several adjacent laminations. by a careful selection of quality tension laminations.

Aside from the beneficial effect of dispersing imperfections, available test data do not indicate that laminating improves strength properties over those of a comparable solid piece. That is, gluing together pieces of wood does not, of itself, improve strength properties, unless the laminations are so thin that the glue bonds significantly affect the strength of the member. In laminating material of lumber thicknesses, that would not occur.

Most of the criteria relating strength to characteristics of the wood were developed in the 1940's from data on a large number of relatively small beams—12 inches in depth. Very large beams are now being manufactured. Current research is reevaluating the criteria for deriving design stresses for glued-laminated timbers. Specific research relates to the tensile strength of structural lumber. Significant improvement in beam strength can be obtained by a careful selection of quality tension laminations.

Criteria in the following sections are given only as general guides to factors that affect the strength of glued-laminated construction. The most current specific information on the strength of glued-laminated construction should be obtained from the Forest Products Laboratory or from the American Institute of Timber Construction.

The principal determinants of strength are knots, cross grain, and end-joint efficiency. The effects of these three factors are not cumulative; that is, the lowest of the three controls the strength. Where other effects, such as those of curvature or beam depth, are applicable, they should be applied in addition to those for knots, cross grain, and end joints.

The deflection characteristics of glued-laminated timbers can be computed with formulas given in chapter 8.

Effect of Knots on Bending Strength and Stiffness

The effect of knots on the bending strength and stiffness of laminated timbers depends upon the number, size, and position, with respect to the neutral axis of the member, of the knots close to the critical section. Specifically, the bending properties depend upon the sum of the moments of inertia, about the gravity axis of the full cross section, of the areas occupied by all knots within 6 inches of either side of the critical section. This sum may be represented by the symbol I_K. The moment of inertia of the full cross section of the member is represented by I_G. The relations between bending strength and stiffness and the ratio I_K/I_G are shown in figures 10–2 and 10–3. Procedures for calculating the ratio I_K/I_G are given in USDA Technical Bulletin 1069.

The curves shown in figures 10–2 and 10–3 were empirically derived from tests of laminated timbers containing knots in various concentrations.

The I_K/I_G strength relationship yields reliable results for relatively small members; however, for large members modifications are recommended. For large members, the effect of knots in tension laminations is not adequately defined by the I_K/I_G concept. A selected grade of tension laminations must be used for the higher strength large glued-laminated timbers. The current recommended grades of tension lam-

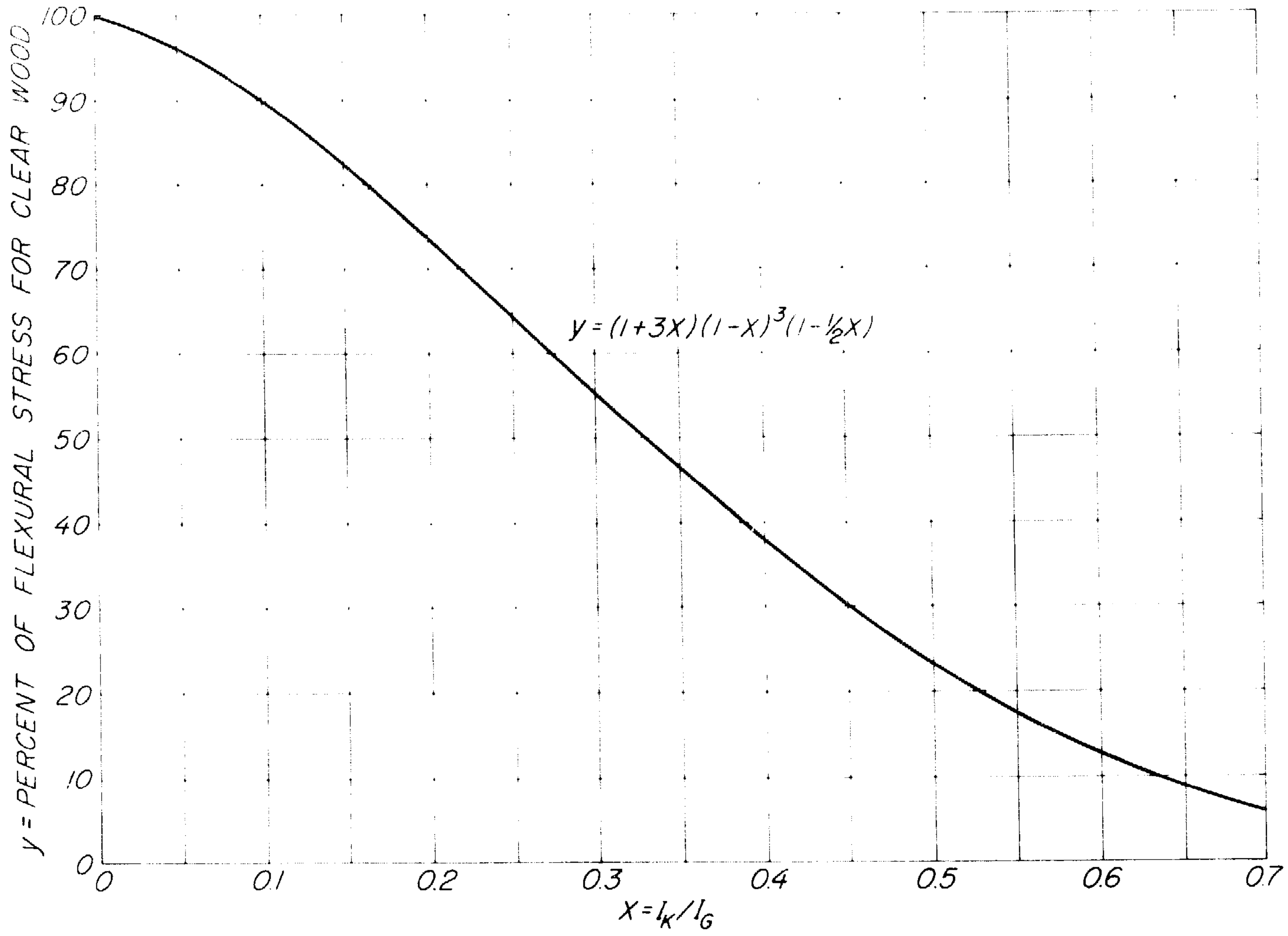

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Figure 10–2.—Curve relating allowable flexural stress to moment of inertia of areas occupied by knots in laminations of laminated timbers.

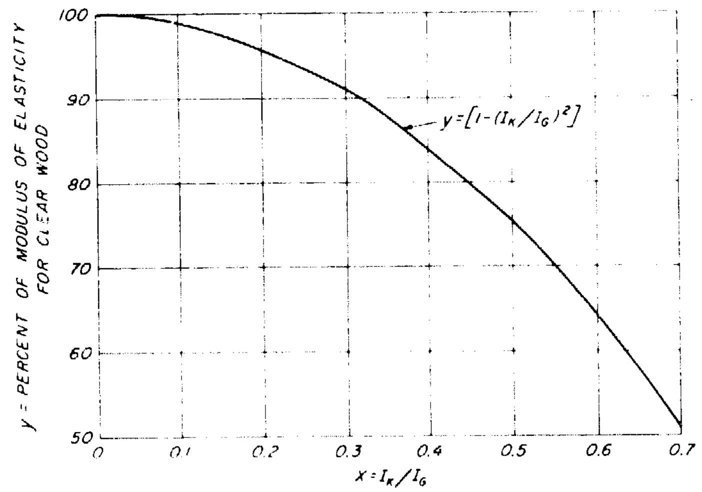

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Figure 10-3.—Curve relating allowable modulus of elasticity to moment of inertia of areas occupied by knots in laminations of laminated timbers.

inations should be obtained from the American Institute of Timber Construction.

Effect of Knots on Compressive Strength

The compressive strength of laminated timbers depends upon the proportion of the cross-sectional area of each lamination occupied by the largest knot in the lamination. Figure 10-4 shows an empirically derived relationship between compressive strength and *K/b*, where *b* is the lamination width and *K* is the average of the largest knot sizes in each of the laminations.

Effect of Knots on Tensile Strength

Test data relating knot size to tensile strength of glued-laminated timbers are not available. Figure 10-5, however, represents a relation between tensile strength and *K/b* derived from figure 10-4.

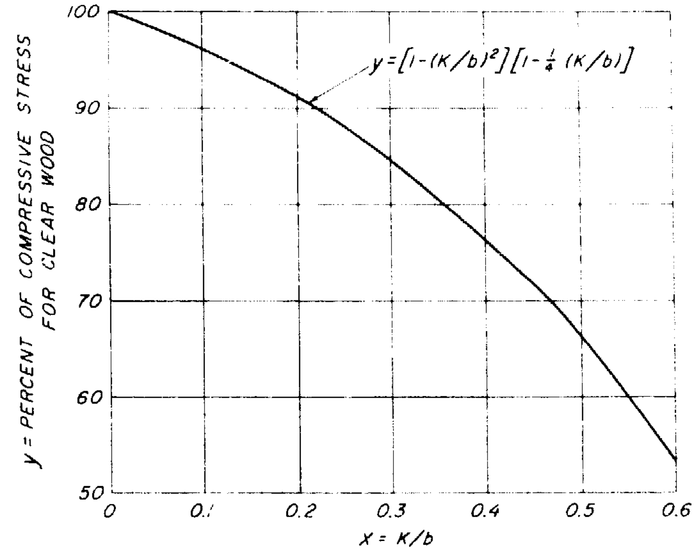

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Figure 10-4.—Design curve relating allowable compressive stress to size of knots in laminations of laminated short columns.

Effect of Cross Grain on Strength

The effect of cross grain on strength is given in table 4-10, chapter 4. For laminated timbers, it is possible to vary the cross-grain limitations at different points in the depth of the beam in accordance with the stress requirements. That is, steeper cross grain may be permitted in laminations in the interior of the timber than in the laminations at and near the outside. The permitted variation should be based on the assumption of linear variation of stress across the depth.

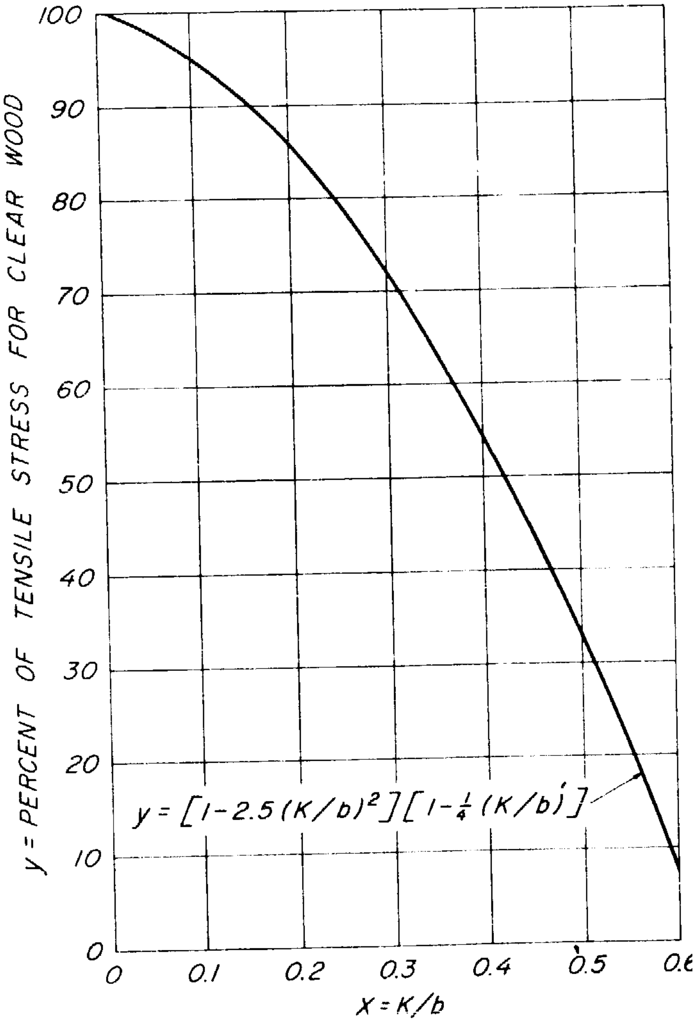

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Figure 10-5.—Curve relating allowable tensile stress to size of knots in laminations of tension members.

Effect of End Joints on Strength

For a large proportion of laminated timbers, because of their size, pieces of wood must be joined end-to-end to provide laminations of sufficient length. In most cases, the strength of timbers is reduced by the presence of end joints.

The highest strength values are obtained with well-made plain scarf joints (ch. 9); the lowest values are with butt joints. This is because scarf joints with flat slopes have essentially side grain surfaces that can be well bonded and develop high strength while butt joints are end grain surfaces that cannot be bonded effectively. Finger joints are a compromise between scarf and butt joints and strength varies with joint design.

Structural end joints

Both plain scarf joints and finger joints can be manufactured with adequate strength for structural glued-laminated timbers. The adequacy is determined by joint efficiency principles in USDA Technical Bulletin 1069 or by physical testing procedures in Voluntary Product Standard PS 56. The physical testing procedures are more commonly used.

The joint efficiency or joint factor is the joint strength as a percentage of the strength of clear straight-grain material. The joint factor of scarf joints in the tension portion of bending members or in tension members is:

Scarf slope	Joint factor *Percent*
1 in 12 or flatter	90
1 in 10	85
1 in 8	80
1 in 5	65

These factors apply to interior laminations as well as to the lamination on the tension face. In a beam of 40 equal laminations, for example, the outer lamination should be stressed no higher than 90 percent of the clear wood stress value if a scarf joint sloping 1 in 12 is used. The stress at the outer face of the second lamination is 95 percent of the outer fiber stress, so a scarf joint of about 1 in 10 would be satisfactory. Usually, however, laminators use the same joint throughout the members for ease in manufacture.

Working stresses need not be reduced if laminations containing scarf joints sloping 1 in 5 or flatter are used in the compression portion of bending members or in compression members.

No general statement can be made regarding the joint factor of finger joints because finger joint strengths vary depending upon the type and configuration of joint and the manufacturing process. High-strength finger joints can be made when the design is such that the fingers have relatively flat slopes and sharp tips. Tips are essentially a series of butt joints and therefore reduce the effective sloping area as well as being possible sources of stress concentration. As a result, the strength of even the best production finger joint developed to date has approached but not equaled the strength of a well-made plain scarf joint.

When the joint factor for a specific finger joint is adequately determined, allowable stresses may be calculated on the same basis as discussed for scarf joints.

The slope of scarf joints in compression members or in the compression portion of bending members should not be steeper than 1 in 5; a limitation of 1 in 10 is suggested for tension members and the tension portion of bending members. Because there is some question as to the durability of steep scarf joints for exterior use or other severe exposure, scarf joints with a slope steeper than 1 in 8 should not be used under such conditions.

Joints should be well scattered in portions of structural glued-laminated timbers highly stressed in tension. Where end joints in adjacent laminations are closely spaced, test results indicate that failure progresses more or less instantaneously from the joint in the outer lamination through the others. Adequate longitudinal separation of end joints in areas of high stress is, therefore, desirable.

No data are available by which to substantiate any proposed spacing requirements. Spacing requirements depend on joint quality and stress level. No spacing requirement should be necessary for well-made, high-strength joints or for joints stressed well below their strength.

Suggested spacings of end joints are given in Voluntary Product Standard PS 56.

Butt joints

Butt joints generally can transmit no tensile stress and can transmit compressive stress only after considerable deformation or if a metal bearing plate is tightly fitted between the abutting ends. In normal assembly operations, such fitting would not be done, and it is therefore necessary to assume that butt joints are ineffective in transmitting both tensile and compressive stresses. Because of this ineffectiveness, and because butt joints cause concentration of both shear stress and longitudinal stress, they are not recommended for use in horizontally laminated structural glued-laminated timbers.

Other types of end joints

In addition to scarf, finger, and butt joints, other types of end joints may be used in laminated members. In general, however, few data are available on their effect on strength. When data are not available for establishing spacing requirements, strength, and like factors for these joints, they may be treated as butt joints.

Effect of Edge Joints on Strength

It is sometimes necessary to join pieces edge-to-edge to provide laminations of sufficient width. For tension members, compression members, and horizontally laminated bending members, the strength of such joints is of little importance to the overall strength of the member. Therefore, from the standpoint of strength alone, it is unnecessary that edge joints be glued if they are not in the same location in adjacent laminations. Edge joints should be glued, however, where torsional loading is involved or where the load is applied parallel to the wide face of the lamination. Other considerations, such as the appearance of face laminations or the possibility that water will enter the unglued joints and promote decay, also may dictate that edge joints should be glued.

In vertically laminated beams (laminations at right angles to the neutral plane) sufficient laminations must be edge glued to provide adequate shear resistance in the beam. Not only is adequate initial strength required of such joints, but they must be durable enough to retain that strength under the conditions to which the beam is exposed in service.

Effect of Curvature on Bending Strength

Stress is induced when laminations are bent to curved forms, such as arches and curved rafters. While much of this stress is quickly relieved, some remains and tends to reduce the strength of a curved member. The ratio of the allowable design stress in curved members to that in straight members is

$$1.00 - \frac{2{,}000}{(R/t)^2} \qquad (10\text{–}1)$$

where t is the thickness of a lamination and R is the radius of the curve to which it is bent, both R and t being in the same units.

Effect of Lamination Thickness on Strength

Laminated timbers are typically made from nominal 1-inch and 2-inch lumber, and tests have indicated that this difference has no effect on the strength of straight timbers. Lamination thickness does, however, affect the strength of curved members, depending upon the radius to which the lamination is bent (see preceding section).

If thin laminations of moderate or low grade are used, somewhat stronger straight members may be obtained than from 1-inch or 2-inch laminations of the same grade. This increase perhaps is due to the greater interaction between thinner laminations, but data do not yet permit design recommendations.

Effect of Shake, Checks, and Splits on Shear Strength

In general, shake, checks, and splits have little effect on the shear strength of laminated timbers. Shake generally occurs infrequently but should be excluded from material for laminations. Most laminated timbers are made from laminations that are thin enough to season readily without developing checks and splits.

Effect of Size on Bending Strength

The bending strength of wood beams has been shown to decrease as the size of beams increases. Laminated members can be of considerable size and the effect of size on strength should be considered in design. Design information is given in chapter 8.

Vertically Laminated Timbers

Data on vertically laminated timbers are limited because, until recently, there was relatively little commercial interest in their use. Evaluations were made of timbers laminated from dimension lumber of high strength ratios. The results indicated that the effect of knots may be taken into account by determining the strength ratio of each lamination (by the method described in the section on stress grades) and averaging these ratios to determine the strength ratio for the timber. Common practice is to increase the average stress 15 percent to account for the interaction of three or more members glued together. The effects of cross grain on strength and limitations on end joints are as described in preceding paragraphs.

Design of Glued-Laminated Timbers

Engineering formulas such as those given in chapter 8 for solid wood structures are applicable also to structures of laminated wood. The fact that laminated timbers can be made in curved form, however, introduces some circumstances not ordinarily met in the design of wood structures.

The application of ordinary engineering formulas to deep, sharply curved bending members may introduce appreciable error in the calculated stresses. For such cases, the methods applicable to curved timbers, as described in standard text books on mechanics, should be used.

When bending moments are applied to curved timbers, stresses are set up in a direction parallel to the radius of curvature (perpendicular to grain). Stresses so induced should be appropriately limited.

Procedures for establishing design stresses and factors affecting the design of glued-laminated structural members are discussed in detail by USDA Technical Bulletin 1069.

Voluntary Product Standard PS 56 for structural glued-laminated timber is widely used throughout the United States. It involves industry specifications that have been developed for several species and which recommend working stresses for members laminated from these species.

Many design details have been devised and presented by the American Institute of Timber Construction.

Allowable Unit Stresses For Clear Wood

Allowable unit stresses for clear wood for use in determining working stresses for the design of glued-laminated timbers are developed by principles given in ASTM standards and in other sections of this handbook. The average clear wood strength properties and variability of properties are given in ASTM Designation D 2555. These properties form the basis for allowable unit stresses for clear wood by considering appropriate adjustments for variability, duration of load, size, moisture content, density and rate of growth, and factor of safety. Discussions of these factors are given in ASTM Designation D 2555 and D 245 and in chapter 6 of this volume.

Bending Members

In designing bending members, a number of factors are involved in choosing an appropriate working stress—the effects of knots, cross grain, end joints, height or depth of the beam, and curvature of the laminations.

The basic allowable unit stress for clear wood is multiplied by the lowest of the first three factors to obtain a working stress for straight timbers up to 12 inches deep. If the depth is over 12 inches, this calculated stress is reduced further by the effect of size as given in chapter 8. For curved members, the reduced value is multiplied by the curvature factor.

Moment of inertia

The full cross section of the beam may be considered effective in design if there are no end joints or if end joints have been qualified by procedures given in PS–56. If butt joints are present, the moment of inertia should be reduced as described for them.

Deflections

Experience with figure 10–3 and statistically derived values of I_K/I_G indicates that, for timbers with relatively high grade laminations, the reduction of modulus of elasticity below the basic value will be less than 5 percent. However, there is a reduction in modulus of elasticity for lower grades of laminations (ASTM D 245). With known modulus of elasticity properties of each lamination, the modulus of elasticity of a completed glued-laminated beam can be calculated with transformed-section criteria.

The deflection calculated with modulus of elasticity values derived by any of the above methods will be only immediate values. Where defection is critical, consideration must be given to the added defection that occurs under long-time loading and that due to shear (see ch. 6 and 8).

Radial stresses

When curved members are subjected to bending moments, stresses are set up in a direction parallel to the radius of curvature (perpendicular to grain). If the moment increases the radius (makes the member straighter), the stress is tension; if it decreases the radius (makes the member more sharply curved), the stress is compression. For members of constant depth, the stress is a maximum at the neutral axis and is approximately

$$S_R = \frac{3}{2}\frac{M}{Rbh} \qquad (10\text{–}2)$$

where M is the bending moment, R is the radius of curvature of the centerline, and b and h are, respectively, the width and height of the cross section.

Values of S_R should be limited to those recommended by accepted industry standards.

Deep, Curved Members

It is known from the principles of mechanics that the stresses in sharply curved members subjected to bending are in error when computed by the ordinary formulas for straight timbers. The amount of the error depends upon the relation of the depth of the member to the centerline radius. Limitations on the sharpness to which laminations can be bent will limit the curvature of deep beams or arches. The analytical methods applicable to curved beams should be used, however, to determine whether or not the usual engineering formulas may be applied without significant error to deep, sharply curved members of glued-laminated wood.

Axially Stressed Members

Three factors must be considered in choosing working stresses for axially stressed members—the effects of knots, cross grain, and end joints. The factor giving the lowest strength ratio is the one that determines the working stress; the three factors are not to be combined.

Effective cross-sectional area

The full cross section may be considered effective in design if there are no end joints of if end joints are scarf joints of 1 in 5 slope or flatter. For finger joints that have been qualified by procedures given in PS-56 or with a tensile joint ratio of 50 percent or greater, it is probable that the full cross section could likewise be considered fully effective. If butt joints are present, the cross-sectional area should be reduced as was described for these joints.

Columns of different classes

The formulas for determining the load-carrying capacities of wood columns as given in chapter 8 should be used for laminated columns. For all classes of columns, the effect of joints should be considered in arriving at the proper value of the effective area.

Fastenings

Design loads or stresses for fastenings that are applicable to solid wood members (ch. 7) are also applicable to laminated timbers. Since greater depths are practical with laminated timbers than with solid timbers, however, design of fastenings for deep laminated timbers requires special consideration. It is desirable to have the moisture content of the timber as near as possible to that which it will attain in service. If moisture content is hihger than the equilibrium moisture content in service, considerable shrinkage may occur between widely separated bolts; if the bolts are held in position by metal shoes or angles, large splitting forces may be set up. Slotting of the bolt holes in the metal fitting will tend to relieve the splotting stresses. Cross bolts will assist in preventing separation if splitting does occur; they will not, however, prevent splits.

WOOD-PLYWOOD GLUED STRUCTURAL MEMBERS

Highly efficient structural components or members can be produced by combining wood and plywood through gluing. The plywood is utilized quite fully in load-carrying capacity while also filling large opening spaces. These components, including box beams, I-beams, "stressed-skin" panels, and folded plate roofs, are discussed in detail and completed designs are also available in the many technical publications of the American Plywood Association. Details on structural design will be given in the following portion of this chapter for beams with plywood webs and for stressed-skin panels wherein the parts are glued together with a rigid, durable adhesive.

These highly efficient designs, while adequate structurally, may suffer from lack of resistance to fire and decay unless treatment or protection is provided. The rather thin portions of plywood, as compared with heavy, solid cross sections, are quite vulnerable to fire.

Beams With Plywood Webs

Box beams and I-beams with lumber or laminated flanges and glued plywood webs can be designed to provide desired stiffness, bending moment resistance, and shear resistance. The flanges resist bending moment, and the webs provide primary shear resistance. Either type of beam must not buckle laterally under design loads; thus, if lateral stability is a problem, the box beam design should be chosen because it is stiffer in lateral bending and in torsion than the I-beam. On the other hand, the I-beam should be chosen if buckling of the plywood web is of concern because its single web, double the thickness of that of a box beam, will offer greater buckling resistance.

Details of design are given for beams shown in cross section in figure 10–6. These beams have both flanges of the same thickness because a construction symmetrical about the neutral plane provides the greatest moment of inertia for the amount of material employed. The formulas given were derived by basic principles of engineering mechanics which can be extended to derive designs for unsymmetrical constructions if necessary.

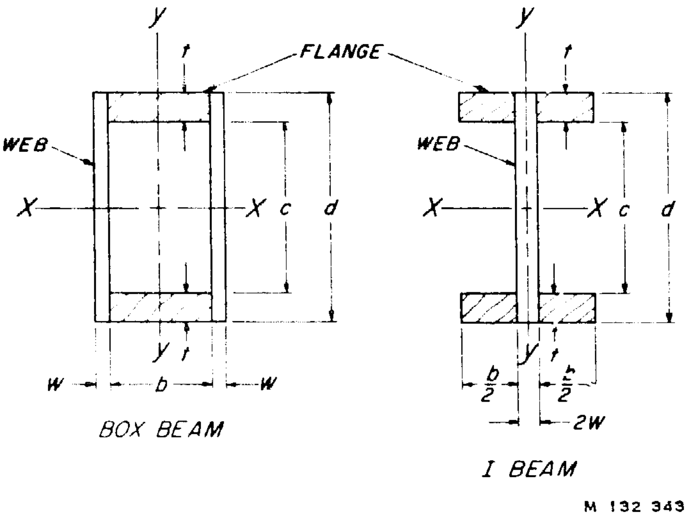

Figure 10–6.—Beams with plywood webs.

Beam Deflections

Beam deflections can be computed with formula (8–1) (ch. 8). The bending stiffness $(EI)_X$ and shear stiffness (GA') are given by the following formula for the box and I-beam shown in figure 10–6.

$$(EI)_x = \frac{1}{12}\left[E(d^3 - c^3)b + 2E_w W d^3\right] \qquad (10\text{–}3)$$

where E is flange modulus of elasticity and E_w is web modulus of elasticity. Values of E_w for the appropriate plywood construction and grain direction can be computed from formulas (11–2), (11–3), and (11–4) for edgewise compression modulus of elasticity of plywood (ch. 11).

Dimensions are as noted by symbols of figure 10–6.

$$(GA') = 2WcG \text{ (approx.)} \qquad (10\text{–}4)$$

where G is plywood shear modulus for appropriate grain direction (see ch. 11). An improvement in shear stiffness can be made if the grain direction of the plywood webs is placed at 45° to the beam neutral plane rather than at 0° or 90° to the neutral plane. Data in chapter 11 on shear modulus given by formulas (11–9) to (11–12) should be used.

Flange Compression and Tension Stresses

Flange compression and tension stresses at outer beam fibers are given by the formula

$$f_x = \frac{6M}{(d^3 - c^3)\dfrac{b}{d} + \dfrac{2E_w W d^2}{E}} \qquad (10\text{–}5)$$

where M is bending moment and other symbols are as defined previously in this chapter.

Web Shear Stress

Web shear stress at the beam neutral plane is given by the formula

$$f_{xy} = \frac{3V}{4W}\left[\frac{E(d^2 - c^2)b + 2E_w W d^2}{E(d^3 - c^3)b + 2E_w W d^3}\right] \qquad (10\text{–}6)$$

where V is shear load and other symbols are as defined previously in this chapter. The shear stress must not exceed values given by formulas in chapter 11 for plywood shear strength or the critical shear buckling stress, F_{scr}, given by formula (11–18) of chapter 11. To avoid web buckling, the web should be increased in thickness or the clear length of web should be broken by stiffeners glued to the webs.

Web edgewise bending stresses at the inside of the flanges can be computed by the formula

$$f_{xw} = \frac{6M}{\dfrac{E}{E_w}(d^3 - c^3)\dfrac{b}{c} + 2\dfrac{d^3}{c}W} \qquad (10\text{–}7)$$

where the symbols are as previously defined in the chapter. It may be possible, but not very likely, for the web to buckle due to bending stresses. Thus the stresses given by formula (10–7) should not exceed those given by F_{bcr} of chapter 11, formula (11–19). Should buckling due to edgewise bending appear possible, the interaction of shear and edgewise bending buckling can be checked approximately by means of an interaction formula such as

$$\left(\frac{f_{xy}}{F_{scr}}\right)^2 + \left(\frac{f_{xw}}{F_{bcr}}\right)^2 = 1 \qquad (10\text{–}8)$$

Web-to-flange glue shear stresses, f_{gl}, can be computed by the approximate formula

$$f_{gl} = \frac{3V}{2}\left[\frac{Eb(d + c)}{E(d^3 - c^3)b + 2E_w W d^3}\right] \qquad (10\text{–}9)$$

where the symbols are as previously defined in this chapter. The stresses computed by formula (10–9) should be less than those given for glued joints. They should also be less than the rolling shear stresses for solid wood, because the thin plies of the plywood web allow the glue shear stresses to be transmitted to adjacent plies and could cause rolling shear failure in the wood.

Possible Lateral Buckling

Possible lateral buckling of the entire beam should be checked. The lateral buckling load is given by the formula

$$P_{cr} \text{ or } W_{cr} \text{ or } M_{cr}/L = \frac{\beta}{L^2}\sqrt{(EI)_y\,(JG)} \qquad (10\text{–}10)$$

where P_{cr} is total concentrated load, W_{cr} is total uniformly distributed load; M_{cr} is bending moment; L is beam span length; β is a lateral buckling coefficient given in figure 8–5 (ch. 8) for various loadings; $(EI)_y$ is lateral stiffness of beam; and (JG) is beam torsional rigidity. Formulas for $(EI)_y$ and (JG) are as follows:

For box beams:

$$(EI)_y = \frac{1}{12}\left\{ E(d-c)b^3 + E_w \left[(b+2W)^3 - b^3 \right] d \right\} \qquad (10\text{–}11)$$

$$(JG) = \left[\frac{(d+c)\,(d^2-c^2)\,(b+W)^2 W}{(d^2-c^2) + 4(b+W)W} \right] G \qquad (10\text{–}12)$$

For I-beams:

$$(EI)_y = \frac{1}{12}\left\{ E\left[(b+2W)^3 - (2W)^3 \right](d-c) + E_{fw}(2W)^3 d \right\} \qquad (10\text{–}13)$$

where E_{fw} is flexural elastic modulus of the plywood web as computed by formulas (11–20) or (11–21) of chapter 11.

$$(JG) = \frac{1}{3}\left[\frac{1}{4}(d-c)^3 b + d(2W)^3 \right] G \qquad (10\text{–}14)$$

In formulas (10–12) and (10–14) the shear modulus G can be assumed without great error to be about one-sixteenth of the flange modulus of elasticity, E_L. The resultant torsional stiffness *(JG)* will be slightly low if beam webs have plywood grain at 45° to the neutral axis. The lateral buckling of I-beams will also be slightly conservative because bending rigidity of the flange has been neglected in writing the formulas given here. If buckling of the I-beam seems possible at design loads, the more accurate analysis of Forest Products Laboratory Report R1687 should be used before redesigning.

Stiffeners and Load Blocks

A determination of the number and sizes of stiffeners and load blocks needed in a particular construction does not lend itself to a rational procedure, but certain general rules can be given that will help the designer of a wood-plywood structure obtain a satisfactory structural member.

Stiffeners serve a dual purpose in a structural member of this type. One function is to limit the size of the unsupported panel in the plywood web, and the other is to restrain the flanges from moving toward each other as the beam is stressed.

Stiffeners should be glued to the webs and should be in contact with both flanges. No rational way of determining how thick the stiffener in contact with the web should be is available, but it appears, from tests of box beams made at the Forest Products Laboratory, that a thickness of at least six times the thickness of the plywood web is sufficient. Because stiffeners must also resist the tendency of the flanges to move toward each other, the stiffeners should be as wide as (extend to the edge of) the flanges.

The spacing of the stiffeners is relatively unimportant for the shear stresses that are allowed in plywood webs in which the grain of the wood in some plies is parallel and the grain of the wood in other plies is perpendicular to the axis of the member. Maximum allowable stresses are below those which will produce buckling. Stiffeners placed with a clear distance between stiffeners equal to or less than two times the clear distance between flanges are adequate.

Load blocks are special stiffeners placed along a wood-plywood structural member at points of concentrated load. Load blocks should be designed so that stresses caused by a load that bears against the side-grain material in the flanges do not exceed the design allowables for the flange material in compression perpendicular to grain.

Stressed-Skin Panels

Constructions consisting of plywood "skins" glued to wood stringers are often called stressed-skin panels. These panels offer efficient structural constructions for building floor, wall, and roof components. They can be designed to provide desired stiffness, bending moment resistance, and shear resistance. The plywood skins resist bending moment, and the wood stringers provide shear resistance.

Details of design are given for a panel cross section shown in figure 10–7. The formulas given were derived by basic principles of engineering mechanics.

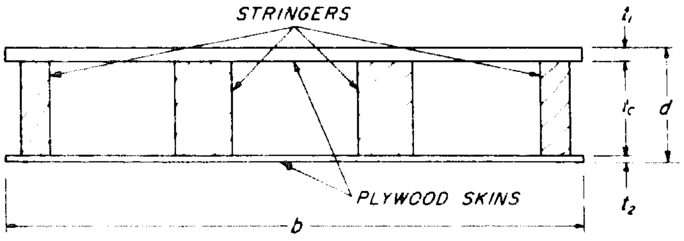

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Figure 10–7.—Stressed-skin panel cross section.

Panel deflections can be computed with formula (8–1) chapter 8. The bending stiffness (EI) and shear stiffness (GA') are given by the following formulas for the stressed-skin panel shown in figure 10–7.

$$(EI) = \frac{b}{\left((E_1t_1 + E_2t_2 + Et_c\frac{s}{b}\right)}\left\{E_1t_1E_2t_2[(t_1 + t_c) + (t_2 + t_c)]^2 + E_1t_1Et_c\frac{s}{b}(t_1 + t_c)^2 + E_2t_2Et_c\frac{s}{b}(t_2 + t_c)^2\right\}$$

$$+ \frac{b}{12}\left[E_{f1}t_1^3 + E_{f2}t_2^3 + Et_c^3\frac{s}{b}\right] \qquad (10\text{–}15)$$

where E_1 and E_2 are modulus of elasticity values for skins 1 and 2 (compression values for plywood—see ch. 11); E_{f1} and E_{f2} are flexural modulus of elasticity values for skins 1 and 2 (also see ch. 11); E is stringer modulus of elasticity; and s is total width of all stringers in a panel. Other dimensions are as noted by symbols of figure 10–7.

$$(GA') = Gst_c \text{ (approx.)} \qquad (10\text{–}16)$$

where G is stringer shear modulus.

Skin Stresses

Skin tension and compression stresses are given by the formulas

$$f_{x1} = \frac{ME_1y_1}{(EI)}$$

$$f_{x2} = \frac{ME_2y_2}{(EI)} \qquad (10\text{–}17)$$

where (EI) is given by formula (10–15); M is bending moment; other symbols are as defined previously in this chapter; and

$$y_1 = \frac{E_2t_2[(t_1 + t_c) + (t_2 + t_c)] + Et_c\frac{s}{b}(t_1 + t_c)}{2\left(E_1t_1 + E_2t_2 + Et_c\frac{s}{b}\right)}$$

$$y_2 = \frac{E_1t_1[(t_1 + t_c) + (t_2 + t_c)] + Et_c\frac{s}{b}(t_2 + t_c)}{2\left(E_1t_1 + E_2t_2 + Et_c\frac{s}{b}\right)}$$

The skins should be thick enough or the stringers spaced closely enough so that buckling does not occur in the compression skin. The buckling stress is given by F_{ccr} (formula (11–7), in ch. 11). The plywood tensile and compressive strength (see ch. 11) should not be exceeded.

Stringer Bending Stress

The stringer bending stress is the larger value given by the formulas

$$f_{sx1} = \frac{ME\left(y_1 - \frac{t_1}{2}\right)}{(EI)}$$

$$f_{sx2} = \frac{ME\left(y_2 - \frac{t_2}{2}\right)}{(EI)} \qquad (10\text{–}18)$$

and these should not exceed appropriate values for the species.

The stringer shear stress is given by the formula

$$f_{sxy} = \frac{V(EQ)}{s(EI)} \qquad (10\text{–}19)$$

where $(EQ) = \left(E_1 t_1 b + \mathrm{Es}\frac{y_1}{2}\right) y_1$ and this should not exceed appropriate values for the species.

Glue Shear Stress

Glue shear stress in the joint between the skins and stringers is given by the formula

$$f_{gl} = \frac{V(EQ)}{s(EI)} \qquad (10\text{–}20)$$

where $(EQ) = E_1 t_1 b y_1$ and this should not exceed values for the glue and species. It should not exceed the wood stress, f_{TR} ("rolling" shear) for solid wood because the thin plywood plies allow the glue shear stresses to be transmitted to adjacent plies to cause rolling shear failure in the wood.

Buckling

Buckling of the stressed-skin panel of unsupported length, L, under end load applied in a direction parallel to the length of the stringers can be computed with the formula

$$P_{cr} = \frac{\pi^2 (EI)}{L^2} \qquad (10\text{–}21)$$

where L is unsupported panel length and (EI) is bending stiffness given by formula (10–15).

Compressive stress in the skins as given by the formula

$$f_{xc1} = \frac{PE_1}{(EA)}$$

$$(10\text{–}22)$$

$$f_{xc2} = \frac{PE_2}{(EA)}$$

and in the stringers as given by the formula

$$f_{sxc} = \frac{PE}{(EA)} \qquad (10\text{–}23)$$

where $(EA) = E_1 t_1 b + E_2 t_2 b + E t_c s$, should not exceed stress values for plywood or stringer material. The plywood stress should also be lower than the buckling stress given by F_{ccr} (formula (11–7), ch. 11).

Loadings

Normally directed loads, uniformly distributed or concentrated, on the panel skins produce deflections and stresses in the plywood skins that can be computed by formulas for plywood panels given in chapter 11.

Racking loads on panels shear the skins, and buckling of the plywood should not occur due to the shear stress caused by racking. The buckling stress can be computed as F_{scr} from formula (11–18) of chapter 11.

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Chapter 11

PLYWOOD

PLYWOOD

Plywood is a glued wood panel made up of relatively thin layers, or plies, with the grain of adjacent layers at an angle, usually 90°. The usual constructions have an odd number of plies. If rather thick layers of wood are used as plies, these are often of two layers with the grain directions of each layer parallel. The plywood produced then is often called four-ply or six-ply. The outside plies are called faces or face and back plies, the inner plies are called cores or centers, and the plies immediately below the face and back are called crossbands. The core may be veneer, lumber, or particleboard, with the total panel thickness typically not less than $\frac{1}{16}$ inch or more than 3 inches. The plies may vary as to number, thickness, species, and grade of wood.

As compared with solid wood, the chief advantages of plywood are its approach to having properties along the length nearly equal to properties along the width of the panel, its greater resistance to splitting, and its form, which permits many useful applications where large sheets are desirable. Use of plywood may result in improved utilization of wood, because it covers large areas with a mimimum amount of wood fiber. This is because it is permissible to use plywood thinner than sawn lumber in some applications.

The properties of plywood depend on the quality of the different layers of veneer, the order of layer placement in the panel, the glue used, and the control of gluing conditions in the gluing process. The grade of the panel depends upon the quality of the veneers used, particularly of the face and back. The type of the panel depends upon the glue joint, particularly its water resistance. Generally, face veneers with figured grain that are used in panels where appearance is important have numerous short, or otherwise deformed, wood fibers. These may significantly reduce strength and stiffness of the panels. On the other hand, face veneers and other plies may contain certain sizes and distributions of knots, splits, or growth characteristics that have no undesirable effects on strength properties for specific uses. Such uses include structural applications such as sheathing for walls, roofs, or floors.

The plywood industry expands and develops new products with each passing year. Hence, the reader should always refer directly to current specifications on plywood and its use for specific details.

GRADES AND TYPES OF PLYWOOD

Broadly speaking, two classes of plywood are available—hardwood and softwood. In general, softwood plywood is intended for construction use and hardwood plywood for uses where appearance is important.

Originally, most softwood plywood was made of Douglas-fir, but western hemlock, larch, white fir, ponderosa pine, redwood, southern pine, and other species are now used.

Most softwood plywood used in the United States is produced domestically, and U.S. manufacturers export some material. Generally speaking, the bulk of softwood plywood is used where strength, stiffness, and construction convenience are more important than appearance. Some grades of softwood plywood are made with faces selected primarily for appearance and are used either with clear natural finishes or with pigmented finishes.

Hardwood plywood is made of many different species, both in the United States and overseas. Well over half of all hardwood panels used in the United States is imported. Hardwood plywood is normally used where appearance is more important than strength. Most of the production is intended for interior or protected uses, although a very small proportion is made with glues suitable for exterior service. A significant portion of all hardwood plywood is available completely finished.

The product standard for softwood plywood, construction and industrial, lists some hardwoods as qualifying for use in plywood made to the standard. Similarly, the product standard for hardwood and decorative plywood lists some softwoods.

The glues used in the hardwood and softwood plywood industries are quite different, but each type is selected to provide the necessary performance required by the appropriate specifications.

SPECIFICATIONS FOR PLYWOOD

The most commonly used specifications for plywood are the product standards established by the industry with the assistance of the U.S. Department of Commerce. The specifications are available from the National Bureau of Standards. Separate standards apply to softwood plywood and hardwood plywood. These specifications cover such items as the grading of veneer, the construction of panels, the glueline performance requirements, and recommendations for use.

Imported plywood is generally not produced in conformance with United States product specifications. However, some countries have their own specifications for plywood manufactured for export to the United States, and these follow the requirements of the domestic product standards.

SPECIAL PLYWOOD

In addition to the all-wood panels, a variety of special plywood panels are made. Paper, plastic, and metal layers are combined with wood veneers, usually as the face layer, to provide special panel characteristics such as improved surface properties.

Special resin-treated papers called "overlays" can be bonded to plywood panels, either on one or both sides. These overlays are either of the "high density" or "medium density" types, and are intended to provide improved resistance to abrasion or wearing, better surfaces when appearance is important or for concrete-form use, or better paint-holding properties. Some panels are also overlaid, usually on the face only, with high-density paper-base decorative laminates, hardboards, or metal sheets. A backing sheet having the same properties (modulus of elasticity, dimensional stability, and vapor transmission rate) as the decorative face sheet must be used to provide a panel free from warp and twist as moisture changes occur. Overlays may be applied in the original layup or they may be applied to plywood after the panels have been surfaced. The two-step method permits a closer thickness tolerance. Requirements for certain types of overlaid softwood panels are included in the aforementioned product standards.

Other special products are embossed, grooved, and other textured panels. Texturing may be achieved by wire brushing or sand blasting. Such products are used primarily as interior paneling and exterior siding.

Prefinished plywood, particularly hardwood plywood, is available in wide variety. The finishes are normally applied in the plywood plants as clear or pigmented liquid finishes. Various printed film patterns are sometimes applied to plywood. Printed panels are also available using liquid finishing systems, and three-dimensional finishes can be achieved by passing the panels under an embossing roller. By these techniques, the appearance for such uses as furniture and wall paneling is improved. Some use is also made of clear, printed, and pigmented plastic films bonded to plywood for the same purpose.

Plywood may be purchased that has been specially treated for protection against fire or decay. It is technically feasible to treat the veneers with chemical solutions and then glue them into plywood. A more general practice is to treat the plywood after gluing, with either fire-retardant or wood-preservative solutions, and then redry the panels. Panels must be glued with durable glues of the exterior type to withstand such treatment.

Large-size panels for special purposes are made by end jointing standard-size panels with scarf joints or finger joints. This is done mainly with softwood panels for structural use as in boats or trailers. Requirements for joints are given in the product standards for conventional plywood.

Curved plywood is sometimes used, particularly in certain furniture items as a specialty product. Much curved plywood is made by gluing the individual veneers to the desired shape and curvature in special jigs or presses. Flat plywood can also be bent to simple curvatures after gluing using techniques similar to those for bending solid wood (see ch. 13).

FACTORS AFFECTING DIMENSIONAL STABILITY OF PLYWOOD

Arrangement of Plies

The tendency of crossbanded products to warp, as the result of uneven shrinking and swelling caused by moisture changes, is largely eliminated by balanced construction. Balanced construction involves plies arranged in similar pairs, a ply on each side of the core. Similar plies have the same thickness, kind of wood with particular reference to shrinkage and density, moisture content at the time of gluing, and grain direction. The importance of having the grain direction of similar plies parallel cannot be overemphasized. A face ply with its grain at a slight angle to the grain of the back ply may result in a panel that will twist excessively with moisture content changes.

An odd number of plies permits an arrangement that gives a substantially balanced effect; that is, when three plies are glued together with the grain of the outer two identical plies at right angles to the grain of the core, the panel is balanced and tends to remain flat through moisture content changes. With five, seven, or some other uneven number of plies, panels may be similarly balanced. Four- or six-ply panels made with the two center plies having grain parallel may also be balanced panels.

Balanced construction is highly important in panels that must remain flat. Conversely, in certain curved members, the natural cupping tendency of an even number of plies may be used to advantage.

Because the outer or face plies of a crossbanded construction are restrained on only one side, changes in moisture content induce relatively large stresses on the outer glue joints. The magnitude of stresses depends upon such factors as thickness of outer plies, density of the veneer involved, and the rate and amount of change in moisture content. In general, the thinner the face veneer the less problem with face checking.

Quality of Plies

In thin plywood where dimensional stability is important, all the plies affect the shape and permanence of form of the panel. All plies should be straight grained, smoothly cut, and of sound wood.

In thick five-ply lumber-core panels the crossbands, in particular, affect the quality and stability of the panel. In such panels thin and dissimilar face and back plies can be used without upsetting the stability of the panel. Imperfections in the crossbands, such as marked differences in the texture of the wood or irregularities in the surface, are easily seen through thin surface veneers. Cross grain that runs sharply through the crossband veneer from one face to the other causes the panels to cup. Cross grain that runs diagonally across the face of the crossband veneer causes the panel to twist unless the two crossbands are laid with their grain parallel. Failure to observe this simple precaution accounts for much warping in crossbanded construction.

In many hardwood plywood uses, both appearance and dimensional stability are important. The best woods for cores of high-grade hardwood panels are those of low density and low shrinkage, of slight contrast between earlywood and latewood, and of species that are easily glued. Edge-grained cores are better than flat-grained cores because they shrink less in width. In softwoods with pronounced latewood, moreover, edge-grained cores are better because the hard bands of latewood are less likely to show through thin veneer, and the panels show fewer irregularities in the surfaces. In most species, a core made entirely of either quartersawed or plainsawed material remains more uniform in thickness through moisture content changes than one in which the two types of material are combined.

Distinct distortion of surfaces has been noted, particularly in softwoods, when the core boards were neither distinctly flat-grained nor edge-grained.

For many uses of softwood plywood, as in sheathing, the appearance, moderate tendencies to warp, and small dimensional changes are of minor importance compared to the strength characteristics of the panel. Strength and stiffness in bending are particularly important. In such panels, veneers are selected mainly to provide strength properties. This selection often permits controlled amounts of knots, splits, and other irregularities that might be considered objectionable from an appearance standpoint.

Moisture Content

The tendency of plywood panels to warp is affected by changes in moisture content as a result of changes in atmospheric moisture conditions or is due to wetting of the surface by free water. Surface appearance may also be affected.

Most plywood is made in hot presses, but other panels are cold-pressed.

Hot-pressed panels come out of the press quite dry. The original moisture content of the veneer and the amount of water added by the glue must be kept low to avoid blister problems in hot-pressing the panels. In addition, water is lost from the glue and the wood during heating.

Cold-pressed panels are generally fairly high in moisture content when removed from the press, the actual values depending on the original moisture content of the veneer, the amount of water in the glue, and the amount of glue spread. Such panels may lose considerable moisture while reaching equilibrium in service.

Differences in the stability and appearance of plywood under service conditions may occur if a change is made from panels produced by one process to those made by the other. However, either type of panel may be used satisfactorily if it is properly designed for the service condition.

Expansion or Contraction

The dimensional stability of plywood, associated with moisture and thermal changes, involves not only cupping, twisting, and bowing but includes expansion or contraction. The usual swelling and shrinking of the wood is effectively reduced because grain directions of adjacent plies are placed at right angles. The low dimensional change parallel to the grain in one ply restrains the normal swelling and shrinking across the grain in the ply glued to it. An additional restraint results from a modulus of elasticity value parallel to the grain of about 20 times that across the grain (see ch. 4). The expansion or contraction of plywood can be closely approximated by the formula

$$\epsilon = \frac{\Sigma m_i E_i t_i}{\Sigma E_i t_i} \qquad (11\text{–}1)$$

where ϵ is the expansion or contraction of the plywood, m_i is the coefficient of expansion of the i^{th} ply over the range of moisture or thermal increase desired, E_i is the modulus of elasticity of the i^{th} ply, and t_i is the thickness of the i^{th} ply. The units of ϵ correspond to the units of m. If m is percent, ϵ is percent; if m is total expansion, ϵ is total expansion. Values of m can be obtained from data given in chapter 3 in the sections on Shrinkage and Thermal Properties. Values of E are obtainable from data given in chapter 4. Plywood expansion or contraction as given by formula (11–1) will be about equal to the parallel-to-grain movement of the veneers.

For all practical purposes, the dimensional change of plywood in thickness does not differ from that of solid wood.

STRUCTURAL DESIGN OF PLYWOOD

The stiffness and strength of plywood can be computed by formulas relating the plywood properties to the construction of the plywood and properties of particular wood species in the component plies. Testing all of the many possible combinations of ply thickness, species, number of plies, and variety of structural components is impractical. The various formulas developed mathematically and presented here were checked by tests to verify their applicability.

Plywood may be used under loading conditions that require the addition of stiffeners to prevent it from buckling. It may also be used in the form of cylinders or curved plates. Such uses are beyond the scope of this handbook, but they are discussed in ANC–18 Bulletin.

It is obvious from its construction that a strip of plywood cannot be so strong in tension, compression, or bending as a strip of solid wood of the same size. Those plies having their grain direction oriented at 90° to the direction of stress can contribute only a fraction of the strength contributed by the corresponding areas of a solid strip, since they are stressed perpendicular to the grain. Strength properties in the directions parallel and perpendicular to the face grain tend to be equalized in plywood, since in some interior plies the grain direction is parallel to the face grain and in others it is perpendicular.

The formulas given in this handbook may be used, in general, for calculating the stiffness of plywood, stresses at proportional limit or ultimate, or for estimating working stresses, depending upon the veneer or wood species property that is substituted in the formulas. Values of the wood properties are given in tables in chapter 4. Chapter 4 also gives values of property coefficients of variation to indicate the variability and reliability of the data as an aid in selection of allowable property values. Modulus of elasticity values given in table 4–2 (ch. 4) should be increased by 10 percent before being used to predict plywood properties; values in table 4–2 represent test data wherein the measured deflection was attributed to bending stiffness and did not consider shear deflection, which effectively increases by about 10 percent the deflection of wood beams having a span-depth ratio of 14:1 as tested.

Properties in Edgewise Compression

Modulus of Elasticity

The modulus of elasticity of plywood in compression parallel to or perpendicular to the face-grain direction is equal to the weighted average of the moduli of elasticity of all plies parallel to the applied load. That is,

$$E_w \text{ or } E_x = \frac{1}{h}\sum_{i=1}^{i=n} E_i h_i \qquad (11\text{–}2)$$

where E_w is the modulus of elasticity of plywood in compression parallel to the face grain; E_x, the modulus of elasticity of plywood in compression perpendicular to the face grain; E_i, the modulus of elasticity parallel to the applied load of the veneer in ply i; h_i, the thickness of the veneer in ply i; h, the thickness of the plywood; and n, the number of plies.

When all plies are of the same thickness and wood species, the formula reduces to

$$E_w = \frac{1}{2n}\left[(E_L + E_T)n + (E_L - E_T)\right]$$
$$(11\text{–}3)$$
$$E_x = \frac{1}{2n}\left[(E_L + E_T)n - (E_L - E_T)\right]$$

where n is the number of plies (n is odd), E_L is the modulus of elasticity of the veneer parallel to the grain, and E_T is the modulus of elasticity of the veneer perpendicular to the grain (see ch. 4). If the veneer is rotary cut, the value of E_T is the modulus of elasticity in the tangential direction. For quarter-sliced veneer, the modulus of elasticity in the radial direction, E_R, should be substituted for E_T.

The modulus of elasticity in compression at angles to the facegrain direction other than 0° or 90° is given approximately by:

$$\frac{1}{E\theta} = \frac{1}{E_w}\cos^4\theta + \frac{1}{E_x}\sin^4\theta + \frac{1}{G_{wx}}\sin^2\theta\cos^2\theta \qquad (11\text{–}4)$$

where E_θ is the modulus of elasticity of a plywood strip in compression at an angle θ to the face grain; G_{wx} is the modulus of rigidity associated with plywood distortion under edgewise shearing forces along axes w (parallel to face grain) and x (perpendicular to face grain); and the other terms are as defined in the formula (11–3). Formulas for computing values of G_{wx} are given under "Properties in Edgewise Shear."

Strength

The compressive strength of plywood subjected to edgewise forces is given by:

$$F_{cw} = \frac{E_w}{E_{cL}}F_{cL}$$
$$(11\text{–}5)$$
$$F_{cx} = \frac{E_x}{E_{cL}}F_{cL}$$

where F_{cw} is the compressive strength of plywood parallel to the face grain; F_{cx}, the compressive strength of plywood perpendicular to the face grain; F_{cL}, the compressive strength of the veneer parallel to the grain; and E_{cL}, the modulus of elasticity of the veneer parallel to the grain. If more than one species is used in the longitudinal plies, values for the species having the lowest ratio of F_{cL}/E_{cL} should be used in the formulas given.

When plywood is loaded at an angle to the face grain, its compressive strength may be computed from:

$$F_{c\theta} \; \frac{1}{\sqrt{\dfrac{\cos^4\theta}{F_{cw}{}^2} + \dfrac{\sin^4\theta}{F_{cx}{}^2} + \left(\dfrac{1}{F_{swx}{}^2} - \dfrac{1}{F_{cw}F_{cx}}\right)\sin^2\theta\cos^2\theta}} \qquad (11\text{–}6)$$

where $F_{c\theta}$ is the compressive strength of plywood at an angle θ to the face grain, and F_{swx} is the shear strength of plywood under edgewise shearing forces along axes w (parallel to face grain) and x (perpendicular to face grain) (eq. 11–13); and the other terms are as previously defined.

If the plywood is a thin panel, compressive edge loads can cause buckling and subsequent reduction of load-carrying capacity. Plywood panels in stressed-skin constructions must be designed so as to preclude buckling under edge compression loads or bending loads causing edgewise compression on one facing. The critical compressive buckling stress for a plywood panel with face grain parallel to edges and simply supported at four edges is given approximately by the formula:

$$F_{ccr} = \frac{\pi^2}{6}\left(\sqrt{E_{fa}E_{fb}} + 0.17E_L\right)\frac{h^2}{b^2} \qquad (11\text{–}7)$$

$$\text{for } a \geq b\left(\frac{E_{fa}}{E_{fb}}\right)^{1/4}$$

where F_{ccr} is the critical compressive buckling stress; h is plywood thickness; b is width of plywood panel loaded edge; a is plywood panel length; E_{fa} and E_{fb} are flexural moduli of elasticity of the plywood in the a and b directions, respectively; and E_L is the modulus of elasticity of the plywood species. Formulas for computing E_f values are elsewhere in this section.

Properties in Edgewise Tension

Modulus of Elasticity

Values of modulus of elasticity in tension are the same as those in compression.

Strength

The strength of a plywood strip in tension parallel or perpendicular to the face grain may be taken as the sum of the strength values of the plies having their grain direction parallel to the applied load. For this purpose, the tensile strength may be taken as equal to the modulus of rupture.

The tensile strength parallel to the face grain will be designated as F_{tw} and the tensile strength perpendicular to the face grain as F_{tx}.

The tensile strength at an angle to the face grain may be computed from:

$$F_{t\theta} = \frac{1}{\sqrt{\dfrac{\cos^4\theta}{F_{tw}^2} + \dfrac{\sin^4\theta}{F_{tx}^2} + \left(\dfrac{1}{F_{swx}^2} - \dfrac{1}{F_{tw}F_{tx}}\right)\sin^2\theta\cos^2\theta}} \qquad (11\text{–}8)$$

where $F_{t\theta}$ is the tensile strength of plywood at an angle θ to the face grain.

Properties in Edgewise Shear

Modulus of Rigidity

The modulus of rigidity of plywood may be calculated from:

$$G_{wx} = \frac{1}{h}\sum_{i=1}^{i=n} G_i h_i \qquad (11\text{–}9)$$

where G_{wx} is the modulus of rigidity of plywood under edgewise shear; G_i is the modulus of rigidity of the i^{th} ply; h_i is the thickness of the i^{th} ply; and h is the plywood thickness.

When the plywood is made of a single species of wood:

$G_{wx} = G_{LT}$ for rotary-cut veneers

$G_{wx} = G_{LR}$ for quarter-sliced veneer

Values of G_{LT} and G_{LR} are given in terms of the modulus of elasticity parallel to grain (E_L) in table 4–2 of chapter 4.

The modulus of rigidity at an angle to the face grain may be computed from:

$$\frac{1}{G_\theta} = \frac{1}{G_{wx}} \cos^2 2\theta + \left[\frac{1}{E_w} + \frac{1}{E_x}\right] \sin^2 2\theta \tag{11–10}$$

This formula gives a maximum value for G_θ when $\theta = 45°$; thus shear deflections of constructions such as box- and I-beams, wherein plywood webs offer principal resistance to shear, can be reduced by orienting the plywood face grain at 45° to the beam axis. The formula for the special case of $\theta = 45°$ reduces to

$$G_{45°} = \frac{E_w E_x}{E_w + E_x} \tag{11–11}$$

This formula has a maximum value for plywood arranged to have the same area of parallel grain plies in the two principal directions to produce $E_w = E_x = \frac{1}{2}(E_L + E_T)$. This maximum 45° shear modulus is then

$$\max G_{45°} = \frac{1}{4}(E_L + E_T) \tag{11–12}$$

For quarter-sliced veneer, E_R is to be substituted for E_T.

Strength

The ultimate strength of plywood elements in shear, with the shearing forces parallel and perpendicular to the face-grain direction, is given by the empirical formula:

$$F_{swx} = 55 \frac{n-1}{h} + \frac{9}{16h} \sum_{i=1}^{i=n} F_{swxi} h_i \tag{11–13}$$

where n is the number of plies and F_{swxi} is the shear strength of the i^{th} ply.

In using this formula, the factor $(n-1)/h$ should not be assigned a value greater than 35.

In some commercial grades of plywood, gaps in the core or crossbands are permitted. These gaps reduce the shear strength of plywood, and the formula just given should be corrected to account for this effect. This may be done approximately by subtracting from the number of plies (n) in the first term twice the number of plies containing openings at any one section, and omitting from the summation in the second term all plies containing openings at any one section. Since the first term represents the contribution of the glue layers to shear, twice the number of plies containing openings at any one section is subtracted to account for the lack of glue on each side of the opening. The modification for the effect of core gaps just outlined represents a logically derived procedure not confirmed by test.

When the plywood is stressed in shear at an angle to the face grain, ultimate shear strength with face grain in tension or compression is given by the following formulas:

$$F_{s\theta t} = \frac{1}{\sqrt{\left(\frac{1}{F_{tw}^2} + \frac{1}{F_{tw}F_{cx}} + \frac{1}{F_{cx}^2}\right)\sin^2 2\theta + \frac{\cos^2 2\theta}{F_{swx}^2}}} \tag{11–14}$$

$$F_{s\theta c} = \frac{1}{\sqrt{\left(\frac{1}{F_{cw}^2} + \frac{1}{F_{cw}F_{tx}} + \frac{1}{F_{tx}^2}\right)\sin^2 2\theta + \frac{\cos^2 2\theta}{F_{swx}^2}}} \tag{11–15}$$

These formulas have maximum values for $\theta = 45°$ as did the modulus of rigidity formula. For $\theta = 45°$, the formulas reduce to:

$$F_{s45t} = \frac{1}{\sqrt{\dfrac{1}{F_{tw}^2} + \dfrac{1}{F_{tw}F_{cr}} + \dfrac{1}{F_{cr}^2}}} \qquad (11\text{–}16)$$

$$F_{s45c} = \frac{1}{\sqrt{\dfrac{1}{F_{cw}^2} + \dfrac{1}{F_{cw}F_{tr}} + \dfrac{1}{F_{tr}^2}}} \qquad (11\text{–}17)$$

If the plywood is a thin panel, edgewise shearing loads can cause buckling and subsequent reduction of load-carrying capacity. Plywood panels in structures, such as webs of I- or box-beams or walls subjected to racking, must be so designed as to preclude buckling due to shearing loads. The critical shear buckling stress for a plywood panel with face grain parallel to edges and simply supported at four edges is given approximately by the formula:

$$F_{scr} = \frac{K_s}{3} (E_{fa}E_{fb}^3)^{1/4} \frac{h^2}{b^2} \qquad (11\text{–}18)$$

where F_{scr} is the critical shear buckling stress; h is plywood thickness; E_{fa} and E_{fb} are flexural moduli of elasticity of the plywood in the a and b directions, respectively; K_s is a buckling coefficient given by figure 11–1; and a and b panel dimensions are chosen so that the abscissa quantity in figure 11–1 is $\leq$ 1.0. If the shear buckling stress is too low for the intended use, the buckling stress can be increased considerably by placing the plywood in shear so that the face grain is in compression and at 45° to the panel edge. Details of design for grain directions other than parallel or perpendicular to panel edges are given in ANC–18 Bulletin.

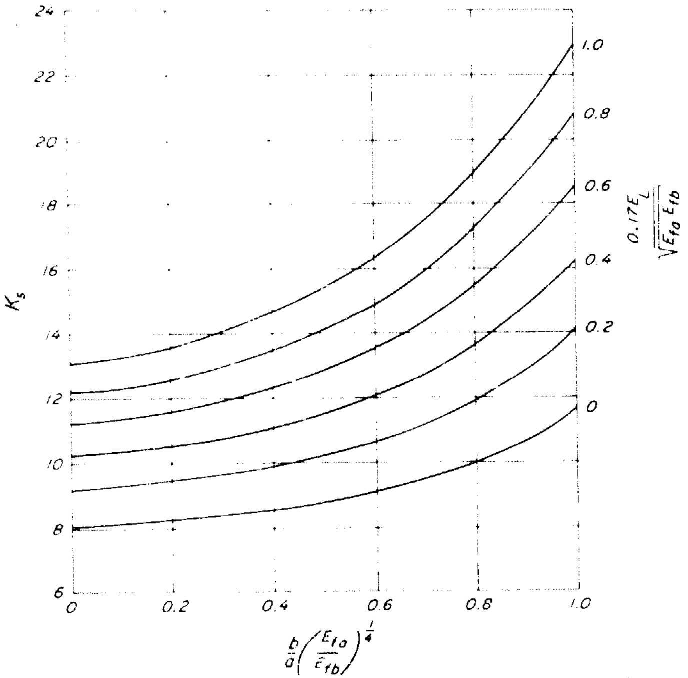

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Figure 11–1.—Shear buckling coefficient for plywood panels having face grain parallel to panel edges.

Properties in Edgewise Bending

For the occasional use where plywood is subjected to edgewise bending, such as in plywood box- and I-beam webs, the values of modulus of elasticity, modulus of rigidity, and strength are the same as those for plywood in compression, tension, or shear, whichever loading is appropriate in the design. If the plywood is a thin panel, edgewise bending can cause buckling, which reduces load-carrying capacity. The critical buckling stress for a simply supported plywood panel under pure edgewise bending is approximately equal to six times the compression buckling stress; thus

$$F_{bcr} \approx 6F_{ccr} \qquad (11\text{–}19)$$

$$\text{for a} \geq 0.7b \left(\frac{E_{fa}}{E_{fb}}\right)^{1/4}$$

Properties in Flexure

The following material pertains to flexure of plywood that causes curvature of the plane of the plywood sheet.

Modulus of Elasticity

The modulus of elasticity in flexure is equal to the average of the moduli of elasticity parallel to the span of the various plies weighted according to their moment of inertia about the neutral plane. That is,

$$E_{fw} \text{ or } E_{fr} = \frac{1}{I} \sum_{i=1}^{i=n} E_i I_i \qquad (11\text{–}20)$$

where E_{fw} is the modulus of elasticity of plywood in bending when the face grain is parallel to the span; E_{fx}, the modulus of elasticity of plywood in bending when the face grain is perpendicular to the span; E_i, the modulus of elasticity of the i^{th} ply in the span direction; I_i, the moment of inertia of the i^{th} ply about the neutral plane of the plywood; and I, the moment of inertia of the total cross section about its centerline. When all plies are of the same thickness and wood species, the formula reduces to

$$E_{fw} = \frac{1}{2n^3}\left[(E_L + E_T)n^3 + (E_L - E_T)(3n^2 - 2)\right] \quad (11\text{–}21)$$

$$E_{fx} = \frac{1}{2n^3}\left[(E_L + E_T)n^3 - (E_L - E_T)\,(3n^2 - 2)\right]$$

where n is the number of plies (n is odd), E_L is the modulus of elasticity of the veneer parallel to the grain, and E_T is the modulus of elasticity of the veneer perpendicular to the grain (see ch. 4). If the veneer is rotary cut, the value of E_T is the modulus of elasticity in the tangential direction. For quarter-sliced veneer, the modulus of elasticity in the radial direction, E_R, should be substituted for E_T.

The effective moduli of elasticity E_{fw} and E_{fx} are useful in computing the deflections of plywood strips that are subjected primarily to bending on a long span. Deflections due to shear are low for strips on long spans but become important for short spans; they can be computed by analyses given in references by March in the Bibliography for this chapter.

The deflection of a plywood plate simply supported on all four edges also depends on plywood bending stiffness and plate aspect ratio. The center deflection of a plywood plate of width b and length a under a uniformly distributed load of intensity p is given by:

$$w = 0.155K \frac{pb^4}{E_{fb}h^3} \quad (11\text{–}22)$$

where K is given in figure 11–2 and h is plywood thickness. The center deflection of a plywood plate of width b and length a under a center concentrated load P is given by:

$$w = 0.252K \left(\frac{E_{fb}}{E_{fa}}\right)^{1/4} \frac{Pb^2}{E_{fb}h^3} \quad (11\text{–}23)$$

where K is given in figure 11–2.

Strength

The resisting moment of plywood strips having face grain parallel to the span is given by:

$$M = 0.85 \frac{E_{fw}}{E_L} \frac{F_bI}{c} \quad (11\text{–}24)$$

For face grain perpendicular to the span,

$$M = 1.15 \frac{E'_{fx}}{E_L} \frac{F_bI}{c} \text{ for three-ply plywood} \quad (11\text{–}25)$$

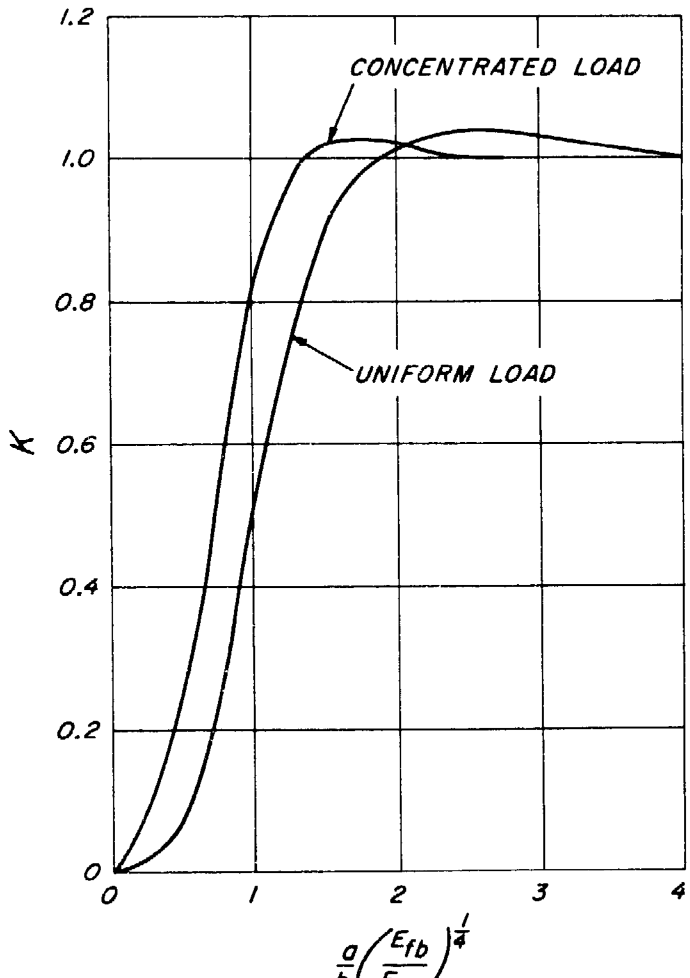

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Figure 11–2.—Deflection coefficients for simply supported plywood plates under normal load.

$$M = \frac{E'_{fr}}{E_L}\frac{F_b I}{c} \quad \text{for plywood having five or more plies} \tag{11-26}$$

where M is the resisting moment of the plywood; F_b, the strength of the outermost longitudinal ply; c, the distance from the neutral plane to the outer fiber of the outermost longitudinal ply; and E'_{fr} is the same as E_{fr}, except that the outermost ply in tension is neglected, and the other terms are as defined previously.

For plywood having five or more plies, the use of E_{fr} in place of E'_{fr} in calculating the resisting moment will result in negligible error. It should be noted that E'_{fr} is used only in strength calculations and is not to be used in deflection calculations.

Other Design Considerations

Plywood of thin, crossbanded veneers is very resistant to splitting and therefore nails and screws can be placed close together and close to the edges of panels.

Highly efficient, rigid joints can, of course, be obtained by gluing plywood to itself or to heavier wood members such as needed in box-beams and stressed-skin panels. Glued joints should not be designed primarily to transmit load in tension normal to the plane of the plywood sheet because of the rather low tensile strength of wood in a direction perpendicular to the grain. Glued joints should be arranged to transmit loads through shear. It must be recognized that shear strength across the grain of wood (often called rolling shear strength because of the tendency to roll the wood fibers) is considerably less than parallel to the grain (see ch. 4). Thus sufficient area must be provided between plywood and flange members of box-beams and plywood and stringers of stressed-skin construction to avoid shearing failure perpendicular to the grain in the face veneer, in the crossband veneer next to the face veneer, or in the wood member. Various details of design are given in chapter 10.

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Chapter 12

STRUCTURAL SANDWICH CONSTRUCTION

STRUCTURAL SANDWICH CONSTRUCTION

Structural sandwich construction is a layered construction formed by bonding two thin facings to a thick core (fig. 12–1). In this construction the facings resist nearly all the applied edgewise loads and flatwise bending moments. The thin, spaced facings provide nearly all the bending rigidity to the construction. The core spaces the facings and transmits shear between them so they are effective about a common neutral axis. The core also provides most of the shear rigidity of the sandwich construction. By proper choice of materials for facings and core, constructions with high ratios of stiffness to weight can be achieved. Sandwich construction is also economical, for only small amounts of the relatively expensive facing materials are used and the core materials are usually inexpensive. The materials are positioned so that each is used to its best advantage.

Specific nonstructural advantages can be incorporated in a sandwich construction by proper selection of facing and core materials. An impermeable facing can be employed to act as a moisture barrier for a wall or roof panel in a house; an abrasion-resistant facing can be used for the top facing of a floor panel; and decorative effects can be obtained by using panels with plywood or plastic facings for walls, doors, tables, and other furnishings. Core material can be chosen to provide thermal insulation, fire resistance, and decay resistance.

Care must be used in choice of sandwich components to avoid problems in sound transmission from room to room because of the light weight of the construction. Methods of joining panels to each other and to other structures must be planned so that the joints function properly and allow for possible dimension change due to temperature and moisture change.

The components of the sandwich construction should be compatible with service requirements. Moisture-resistant facings, cores, and adhesives should be employed if the construction is to be exposed to adverse moisture conditions. Similarly, heat-resistant or decay-resistant facings, cores, and adhesives should be used if exposure to elevated temperatures or decay organisms is expected.

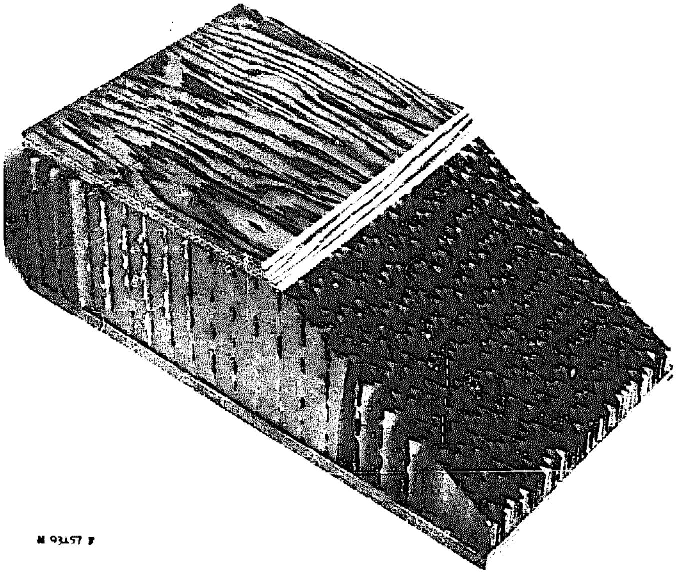

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Figure 12–1.—A cutaway section of sandwich construction with plywood facings and a paper honeycomb core.

FABRICATION OF SANDWICH PANELS

Facing Materials

One of the advantages of sandwich construction is the great latitude it provides in choice of facings and the opportunity to use thin sheet materials because of the nearly continuous support by the core. The stiffness, stability, and, to a large extent, the strength of the sandwich are determined by the characteristics of the facings. Some of the different facing materials used include plywood, single veneers or plywood overlaid with a resin-treated paper, hardboard, asbestos cement board, particleboard, fiber-reinforced plastics or laminates, veneer bonded to metal, and such metals as aluminum, enameled steel, stainless steel, or magnesium.

Core Materials

Many lightweight materials, such as balsa wood, rubber or plastic foams, and formed sheets of cloth, metal, or paper, have been used as core for sandwich construction. Cores of formed sheet materials are often called honeycomb cores. By varying the sheet material, sheet thickness, cell size, and cell shape, cores of a wide range in density can be produced.

Various core configurations are shown in figures 12–2 and 12–3. The core cell configurations shown in figure 12–2 can be formed to moderate amounts of single curvature, but cores shown in figure 12–3 of configurations *A*, *B*, and *C* can be formed to severe single curvature and mild compound curvature (spherical).

Four types of readily formable cores are shown as configurations *D*, *E*, *F*, and *G* in figure 12–3. The type *D* and *F* cores form to cylindrical shape, the type *D* and *E* cores to spherical shape, and the type *D* and *G* cores to various compound curvatures.

If the sandwich panels are likely to be subjected to damp or wet conditions, a core of paper honeycomb should contain a synthetic resin. Paper with 15 percent phenolic resin provides good strength when wet, decay resistance, and desirable handling characteristics during fabrication. Resin amounts in excess of about 15 percent do not seem to produce a gain in strength commensurate with the increased quantity of resin required. Smaller amounts of resin may be combined with fungicides to offer primary protection against decay.

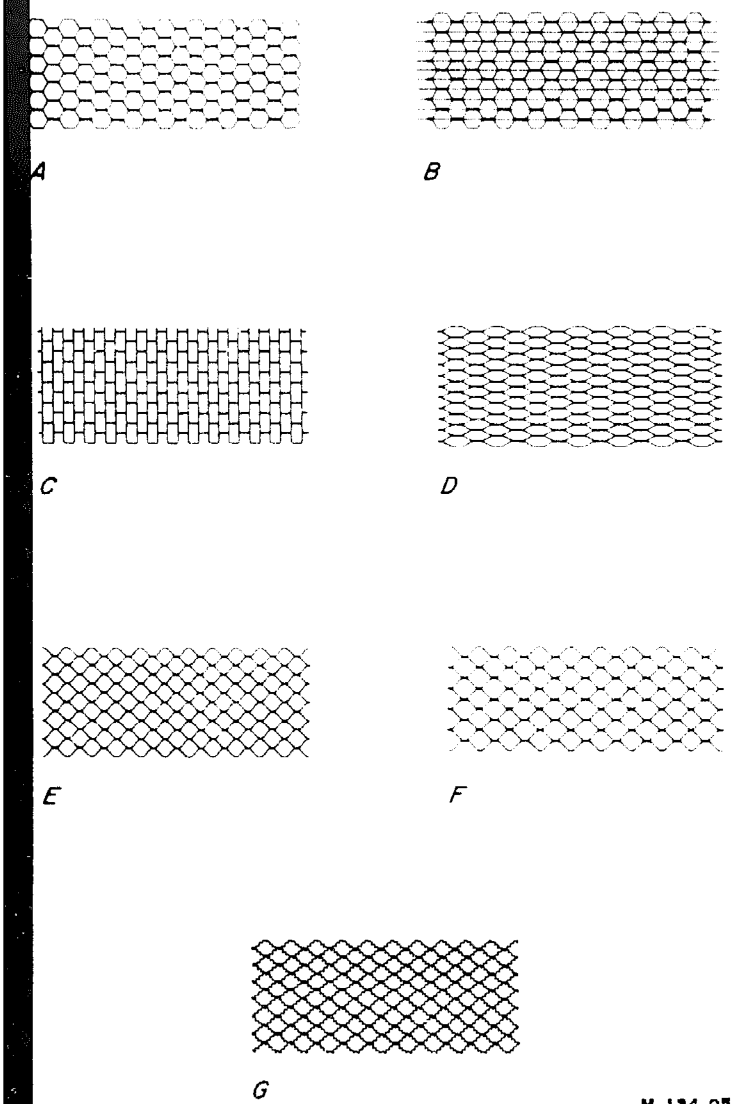

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Figure 12–2.—Honeycomb core cell configurations.

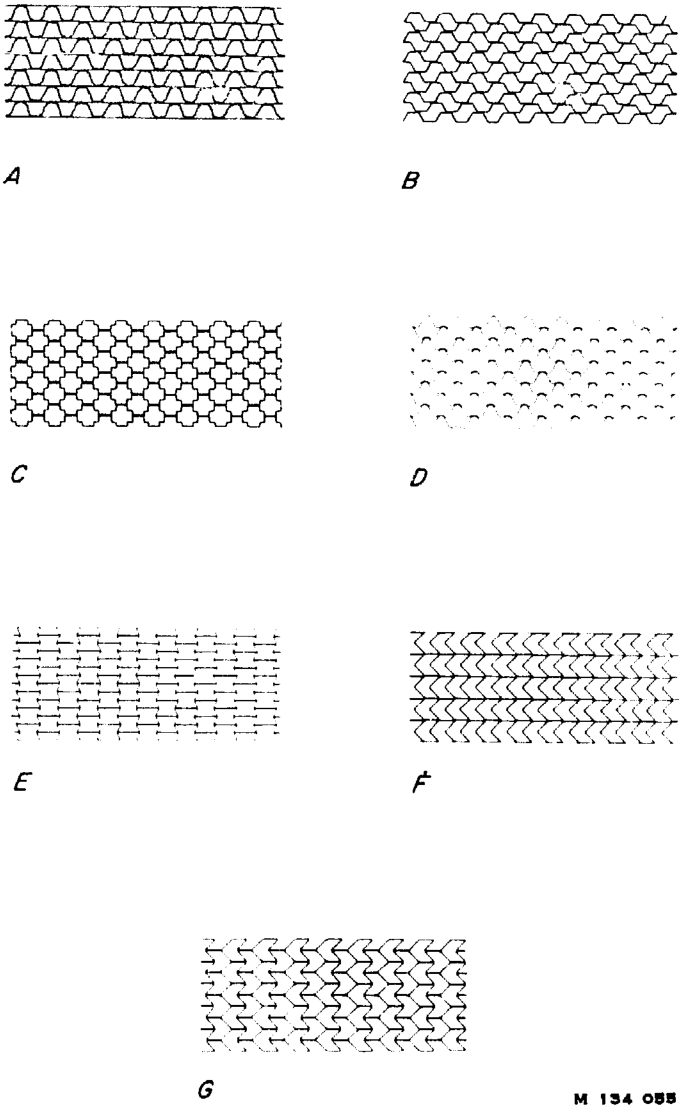

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Figure 12–3.—Cell configurations for formable paper honeycomb cores.

Manufacturing Operations

The principal operation in the manufacture of sandwich panels is bonding the facings to the core. Special presses are needed for sandwich panel manufacture to avoid crushing lightweight cores; pressures required are usually lower than can be obtained in the range of good pressure control on presses ordinarily used for plywood or plastic manufacture. Because pressure requirements are low, however, simple and perhaps less costly presses could be used. Continuous roller presses or fluid pressure equipment may also be suitable. Certain special problems arise in the pressing of sandwich panels, but their manufacture is basically not complicated.

Adhesives must be selected to provide the necessary joint strength and permanence, as well as the working properties needed for fabrication of the panels. The facing materials, especially if metallic, may need special surface preparation before the adhesive is applied.

In certain sandwich panels, loading rails or edgings are placed between the facings at the time of assembly. Special fittings or equipment, such as heating coils, plumbing, or electrical wiring conduit, can be placed more easily in the panel during manufacture than after it is completed.

Some of the most persistent difficulties in the use of sandwich panels are caused by the necessity for edges, inserts, and connectors for panels. In some cases, the problem involves tying together thin facing materials without causing severe stress concentrations; in other cases, such as furniture manufacture, the problem is "showthrough" of core or inserts through decorative facings. These difficulties are minimized by a choice of materials in which the rate and degree of differential dimensional movement between core and insert are at a minimum.

STRUCTURAL DESIGN OF SANDWICH CONSTRUCTION

The structural design of sandwich construction may be compared to the design of an I-beam; the facings of the sandwich represent the flanges of the I-beam, and the sandwich core represents the I-beam web. The core of the sandwich, through the bonding adhesive, carries shearing loads and supports the thin facings against lateral wrinkling caused by compressive loads in the facings.

In general, the procedure is to provide facings thick enough to carry the compression and tension stresses, and then to space the facings with a core thick enough to impart stiffness and bending strength to the construction. The core should be strong enough to carry the shearing loads specified for the design. The construction should be checked for possible buckling, as for a column or panel in compression, and for possible wrinkling of the facings.

The core material itself is assumed to contribute nothing to the stiffness of the sandwich construction, because it usually has a low modulus of elasticity. The facing moduli of elasticity are usually at least 100 times as great as the core modulus of elasticity. The core material may also have a small shear modulus. This small shear modulus causes increased deflections of sandwich constructions subjected to bending and decreased buckling loads of columns and edge-loaded panels, compared to constructions in which the core shear modulus is large. The effect of this low shear modulus is greater for short beams and columns and small panels than it is for long beams and columns and large panels.

The bending stiffness of sandwich construction having facings of equal or unequal thickness is given by:

$$D = \frac{E_1 t_1 E_2 t_2 h^2}{E_1 t_1 + E_2 t_2} \qquad (12\text{–}1)$$

where D is the stiffness per unit width of sandwich construction (product of modulus of elasticity and moment of inertia of the cross section); E_1, E_2 are the moduli of elasticity of facings 1 and 2; t_1, t_2 are the facing thicknesses; and h is the distance between facing centroids.

The shear stiffness of sandwich, per unit width, is given by:

$$U = hG_c \qquad (12\text{–}2)$$

where G_c is the core shear modulus associated with distortion of the plane perpendicular to sandwich facings and parallel to the sandwich length.

The bending stiffness, D, and shear stiffness, U, of sandwich construction are used to compute deflections and buckling loads of sandwich panels.

The general expression for the deflection of flat sandwich beams is given by:

$$\frac{d^2y}{dx^2} = -\frac{M_x}{D} + \frac{1}{U}\frac{dS_x}{dx} \qquad (12\text{–}3)$$

where y is deflection; x is distance along the beam, M_x is bending moment at point x (per unit beam width); S_x is shearing force at point x (per unit beam width); D is flexural stiffness; and U is shear stiffness. Integration of this formula leads to the following general expression for deflection of a sandwich beam:

$$y = \frac{k_b P a^3}{D} + \frac{k_s P a}{U} \qquad (12\text{–}4)$$

where y is deflection, P is total beam load per unit beam width, a is span, and k_b and k_s are constants dependent upon beam loading. The

Table 12-1.—*Values of k_b and k_s for several beam loadings*

Loading	Beam ends	Deflection at—	k_b	k_s
Uniformly distributed	Both simply supported	Midspan	$\frac{5}{384}$	$\frac{1}{8}$
	Both clamped	Midspan	$\frac{1}{384}$	$\frac{1}{8}$
Concentrated at midspan	Both simply supported	Midspan	$\frac{1}{48}$	$\frac{1}{4}$
	Both clamped	Midspan	$\frac{1}{192}$	$\frac{1}{4}$
Concentrated at outer quarter points	Both simply supported	Midspan	$\frac{11}{768}$	$\frac{1}{8}$
	Both simply supported	Load point	$\frac{1}{96}$	$\frac{1}{8}$
Uniformly distributed	Cantilever, 1 free, 1 clamped	Free end	$\frac{1}{8}$	$\frac{1}{2}$
Concentrated at free end	Cantilever, 1 free, 1 clamped	Free end	$\frac{1}{3}$	1

first term in the right side of this formula gives the bending deflection and the second term the shear deflection. Values of k_b and k_s for several loadings are given in table 12-1.

If the sandwich panel is supported on all four edges instead of two ends, the deflections and stresses are decreased. For a complete treatment of sandwich plates under loads normal to the plane of the plate see the Bibliography at the end of this chapter.

The buckling load, per unit width, of a sandwich panel with no edge members and loaded as a simply supported column is given by the formula:

$$N = \frac{\pi^2 n^2 D}{a^2\left(1 + \frac{\pi^2 n^2 D}{a^2 U}\right)} \qquad (12\text{-}5)$$

where N is the buckling load per unit panel width, a is panel length, D is flexural stiffness, U is shear stiffness, and n is number of half waves into which the panel buckles. A minimum of N is obtained for $n = 1$ and this minimum is then

$$N_{cr} = \frac{\pi^2 D}{a^2\left(1 + \frac{\pi^2 D}{a^2 U}\right)} \quad (n = 1) \qquad (12\text{-}6)$$

This buckling form is often called "general buckling" and is illustrated in sketch *A* of figure 12-4. An upper limit is also obtainable from the formula for N and this is given for $n = \infty$. This limit is often called the "shear instability" limit because the formula for N becomes

$$N_s = U \quad (n = \infty) \qquad (12\text{-}7)$$

The appearance of this buckling failure resembles a crimp as illustrated in sketch *B* of figure 12-4. "Shear instability" or "crimping" failure is always possible for edge-loaded sandwich and is a limit for general instability and not a localized failure.

If the sandwich panel under edge load has edge members, inserts perhaps, the edge members will carry a load proportional to their transformed area (area multiplied by ratio of

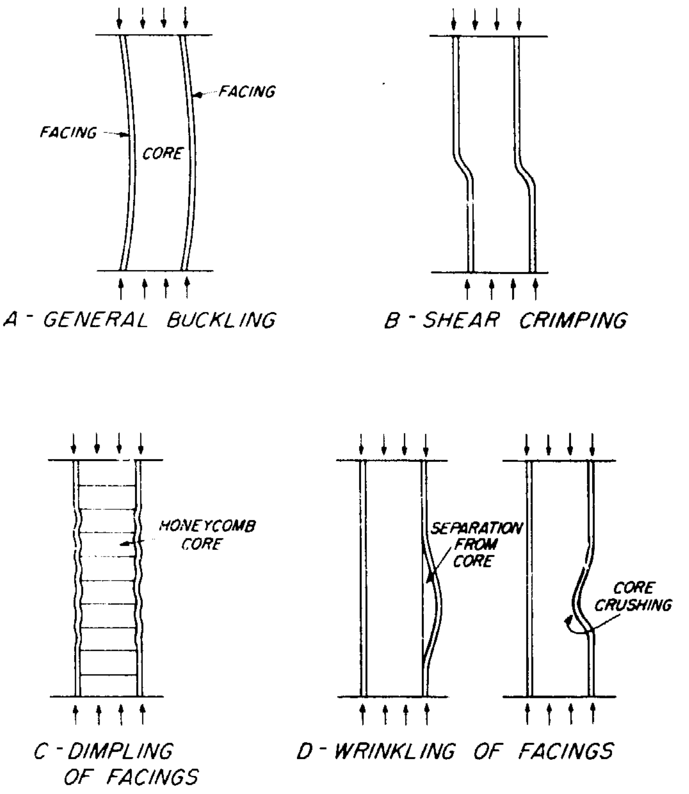

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Figure 12-4.—Modes of failure of sandwich construction under edgewise loads. *A*, general buckling; *B*, shear crimping; *C*, dimpling of facings; *D*, wrinkling of facings either away from or into core.

edge member modulus of elasticity to the facing modulus of elasticity). Edge members will also raise the overall panel buckling load because of restraints at edges. Estimates of the effects of edge members can be obtained from Zahn and Cheng. If the edge members are rigid enough to provide simple support but do not clamp the panel edge, an increase in buckling load per unit panel width is obtained. For a sandwich of isotropic facings on an isotropic core, the buckling load for a panel with a length greater than its width (loaded edge) is given by the formula:

$$N_{cr} = \frac{4\pi^2 D}{b^2\left(1 + \frac{\pi^2 D}{b^2 U}\right)^2} \quad \text{for } \frac{\pi^2 D}{b^2 U} \leq 1 \tag{12-8}$$

$$N_{cr} = U \text{ for } \frac{\pi^2 D}{b^2 U} \geq 1$$

where N_{cr} is buckling load per unit panel width and b is panel width. More complete formulas including sandwich with both facings orthotropic, one facing isotropic and one orthotropic, and with orthotropic cores, are given by Kuenzi, Norris, and Jenkinson.

Buckling criteria for flat rectangular sandwich panels under loads other than compression have also been derived. Details for panels in edgewise shear are given by Kuenzi, Ericksen, and Zahn, and for panels in edgewise bending and under combined loading by Kimel.

Buckling of sandwich walls of cylinders has been derived for axial compression loading by Kimel and Stein and Mayers, for torsion loading by March and Kuenzi, and for external pressure by Kuenzi, Bohannan, and Stevens. All are covered in Military Handbook 23A.

Buckling of sandwich components has been emphasized because buckling causes complete failure, usually producing severe shear crimping at the edges of the buckles. Another important factor is the necessity that facing stresses be no more than allowable values at design loads. Facing stresses are obtained by dividing the load by the facing area under load. (Thus for sandwich in compression, the facing stress $f = \frac{N}{2t}$.)

In a strip of sandwich construction subjected to both bending moments and shear loads, the mean facing stresses are given by:

$$f_{cs} = \frac{M}{t_{1,2}h} \tag{12-9}$$

where $f_{1,2}$ is the mean compression or tension stress in facing 1 or 2; $t_{1,2}$ is the thickness of facing 1 or 2; and M is the bending moment per unit width of sandwich. The shear stress in the core is given by

$$f_{cs} = \frac{S}{h} \tag{12-10}$$

where f_{cs} is core shear stress and S is applied shear load per unit width of sandwich.

Localized failure of sandwich must be avoided. Such failure is shown as dimpling of the facings in sketch C and as wrinkling of the facings in sketch D of figure 12–4. The stress at which dimpling of the facings into a honeycomb core begins is given approximately by the formula:

$$f_d = 2E\left(\frac{t}{s}\right)^2 \tag{12-11}$$

where f_d is facing stress at beginning of dimpling, E is facing modulus of elasticity, t is facing thickness, and s is cell size of honeycomb core (radius of inscribed circle). Increase in dimpling stress can be attained by decreasing the cell size. Wrinkling of the sandwich facings can occur because of instability of the thin facing supported by a lightweight core which acts as the facing elastic foundation. Wrinkling can occur because of poor facing-to-core bond, resulting in a separation of facing from the core (fig. 12–4, D). Increase in bond strength should produce wrinkling by core crushing. Thus a convenient rule of thumb is to require that the sandwich flatwise tensile strength (bond strength) is no less than flatwise compressive core strength. Approximate wrinkling stress for a fairly flat facing (precluding bond failure) is given by:

$$f_w = \frac{1}{2}(EE_cG_c)^{1/3} \tag{12-12}$$

where f_w is facing wrinkling stress, E_c is core modulus of elasticity in a direction perpendicular to facing, and G_c is core shear modulus. Localized failure is not accurately predictable and designs should be checked by ASTM tests of small specimens.

Because sandwich constructions are composed of several materials, it is often of interest to attempt to design a minimum weight of the construction for a particular component. Several components and a general analysis for stiffness are discussed by Kuenzi. For a sandwich with similar facings having a required bending stiffness, D, the dimensions to produce the minimum weight sandwich are given by:

$$h = 2\left(\frac{Dw}{Ew_c}\right)^{1/3} \qquad (12\text{–}13)$$

$$t = \frac{w_c}{4w}\,h$$

where h is distance between facing centroids, t is facing thickness, E is facing modulus of elasticity, w is facing density, and w_c is core density. The resulting construction will have very thin facings on a very thick core and will be proportioned so that the total core weight is two-thirds the total sandwich weight minus bond weight. It may be a most impractical construction because the required exceedingly thin facings may not be available.

Many detailed design procedures necessary for rapid design of sandwich components for aircraft are summarized in Military Handbook 23A. Although the design of aircraft sandwich has many details not needed for other applications, the principles are broad and can be applied to components of structures other than aircraft.

DIMENSIONAL STABILITY, DURABILITY, AND BOWING OF SANDWICH PANELS

In a sandwich panel any dimensional movement of one facing with respect to the other due to changes in moisture content and temperature causes bowing of an unrestrained panel. Thus, although the use of dissimilar facings is often desirable from an economic or decorative standpoint, the dimensional instability of the facings during panel manufacture or exposure may rule out possible benefits. If dimensional change of both facings is equal, the length and width of the panel will increase or decrease but bowing will not result.

The problem of dimensional stability is chiefly related to the facings, because the core does not have enough stiffness to cause bowing of the panel or to cause it to remain flat. The magnitude of the bowing effect, however, depends on the thickness of the core.

It is possible to calculate mathematically the bowing of a sandwich construction if the percent expansion of each facing is known. The maximum deflection is given approximately by:

$$\Delta = \frac{ka^2}{800h} \qquad (12\text{–}14)$$

where k is the percent expansion of one facing as compared to the opposite facing; a, the length of the panel; and h, the total sandwich thickness.

In conventional construction, vapor barriers are often installed to block migration of vapor to the cold side of a wall. Various methods have been tried or suggested for reducing vapor movement through sandwich panels, which causes a moisture differential with resultant bowing of the panels. These include bonding metal foil within the sandwich construction; blending aluminum flakes with the resin bonding adhesives; and using plastic vapor barriers between veneers, overlay papers, special finishes, or metal or plastic facings. Because added cost is likely, some of these methods should not be resorted to unless need for them has been demonstrated.

A large test unit simulating use of sandwich panels in houses was constructed at the Forest Products Laboratory in 1947. The panels used, comprising various facings on paper honeycomb cores, were observed for bowing and general performance. The experimental assembly shown in figure 12–5 represents the type of construction used in the test unit. Details of observed behavior of various sandwich panel constructions after exposure in the test unit for 20 years are given by Sherwood. The major conclusions were that with proper combinations of facings, core, and adhesives, satisfactory sandwich panels can be assured by careful fabrication techniques. This was indicated by results of strength tests conducted on panels exposed for up to 20 years in the unit.

THERMAL INSULATION OF SANDWICH PANELS

Satisfactory thermal insulation can best be obtained with sandwich panels by using cores having low thermal conductivity, although the use of reflective layers on the facings is of some value. Paper honeycomb cores have thermal conductivity values (k values) ranging from 0.30 to 0.65 British thermal units per hour per 1° F. per square foot per inch of thickness, depending on the particular core construction. The k value does not vary linearly with core

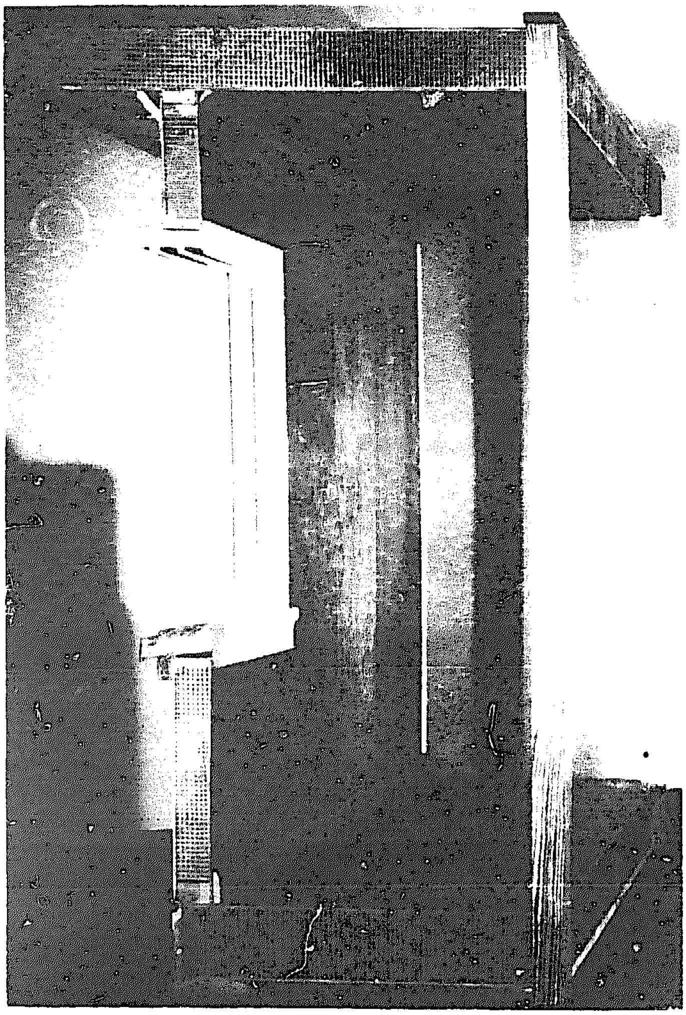

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Figure 12–5.—Experimental assembly used to investigate the performance of sandwich panels for house construction.

thickness for a true honeycomb core because of direct radiation through the core cell opening from one facing to the other. Honeycomb with open cells can also have greater conductivity if cells are large enough (larger than about ⅜ inch) to allow convection currents to develop.

An improvement in the insulation value can be realized by filling the honeycomb core with fill insulation or a foamed-in-place resin.

FIRE RESISTANCE OF SANDWICH PANELS

In tests at the Forest Products Laboratory, the fire resistance of wood-faced sandwich panels was appreciably higher than that of hollow panels faced with the same thickness of plywood. Fire resistance was greatly increased when coatings that intumesce on exposure to heat were applied to the core material. The spread of fire through the honeycomb core depended to a large extent on the alinement of the flutes in the core. In panels having flutes perpendicular to the facings, only slight spread of flame occurred. In cores in which flutes were parallel to the length of the panel, the spread of flame occurred in the vertical direction along open channels. Resistance to flame spread could be improved by placing a barrier sheet at the top of the panel or at intervals in the panel height, or, if strength requirements permit, by simply turning the length of the core blocks at 90° to the vertical direction.

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Chapter 13

BENT WOOD MEMBERS

BENT WOOD MEMBERS

Bending can provide a variety of functional and esthetically pleasing wood members, ranging from large curved arches to small furniture components. Bent wood may be formed with or without softening or plasticizing treatments and with or without end pressure. The curvature of the bend, size of the member, and intended use of the product determine the production method.

LAMINATED MEMBERS

In the United States, curved pieces of wood were once laminated chiefly to produce such small items as parts for furniture and pianos. However, the principle was extended to the manufacture of arches for roof supports in farm, industrial, and public buildings (fig. 13–1) and other types of structural members.

Both softwoods and hardwoods are suitable for laminated bent structural members, and thin material of any species can be bent satisfactorily for such purposes. The choice of species and adhesive depends primarily on the cost, required strength, and demands of the application (see ch. 9 and 10).

Laminated curved members are produced from dry stock in a single bending and gluing operation. This process has several advantages over bending single-piece members:

(1) Bending thin laminations to the required radius involves only moderate stress and deformation of the wood fibers, eliminating the need for treatment with steam or hot water and associated drying and conditioning of the finished product.

(2) Because of the moderate stress induced in bending, stronger members are produced.

(3) The tendency of laminated members to change shape with changes in moisture content is less than that of single-piece bent members.

(4) Ratios of thickness of member to radius of curvature that are impossible to obtain by bending single pieces can be attained readily by laminating.

(5) Curved members of any desired length can be produced by staggering the joints in the laminations.

Design criteria for glued-laminated timbers are discussed in chapter 10.

Straight laminated members also can be steamed and bent after they are glued. However, this type of procedure requires an adhesive that will not be affected by the steaming or boiling treatment and complicates conditioning of the finished product.

CURVED PLYWOOD

Curved plywood is produced (1) by bending and gluing the plies in one operation, or (2) by bending previously glued flat plywood. Curved plywood made by method (1) is more stable in curvature than plywood curved by method (2).

Plywood Bent and Glued Simultaneously

In bending and gluing plywood in a single operation, glue-coated pieces of veneer are assembled and pressed over or between curved forms; pressure and sometimes heat are applied through steam or electrically heated forms until the glue sets and holds the assembly to the desired curvature. Some of the laminations are at an angle, usually 90°, to other laminations, as in the manufacture of flat plywood. The grain direction of the thicker laminations is normally parallel to the axis of the bend to facilitate bending.

A high degree of compound curvature can be obtained in an assembly comprising a considerable number of thin veneers. First, for both the face and back of the assembly, the two outer plies are bonded at 90° to each other in a flat press. The remaining veneers are then glue-coated and assembled at any desired angle to each other. The entire assembly is hot pressed to the desired curvature.

Bonding the two outer plies before molding allows a higher degree of compound curvature without cracking the face plies than could otherwise be obtained. Where a high degree of compound curvature is required, the veneer should be relatively thin, $\frac{1}{32}$ inch or less, with a moisture content of about 12 percent.

The advantages of bending and gluing plywood simultaneously to form a curved shape are similar to those for curved laminated members, and in addition, the cross plies give the curved members properties characteristic of cross-banded plywood. Curved plywood shells for furniture manufacture are examples of these bent veneer and glued products.

Molded Plywood

Although any piece of curved plywood may properly be considered to be molded, the term "molded" is usually reserved for plywood that is glued to the desired shape, either between curved forms or with fluid pressure. The molding of plywood with fluid pressure applied by flexible bags of some impermeable material produces plywood parts of various degrees of compound curvature. In "bag molding" fluid pressure is applied through a rubber bag by air, steam, or water. The veneer may be wrapped around a form and the whole assembly enclosed in a bag and subjected to pressure in an autoclave, the pressure in the bag being "bled." Or the veneer may be inserted inside a metal form and, after the ends have been attached and sealed, pressure applied by inflating a rubber bag. The form may be heated electrically or by steam.

Plywood Bent After Gluing

After the plies are glued together, flat plywood is often bent by methods that are somewhat similar to those used in bending solid wood. To bend plywood properly to shape, it must be plasticized by some means, usually moisture or heat, or a combination of both. The amount of curvature that can be introduced into a flat piece of plywood depends on numerous variables, such as moisture content, direction of grain, thickness and number of plies, species and quality of veneer, and the

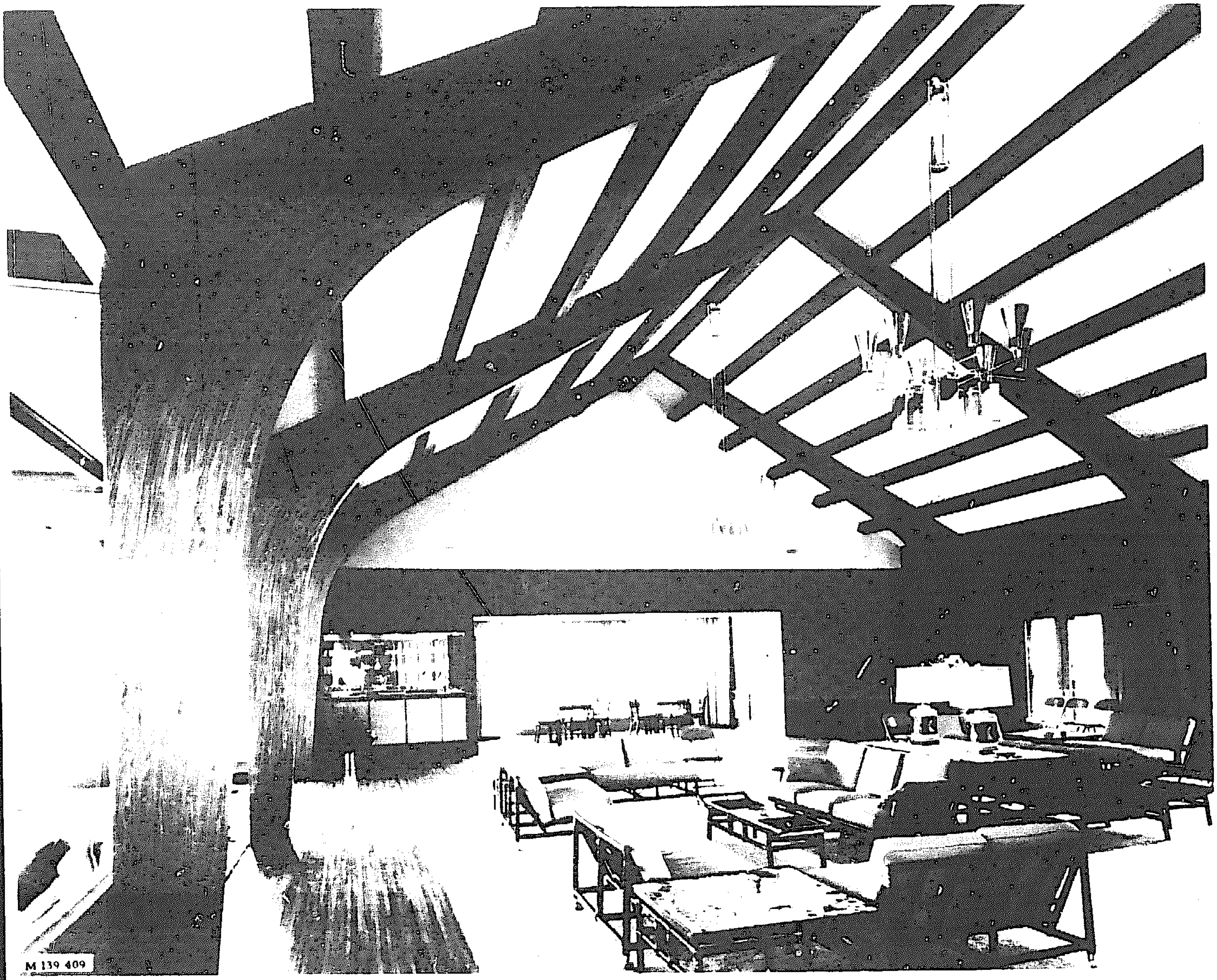

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Figure 13-1.—Curved laminated arch provides pleasing lines in this building. The laminations are bent without end pressure against a form and glued together.

technique applied in producing the bend. Plywood is normally bent over a form or a bending mandrel.

Flat plywood glued with a waterproof adhesive can be bent to compound curvatures after gluing. No simple criterion, however, is available for predetermining whether a specific compound curvature can be imparted to flat plywood. Soaking the plywood and the use of heat during forming are aids in manipulation. Normally the plywood to be postformed is first thoroughly soaked in hot water and then dried between heated male and female dies attached to a hydraulic press. If the use of postforming for bending flat plywood to compound curvatures is contemplated, exploratory trials to determine the practicability and the best procedure are recommended. It should be remembered that in postforming plywood to compound curvatures, all of the deformation must be by compression or shear, as plywood cannot be stretched. Hardwood species, such as birch, poplar, and gum, are normally used in plywood that is to be postformed.

VENEERED CURVED MEMBERS

Veneered curved members are usually produced by gluing veneer to one or both faces of a curved solid wood base. The bases are ordinarily bandsawed to the desired shape or bent from a piece grooved with saw kerfs on the concave side at right angles to the directions of bend. Pieces bent by making saw kerfs on the concave side are commonly reinforced and kept to the required curvature by gluing splines, veneer, or other pieces to the curved base.

Veneering over curved solid wood finds use mainly in furniture. The grain of the veneer is commonly laid in the same general direction as the grain of the curved wood base. The use of crossband veneers, that is, veneers laid with the grain at right angles to the grain of the base and face veneer, reduces the tendency of the member to split.

SOLID WOOD MEMBERS

With material thicker than veneer, some type of softening or plasticizing treatment normally is required to bend solid wood to sharp curvatures. Bent solid wood members are used primarily as furniture parts (fig. 13–2), boat frames, implement handles, and in manufacture of sporting goods.


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Figure 13–2.—A chair with bent solid wood parts.

In general, hardwoods possess better bending quality than softwoods for this type of member. The species commonly used to produce solid bent members are white oak, red oak, elm, hickory, ash, beech, birch, maple, walnut, sweetgum, and mahogany. Some softwoods can be used, however, including yew and Alaska-cedar, and Douglas-fir, southern pine, northern and Atlantic white-cedar, and redwood are used for boat planking. Solid lumber for boat planks is often bent to moderate curvature after being steamed or soaked.

Bending Process

When a piece of wood is bent along its length, it is stretched in tension along the convex side of the bend and compressed along the concave side. If bending involves severe deformation, most of the deformation should be forced to take place as compression.

Wood softened with moisture and heat or by plasticizing with chemicals can be compressed considerably but stretched very little. In bending, therefore, the wood must be compressed lengthwise while restraining it from stretching along the convex side. Various devices have been developed to accomplish this, the most efficient being a tension strap complete with end blocks or clamps or a tension strap with a reversed lever and end blocks. In hot-plate pressing operations a metal pan is fitted with end bars to provide needed end pressure. Other devices have been developed for bending solid wood, and most involve forcing the wood member against a form.

Hand- and machine-bent members restrained by end pressure are cooled and dried while held in their curved shapes. When the bent member has dried to a moisture content suited for its application, the restraining devices are removed and the piece will hold its curved shape.

Bending Stock

Bending stock should be free from serious cross grain and distorted grain, such as may occur near knots. The slope of grain should not be greater than about 1 to 15. Knots, decay, surface checks, shake, pith, and exceptionally light or brashy wood should be avoided.

Although green wood can be bent to produce most curved members, difficulties are introduced in drying and fixing the bent piece and reducing the moisture content to a level suited for the end use. Bending stock that has been dried to a low moisture content (12 to 20 pct.) requires steaming or soaking to increase its moisture content to the point where it is sufficiently plastic for successful bending.

Wood of poor bending quality can be improved by gluing veneer of good bending quality to the surface that is to be concave. The veneer assumes the maximum amount of compressive deformation and supports the inner face of the wood. Wood treated with preservatives can be bent satisfactorily.

Plasticizing Bending Stock

Steaming at atmospheric or low gage pressure or soaking in boiling or nearly boiling water are satisfactory methods of plasticizing many wood species for bending. Heat and moisture are added to wood below 20 percent moisture content, and wood at moisture contents of 20 to 25 percent is heated while the moisture is retained. Steaming at high pressures causes wood to become plastic, but wood treated with high-pressure steam generally does does not bend as well as wood treated at low or atmospheric pressure.

Wood can be plasticized by a great variety of chemicals. Such chemicals behave like water, in that they are adsorbed and cause swelling. Common chemicals that plasticize wood include urea, dimethylol urea, low-molecular weight phenol-formaldehyde resin, dimethyl sulfoxide, and liquid ammonia. Urea and dimethylol urea have received limited commercial attention, and a free-bending process using liquid ammonia has been patented. Wood members after immersion in liquid ammonia or treatment under pressure with ammonia in the gas phase can be readily molded or shaped. As the ammonia evaporates, the wood stiffens and retains its new shape.

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Chapter 14

CONTROL OF MOISTURE CONTENT AND DIMENSIONAL CHANGES

CONTROL OF MOISTURE CONTENT AND DIMENSIONAL CHANGES

Correct seasoning, handling, and storage of wood will minimize moisture content changes that might occur in service. If moisture content is controlled within reasonable limits by such methods, major problems from dimensional changes will be avoided. Wood is subject naturally to dimensional changes. In the living tree, wood contains large quantities of water. As green wood dries, most of this water is removed. The moisture remaining in the wood tends to come to equilibrium with the relative humidity of the air. Also, when the moisture content is reduced below the fiber saturation point, shrinkage starts to occur.

This discussion is concerned with moisture content determination, recommended moisture content values, seasoning methods, methods of calculating dimensional changes, design factors affecting such changes in structures, and moisture content control during transit, storage, and construction. Data on green moisture content, fiber saturation point, shrinkage, and equilibrium moisture content are given with information on other physical properties in chapter 3.

Wood in service is virtually always undergoing at least slight changes in moisture content. The changes in response to daily humidity changes are small and usually of no consequence. Changes due to seasonal variation, although gradual, tend to be of more concern. Protective coatings retard changes but do not prevent them.

Generally, no significant dimensional changes will occur if wood is fabricated or installed at a moisture content corresponding to the average atmospheric conditions to which it will be exposed. When incompletely seasoned material is used in construction, some minor changes can be tolerated if the proper design is used.

DETERMINATION OF MOISTURE CONTENT

The amount of moisture in wood is ordinarily expressed as a percentage of the weight of the wood when ovendry. Four methods of determining moisture content are covered by Designation D 2016 of the American Society for Testing and Materials. Two of these, the ovendrying and the electrical method, are described here.

Ovendrying has been the most universally accepted method for determining moisture content, but it is slow and necessitates cutting the wood. In addition it gives values slightly higher than true moisture content with woods containing volatile extractives. The electrical method is rapid, does not require cutting the wood, and can be used on wood in place in a structure. However, considerable care must be taken to use and interpret the results correctly. Generally, use of the electrical method is limited to moisture content values below 30 percent.

Ovendrying Method

In the ovendrying method, specimens are taken from representative boards or pieces of a quantity of lumber or other wood units. With lumber, the specimens should be obtained at least 20 inches from the ends of the pieces. They should be free from knots and other irregularities, such as bark and pitch pockets. Specimens from lumber should be full cross sections 1 inch along the grain. Specimens from larger items may be representative sectors of such sections or subdivided increment borer or auger chip samples. Convenient amounts of chips and particles can be selected at random from larger batches, with care being taken to insure that the sample is representative of the batch. Samples of veneer should be selected from four or five locations in a sheet to insure that the sample average will accurately indicate the average of the sheet.

Each specimen should be weighed immediately, before any drying or reabsorption of moisture has taken place. If the specimen cannot be weighed immediately after it is taken, it should be placed in a plastic bag or tightly wrapped in metal foil to protect it from moisture change until it can be weighed. After weighing, the specimen is placed in an oven heated to 214° to 221° F. (101° to 105° C.) and kept there until constant weight is reached. A lumber section will reach a constant weight in 12 to 48 hours. Smaller specimens will take less time.

The constant or ovendry weight and the weight of the specimen when cut are used to determine the percentage moisture content with the following formula:

$$\text{Percent moisture content} = \frac{\text{Weight when cut} - \text{Ovendry weight}}{\text{Ovendry weight}} \times 100 \qquad (14\text{–}1)$$

Electrical Method

The electrical method for determining moisture content makes use of such properties of wood as its resistance, dielectric constant, and power-loss factor. Accurate moisture meters for solid wood items are commercially available. The instruments determine the moisture content through its effect upon the direct-current electrical resistance of wood (resistance-type meters) or its effect on a capacitor in a high-frequency circuit in which the wood serves as the dielectric material (power-loss and capacitive admittance meters).

The principal advantages of the electrical method over the ovendrying method are its speed and convenience. Only a few seconds are required, and the piece of wood being tested is not cut or damaged, except for driving a few electrode needle points into the wood when using the resistance-type meters. Thus, the electrical method is adaptable to rapid sorting of lumber on the basis of moisture content, measuring the moisture content of wood installed in a building, or, when used in accordance with the ASTM Designation D 2016, establishing the moisture content of a quantity of lumber or other wood items.

For resistance meters, the 5/16- to 7/16-inch needle electrodes ordinarily supplied are appropriate for wood that has been in use for 6 months or longer, or for lumber up to 1½ inches thick with a normal drying moisture gradient. For wood with normal moisture gradients, the pins should be driven to a depth of one-fifth to one-fourth of the wood thickness. If other than normal drying gradients are present, best accuracy can be obtained by exploring the gradient through readings made at various penetration depths.

Radiofrequency power loss meters are supplied with electrodes appropriate to the type and size of material to be tested. The field from the electrodes should penetrate roughly to the middle of the specimen.

Ordinarily, moisture meters should not be used on lumber with wet or damp surfaces, because the wet surface will cause inaccurate readings. A resistance meter with insulated-pin electrodes can be used, with caution, on such stock.

Although some meters have scales that go up to 120 percent, the range of moisture content that can be measured reliably is 0 to about 30 percent for radiofrequency meters and about 6 to 30 percent for resistance meters. The precision of the individual meter readings decreases near the limits of these ranges. Any readings above 30 percent must be considered only qualitative. When the meter is properly used on a quantity of lumber dried below fiber saturation, the average moisture content from the corrected meter readings should be within 1 percent of the true average.

To obtain accurate moisture content values, each instrument should be used in accordance with its manufacturer's instructions. The electrodes should be appropriate for the material being tested and properly oriented. The readings should be carefully taken as soon as possible after inserting the electrode. A species correction supplied with the instrument should be applied when appropriate. Temperature corrections then should be made for resistance-type meters if the temperature of the wood differs considerably from the temperature of calibration used by the manufacturer. Approximate corrections are to add or subtract about 0.5 percent for each 10° F. the wood differs from the calibration temperature; the correction factors are added to the readings for temperatures below the calibration temperature and subtracted from the readings for temperatures above this temperature.

RECOMMENDED MOISTURE CONTENT

Installation of wood at the moisture content percentages recommended here for different environments will reduce future changes in moisture content, thus minimizing dimensional changes after the wood is placed in service. The service condition to which the wood will be exposed—outdoors, in unheated buildings, or in heated and air-conditioned buildings—should be considered in determining moisture content requirements.

Timbers

Ideally, solid timbers should be seasoned to the average moisture content they will reach in service. While this optimum is possible with lumber less than 3 inches thick, it is seldom practical to obtain fully seasoned timbers, thick joists, and planks. When thick solid members are used, some shrinkage of the assembly should be expected. In the case of builtup assemblies such as roof trusses, it may be necessary to tighten the bolts or other fastenings from time to time as the members shrink.

Lumber

The moisture content requirements are more exacting for finish lumber and wood products used inside heated and air-conditioned buildings than those for lumber used outdoors or in unheated buildings. For general areas of the United States, the recommended moisture content values for wood used inside heated buildings are shown in figure 14–1. Values and tolerances both for interior and exterior use of wood in various forms are given in table 14–1. If the average moisture content value is within 1 percent of that recommended and all pieces fall within the individual limits, the entire lot is probably satisfactory.

General commercial practice is to kiln-dry wood for some products, such as flooring and furniture, to a slightly lower moisture content than service conditions demand, anticipating a moderate increase in moisture content during processing and construction. The practice is intended to assure uniform distribution of moisture among the individual pieces. Common grades of softwood lumber and softwood dimension are not normally seasoned to the moisture content values indicated in table 14–1. When they are not, shrinkage effects should be considered in the structural design and construction methods.

The American Softwood Lumber Standard requires that, to be classified as dry lumber, moisture content shall not exceed 19 percent. Much softwood dimension lumber meets this requirement. Some industry grading rules provide for even lower maximums. For example, to be grademarked KD (kiln dry) the maximum moisture content permitted is generally 15 percent.

Glued Wood Products

When veneers are bonded together with cold-setting glues to make plywood, they absorb comparatively large quantities of moisture. To keep the final moisture content low and to minimize redrying of the plywood, the initial moisture content of the veneer should be as low as practical. Very dry veneer, however, is difficult to handle without damage, so the minimum practical moisture content is about 4 percent. Freshly glued plywood intended for interior service should be dried to the moisture content values given in table 14–1.

Hot-pressed plywood and other board products, such as particleboard and hardboard, often do not arrive at the same equilibrium moisture content values given for lumber. The high temperatures used in hot presses cause these products to assume a lower moisture content for a given relative humidity. Since this lower equilibrium moisture content varies widely, depending on the specific type of hot-pressed product, it is recommended that such products be conditioned at 40 to 50 percent relative humidity for interior use and 65 percent for exterior use.

Lumber used in the manufacture of large laminated members should be dried to a moisture content slightly below the moisture content expected in service; thus, moisture absorbed from the glue will not cause the moisture content of the product to exceed the service value. The range of moisture content among laminations assembled into a single member should not exceed 5 percent. Although laminated members are often massive and respond rather slowly to changes in environmental conditions, it is desirable to follow the recommendations in table 14–1 for moisture content at time of installation.

SEASONING OF WOOD

Well-developed techniques have been established for removing the large amounts of moisture normally present in green wood (ch. 3). Seasoning is essentially a drying process but, for uses that require them, seasoning includes equalizing and conditioning treatments to improve moisture uniformity and relieve residual stresses and sets. Careful techniques are necessary, especially during the drying phase, to protect the wood from stain and decay and from excessive drying stresses that cause defects and degrade. The established seasoning methods are air drying, accelerated air drying, and kiln drying. Other methods, such as high-frequency dielectric heating, vapor drying, and solvent seasoning have been developed for special uses.

Drying reduces the weight of wood, with a resulting decrease in shipping costs; reduces or eliminates shrinkage, checking, and warping in service; increases strength and nail-holding power; decreases susceptibility to infection by blue stain and other fungi; reduces chance of attack by insects; and improves the

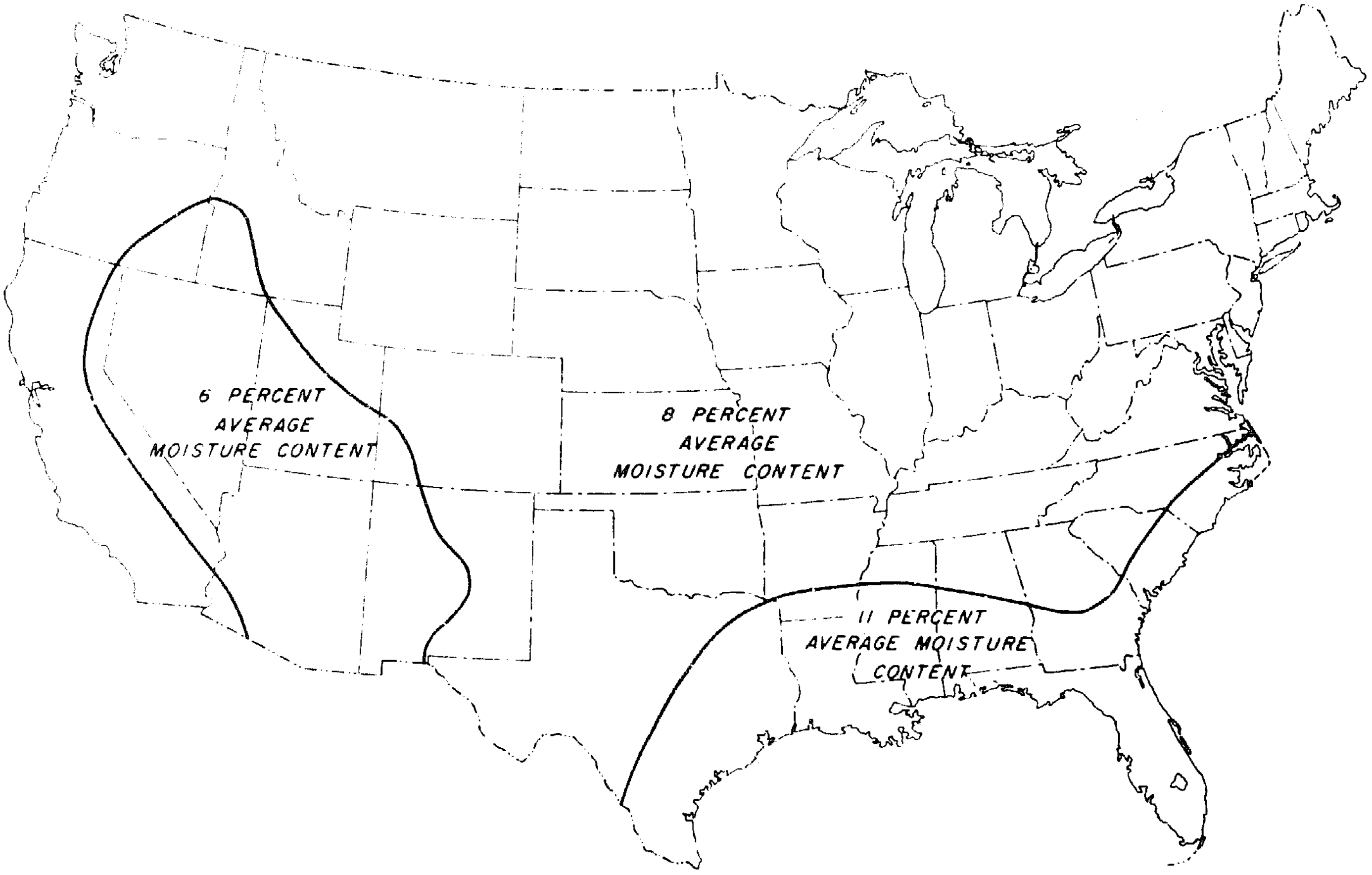

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Figure 14–1.—Recommended average moisture content for interior use of wood products in various areas of the United States.

Table 14–1.—*Recommended moisture content values for various wood items at time of installation*

Use of wood	Moisture content for—					
	Most areas of United States		Dry southwestern area [1]		Damp, warm coastal areas [1]	
	Average [2]	Individual pieces	Average [2]	Individual pieces	Average [2]	Individual pieces
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Interior:						
Woodwork, flooring, furniture, wood trim, laminated timbers, cold-press plywood	8	6–10	6	4–9	11	8–13
Exterior:						
Siding, wood trim, framing, sheathing, laminated timbers	12	9–14	9	7–12	12	9–14

[1] Major areas are indicated in fig. 14–1.

[2] To obtain a realistic average, test at least 10 pct. of each item. If the amount of a given item is small, several tests should be made. For example, in an ordinary dwelling having about 60 floor joists, at least 10 tests should be made on joists selected at random.

capacity of wood to take preservative and fire-retardant treatment and to hold paint.

Sawmill Practice

It is common practice at most softwood sawmills to kiln dry all upper grade lumber intended for finish, flooring, and cut stock. Lower grade boards are often air dried. Dimension lumber is air dried or kiln dried, although some mills ship certain species without seasoning. Timbers are generally not held long enough to be considered seasoned, but some drying may take place between sawing and shipment or while they are held at a wholesale or distributing yard. Sawmills cutting hardwoods commonly classify the lumber for size and grade at the time of sawing. Some mills send all freshly sawed stock to the air-drying yard or an accelerated air-drying operation. Others kiln dry directly from the green condition. Air-dried stock is kiln dried at the sawmill, at a custom drying operation during transit, or at the remanufacturing plant before being made up into such finished products as furniture, cabinet work, interior finish, and flooring.

Air Drying

Air drying is not a complete drying process, except as preparation for uses for which the recommended moisture content is not more than 5 percent below that of the air-dry stock. Even when air-drying conditions are mild, air-dry stock used without kiln drying may have some residual stress and set that can cause distortions after nonuniform surfacing or machining. On the other hand, rapid air drying accomplished by low relative humidities produces a large amount of set that will assist in reducing warp during final kiln drying. Rapid surface drying also greatly decreases the incidence of chemical and sticker stain, blue strain, and decay.

Air drying is an economical seasoning method when carried out (1) in a well-designed yard or shed, (2) with proper piling practices, and (3) in favorable drying weather. In cold or humid weather, air drying is slow and cannot readily reduce wood moisture to levels suitable for rapid kiln drying or for use.

Accelerated air drying involves the use of fans to force the air through the lumber piles in a shed or under other protection from the weather. Sometimes small amounts of heat are used to reduce relative humidity and slightly increase temperature. Accelerated air drying to moisture content levels between 20 and 30 percent may take only one-half to one-fourth as long as ordinary air drying. Moisture content in the stock dried with such acceleration may vary somewhat more than that of stock air dried under natural conditions to the same average moisture level.

Kiln Drying

In kiln drying, higher temperatures and fast air circulation are used to increase the drying rate considerably. Average moisture content can be reduced to any desired value. Specific schedules are used to control the temperature and humidity in accordance with the moisture and stress situation within the wood, thus minimizing shrinkage-caused defects. For some purposes, equalizing and conditioning treatments are used to improve moisture content uniformity and relieve stresses and set at the end of drying, so the material will not warp when resawed or machined to smaller sizes or irregular shapes. Further advantages of kiln drying are the setting of pitch in resinous woods, the killing of staining or decay fungi or insects in the wood, and reductions in weight greater than those achieved by air-drying. At the end of kiln-drying, moisture-monitoring equipment is sometimes used to sort out moist stock for redrying and to insure that the material ready for shipment meets moisture content specifications.

Temperatures of ordinary kiln drying generally are between 110° and 180° F. Elevated-temperature (180° to 212° F.) and high-temperature (above 212° F.) kilns are becoming increasingly common, although some strength loss is possible with higher temperatures (see ch. 4).

Special Drying Methods

Wood has been dried for construction use by boiling in oily liquids, and vapor drying is being used for the partial drying of crossties prior to preservative treatment. Neither process can yet be considered a complete drying method, and each leaves some drying medium in the wood. Drying by high-frequency electrical energy is being used commercially for short blocks of permeable sapwood. Solvent seasoning, involving water-miscible chemicals that replace water as a first step in the process, has been technically developed for some western softwoods but has not been adopted commercially. High-frequency drying and solvent seasoning, properly carried out to dry the wood to low average moisture content values, may give as good results as kiln drying. Such other special drying methods as vacuum and infrared drying have been found unsuitable for commercial use.

Seasoning Degrade

The grading rules of the lumber associations specify the types and amounts of defects permitted in the various grades of dimension stock. Seasoning defects and other degrading factors are considered. The higher grades are practically free of defects, but high-quality material may not be needed for all uses. The defects permitted in the other approved grades have no detrimental effect on the wood's utility in many applications.

Seasoning defects that cause degrade may be classified into three main groups: (1) Those caused by unequal shrinkage (checks, honeycomb, warp, loosening of knots, and collapse); (2) those associated with the action of fungi (molds and stains); and (3) those associated with soluble wood constituents (brown stain and sticker stain). Collapse and warp affect appearance and ease of application. Checking and honeycombing may, in addition, reduce strength. Defects caused by fungi may affect both appearance and strength (see ch. 17).

Brown stain occurs in softwoods. It is a yellow to dark-brown discoloration apparently caused by concentration or chemical transformation of water-soluble materials in the wood. Sticker stain may occur in the air drying of both softwoods and hardwoods. It is caused by color changes of water-soluble materials in the wood under the stickers. Conversely, the chemicals through the rest of the board may undergo color changes while those under the stickers do not, causing light-colored "sticker marking." General blue-gray or gray-brown chemical stain of hardwoods may also be a problem. Although chemical stains cause considerable degrade because of appearance, none of them lower the strength.

Seasoning defects can be largely eliminated by good practice in either air drying or kiln drying. The period immediately after sawing is the most critical. Lumber subject to chemical or brown stain should not be solid piled. It should be piled on stickers under good drying conditions within 2 or 3 days after sawing. Rapid surface drying decreases the incidence of mold, stain, and decay but sometimes additional measures are required (ch. 17). Too-rapid surface drying, however, may cause checking and splitting. Honeycombing and collapse are more likely to occur in hardwoods than in softwoods. These defects are more likely to occur under improper kiln-drying than under air drying, although very severe air-drying conditions can cause them to occur.

Moisture-resistant coatings are sometimes applied to the end-grain surfaces of green lumber to retard end drying and minimize the formation of end checks and end splits. To be effective, the coatings must be applied to the freshly trimmed green lumber before any checking has started. Sprayable wax emulsions are sometimes used on the ends of 1-inch lumber subject to considerable loss by end checking.

Moisture Content of Seasoned Lumber

The trade terms "shipping dry," "air dry," and "kiln dry," although widely used, may not have identical meanings as to moisture content in the different producing regions. Despite the wide variations in the use of these terms, they are sometimes used to describe seasoned lumber. The following statements, which are not exact definitions, outline the categories:

Shipping-dry Lumber.

Lumber that is partially dried to prevent stain or mold in brief periods of transit, preferably with the outer 1/8 inch dried to 25 percent moisture content or below.

Air-dry lumber.

Lumber that has been dried by exposure to the air outdoors or in a shed, or by forced circulation of unhumidified air that has not been heated above 120° F. Commercial air-dry stock generally will have an average moisture content low enough for rapid kiln drying or for rough construction use. These values generally would be in the range of 20 to 25 percent for dense hardwoods and 15 to 20 percent for softwoods and low-density hardwoods. Extended exposure can bring 1- and 2-inch lumber within a percentage point or two of the average exterior equilibrium moisture content of the region. For much of the United States, the minimum moisture content of thoroughly air-dried lumber is 12 to 15 percent.

Kiln-dry lumber.

Lumber that has been dried in a kiln or by some special drying method to an average moisture content specified or understood to be suitable for a certain use. The average should have upper and lower tolerance limits, and all values should fall within the limits. Kiln-dry lumber generally has an average moisture content of 12 percent or below and can be specified to be free of drying stresses.

The importance of suitable moisture content values is recognized, and provisions covering them are now incorporated in some standards and grading rules. Moisture content values in the general grading rules may or may not be suitable for a specific use; if not, a special moisture content specification should be made.

MOISTURE CONTROL DURING TRANSIT AND STORAGE

Lumber and other wood items may change in moisture content and dimension while awaiting shipment, fabrication, or in transit, as well as when stored in a wholesale or retail yard.

When 1-inch dry softwood lumber is shipped in tightly closed boxcars or trucks, or in packages with complete and intact wrappers, average moisture content changes for a package can generally be held to 0.2 percent per month or less. In holds or between decks of ships, dry material absorbs usually about 1.5 percent moisture during normal shipping periods. If green material is included in the cargo, the moisture regain of the dry lumber may be doubled. On the top deck, the moisture regain may be as much as 7 percent.

When 1-inch softwood lumber, kiln-dried to 8 percent or less, is piled solid under a good pile roof in a yard in humid weather, average moisture content of a pile can increase at the rate of about 2 percent per month during the first 45 days. An absorption rate of about 1 percent per month then may be sustained throughout a humid season. Comparable initial and sustaining absorption rates are about 1 percent per month in open sheds and 0.3 percent per month in closed sheds. Stock piled in an open shed in a western location increased 2.7 percent on the inside of solid piles and 3.5 percent on the outside of the pile in a year.

All stock on which any manufacturing has been done should be protected from precipitation and spray, because water that gets into a solid pile tends to be absorbed by the wood instead of evaporating. The extent to which additional control of the storage environment i required depends upon the use to which th wood will be put and the corresponding moisture content recommendations. The moistur content and stress condition of all stock shoul be determined when it is received. If moisture content and stress condition are not a specified or required, stickered storage in a appropriate condition could ultimately brin the stock within the desired moisture conten range. Such storage may also be helpful i relieving stresses in softwoods. If the degre of moisture change required is large, or th material is a hardwood with stress not appropriately relieved, the stock must be redried.

Sheathing and Structural Items

Green or only partially seasoned lumber an timbers should be open piled on stickers an protected from sunshine and precipitation by tight roof. Framing lumber and plywood wit 20 percent or less moisture content can b solid piled in a shed, which affords good protection against sunshine and direct or wind driven precipitation. Preferably, stock abov 12 percent moisture content should be sticke piled to bring its moisture content more in lin with the moisture content in use. Dry lumbe can be piled solid in the open for relativel short periods, but at least a minimum pile cove of waterproofed paper should be used whenever possible. Protective treatments containin a fungicide and water repellents reduce moisture absorption about 50 percent under exposure to intermittent short-term wetting, but d not protect against absorption when exposur to water is prolonged. Because it is difficult t keep rain out completely, long storage of solid piled lumber in the open is not recommended If framing lumber must be stored in the ope for a long time, the lumber should be pile on stickers over good supports, and the pile should be roofed. Solid-piled material that ha become wet again should be treated the sam way.

Finish and Factory Items

Such kiln-dried items as exterior finish, siding, and exterior millwork can be stored in closed but unheated shed. They should b placed on supports raised above the floor, inches if the floor is paved, 12 inches if no paved.

Interior trim, flooring, cabinet work, an material for processing into furniture shoul be stored in a room or closed shed that is heated or dehumidified. Kiln-dried and machined hardwood dimension or softwood cut stock also should be stored under controlled humidity conditions. Under uncontrolled conditions, the ends of such stock may come to a higher moisture content than the balance of the length; then when the stock is straight-line ripped or jointed before edge gluing, subsequent shrinkage will cause splitting or open glue joints.

The simplest way to reduce relative humidity in storage areas of all sizes is to heat the space to a temperature slightly above that of the outside air. Dehumidifiers can be used in small, well-enclosed spaces. If the heating method is used, and there is no source of moisture except that contained in the air, the equilibrium moisture content can be maintained by using the data in the following tabulation:

Desired Equilibrium Moisture Content	Degrees Fahrenheit Above Outside Temperature
Percent	
6	25
7	19
8	15
9	12
10	8
11	5
12	3

Good control can be obtained by using data from the Weather Bureau on the average temperature to be expected for the next 15 or 30 days and setting an ordinary thermostat to control at the desired temperature. Adjustments should be made when actual weather conditions differ considerably from those anticipated. Precise control can be maintained by use of a wood-element hygrostat or relative humidity sensor.

When a dehumidifier is used, the average temperature in the storage space should be known or controlled and table 3–4 should be used to select the proper relative humidity to give the desired average moisture content.

Wood in a factory awaiting or following manufacture can become too dry if the area is heated to 70° F. or higher when there is a low outdoor temperature. Under such circumstances, exposed ends and surfaces of boards or cut pieces will tend to dry to the equilibrium moisture content condition, causing shrinkage and warping. Also an equilibrium moisture content of 4 percent or more below the moisture content of the core of freshly crosscut boards may cause end checking. Simple remedies are to cover piles of partially manufactured items with plastic film and to use properly lowered shop temperatures during nonwork hours. More precise control can be obtained in critical shop and storage areas by humidification. In warm weather, cooling may increase relative humidity, and dehumidification may be necessary.

DIMENSIONAL CHANGES IN WOOD ITEMS

Dry wood undergoes small changes in dimension with normal changes in relative humidity. More humid air will cause slight swelling, and drier air will cause slight shrinkage. These changes are considerably smaller than those involved with shrinkage from the green condition. Approximate changes in dimension can be estimated by a simple formula involving a dimensional change coefficient when moisture content remains within the range of normal use.

Estimate Using Dimensional Change Coefficient

The change in dimension within the moisture content limits of 6 to 14 percent can be estimated satisfactorily by using a dimensional change coefficient based on the dimension at 10 percent moisture content:

$$\Delta D = D_I \left[C_T(M_F - M_I)\right] \quad (14\text{–}2)$$

where: ΔD = change in dimension,
D_I = dimension in inches or other units at start of change,
C_T = dimensional change coefficient, tangential direction (for radial direction, use C_R),
M_F = moisture content (percent) at end of change,
M_I = moisture content (percent) at start of change.

Values for C_T and C_R, derived from total shrinkage values, are given in table 14–2. When M_F is less than M_I, the quantity $(M_F - M_I)$ will be negative, indicating a decrease in dimension; when greater, it will be positive, showing an increase in dimension.

As an example, assuming the width of a flat-grained white fir board is 9.15 inches at 8 percent moisture content, its change in width at 11 percent moisture content is estimated as:

Table 14-2.—*Coefficients for dimensional change due to shrinkage or swelling within moisture content limits of 6 to 14 percent*

Species	Dimensional change coefficient [1]	
	Radial C_R	Tangential C_T
HARDWOODS		
Alder, red	0.00151	0.00256
Apple	.00205	.00376
Ash:		
Black	.00172	.00274
Oregon	.00141	.00285
Pumpkin	.00126	.00219
White, green	.00169	.00274
Aspen, quaking	.00119	.00234
Basswood, American	.00230	.00330
Beech, American	.00190	.00431
Birch:		
Paper	.00219	.00304
River	.00162	.00327
Yellow, sweet	.00256	.00338
Buckeye, yellow	.00123	.00285
Butternut	.00116	.00223
Catalpa, northern	.00085	.00169
Cherry, black	.00126	.00248
Chestnut, American	.00116	.00234
Cottonwood:		
Black	.00123	.00304
Eastern, southern	.00133	.00327
Elm:		
American	.00144	.00338
Rock	.00165	.00285
Slippery	.00169	.00315
Winged, cedar	.00183	.00419
Hackberry	.00165	.00315
Hickory:		
Pecan	.00169	.00315
True hickory	.00259	.00411
Holly, American	.00165	.00353
Honeylocust	.00144	.00230
Locust, black	.00158	.00252
Madrone, Pacific	.00194	.00451
Magnolia:		
Cucumbertree	.00180	.00312
Southern	.00187	.00230
Sweetbay	.00162	.00293
Maple:		
Bigleaf	.00126	.00248
Red	.00137	.00289
Silver	.00102	.00252
Sugar, black	.00165	.00353
Red oak:		
Commercial red	.00158	.00369
California black	.00123	.00230
Water, laurel, willow	.00151	.00350
White oak:		
Commercial white	.00180	.00365
Live	.00230	.00338
Oregon white	.00144	.00327
Overcup	.00183	.00462
Persimmon, common	.00278	.00403
Sassafras	.00137	.00216
Sweetgum	.00183	.00365
Sycamore, American	.00172	.00296
Tanoak	.00169	.00423
Tupelo:		
Black	.00176	.00308
Water	.00144	.00267
Walnut, black	.00190	.00274
Willow:		
Black	.00112	.00308
Pacific	.00099	.00319
Yellow-poplar	.00158	.00289
SOFTWOODS		
Baldcypress	.00130	.00216
Cedar:		
Alaska-	.00095	.00208
Atlantic white-	.00099	.00187
Eastern redcedar	.00106	.00162
Incense-	.00112	.00180
Northern white- [2]	.00101	.00229
Port-Orford-	.00158	.00241
Western redcedar [2]	.00111	.00234
Douglas-fir:		
Coast-type	.00165	.00267
Interior north	.00130	.00241
Interior west	.00165	.00263
Fir:		
Balsam	.00099	.00241
California red	.00155	.00278
Noble	.00148	.00293
Pacific silver	.00151	.00327
Subalpine, corkbark	.00088	.00259
White, grand	.00112	.00245
Hemlock:		
Eastern	.00102	.00237
Western	.00144	.00274
Larch, western	.00155	.00323
Pine:		
Eastern white	.00071	.00212
Jack	.00126	.00230
Loblolly, pond	.00165	.00259
Lodgepole, Jeffrey	.00148	.00234
Longleaf	.00176	.00263
Ponderosa, Coulter	.00133	.00216
Red	.00130	.00252
Shortleaf	.00158	.00271
Slash	.00187	.00267
Sugar	.00099	.00194
Virginia, pitch	.00144	.00252
Western white	.00141	.00259
Redwood:		
Old-growth [2]	.00120	.00205
Second-growth [2]	.00101	.00229
Spruce:		
Black	.00141	.00237
Engelmann	.00130	.00248
Red, white	.00130	.00274
Sitka	.00148	.00263
Tamarack	.00126	.00259

Table 14-2.—*Coefficients for dimensional change due to shrinkage or swelling within moisture content limits of 6 to 14 percent*—continued

Species	Dimensional change coefficient[1]	
	Radial C_R	Tangential C_T
IMPORTED WOODS		
Andiroba, crabwood	.00137	.00274
Angelique	.00180	.00312
Apitong, keruing[2] (All *Dipterocarpus* spp.)	.00243	.00527
Avodire	.00126	.00226
Balsa	.00102	.00267
Banak	.00158	.00312
Cativo	.00078	.00183
Emeri	.00106	.00169
Greenheart[2]	.00390	.00430
Iroko[2]	.00153	.00205
Ishpingo[2]	.00125	.00205
Khaya	.00141	.00201
Kokrodua[2]	.00148	.00297
Lauans:		
Dark red "Philippine mahogany"	.00133	.00267
Light red "Philippine mahogany"	.00126	.00241
Limba	.00151	.00187
Lupuna	.00126	.00230
Mahogany[2]	.00172	.00238
Meranti	.00126	.00289
Nogal[2]	.00129	.00258
Obeche	.00106	.00183
Okoume	.00194	.00212
Parana pine	.00137	.00278
Pau marfim	.00158	.00312
Primavera	.00106	.00180
Ramin	.00133	.00308
Santa Maria	.00187	.00278
Spanish-cedar	.00141	.00219
Teak[2]	.00101	.00186
Virola	.00183	.00342
Walnut, European	.00148	.00223

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[1] Per 1 pct. change in moisture content, based on dimension at 10 pct. moisture content and a straightline relationship between the moisture content at which shrinkage starts and total shrinkage. (Shrinkage assumed to start at 30 pct. for all species except those indicated by footnote 2.)

[2] Shrinkage assumed to start at 22 pct. moisture content.

$$\begin{aligned}\Delta D &= 9.15[0.00245(11-8)]\\ &= 9.15[0.00735]\\ &= 0.06725 \text{ or } 0.067 \text{ inch}\end{aligned}$$

Then dimension at end of change $= D_I + \Delta D$

$$\begin{aligned}&= 9.15 + 0.067\\ &= 9.217 \text{ inches}\end{aligned}$$

The thickness at 11 percent moisture content of the same board can be estimated by using the coefficient $C_R = 0.00112$.

The tangential coefficient, C_T, can be used for both width and thickness if a maximum estimate for dimensional change is desired. The dimension change for boards that are not truly flat- or quartersawn is most easily estimated by using the tangential coefficient, C_T.

Calculation Based on Green Dimensions

Approximate dimensional changes associated with moisture content changes larger than 6 to 14 percent, or when one moisture value is outside of those limits, can be calculated by:

$$\Delta D = \frac{D_I\,(M_F - M_I)}{\dfrac{30(100)}{S_T} - 30 + M_I} \qquad (14\text{-}3)$$

where: ΔD = change in dimension, D_I = dimension in inches or other units at start of change, M_F = moisture content (percent) at end of change, M_I = moisture content (percent) at start of change, S_T = tangential shrinkage (percent) from green to ovendry (tables 3-5 and 3-6) (use radial shrinkage S_R when appropriate).

Neither M_I nor M_F should exceed 30, the assumed moisture content value when shrinkage starts for most species.

DESIGN FACTORS AFFECTING DIMENSIONAL CHANGE IN A STRUCTURE

Framing Lumber in House Construction

Ideally, house framing lumber should be seasoned to the moisture content it will reach in use, thus minimizing future dimensional changes due to frame shrinkage. This ideal condition is difficult to achieve, but some shrinkage of the frame may take place without being visible or causing serious defects after the house is completed. If, at the time the wall and ceiling finish is applied, the moisture content of the framing lumber is not more than about 5 percent above that which it will reach in service (table 14–1), there will be little or no evidence of defects caused by shrinkage of the frame. In heated houses in cold climates, joists over heated basements, studs, and ceiling joists may reach a moisture content as low as 6 to 7 percent. In mild climates the minimum moisture content will be higher.

The most common evidences of excessive shrinkage are cracks in plastered walls, open joints and nail pops in dry-wall construction, distortion of door openings, uneven floors, or loosening of joints and fastenings. The extent of vertical shrinkage after the house is completed is proportional to the depths of wood used as supports in a horizontal position, such as girders, floor joists, and plates. After all, shrinkage occurs primarily in the width of members, not the length.

Thorough consideration should be given to the type of framing best suited to the whole building structure. Methods should be selected that will minimize or balance the use of wood across the grain in vertical supports. These involve variations in floor, wall, and ceiling framing. The factors involved and details of construction are covered extensively in "Wood-Frame House Construction," USDA Agriculture Handbook 73.

Heavy Timber Construction

In heavy timber construction, a certain amount of shrinkage is to be expected. If not provided for in the design, it may cause weakening of the joints or uneven floors or both. One means of eliminating part of the shrinkage in mill buildings and similar structures is with metal post caps, separating the upper column from the lower column only by the metal in the post cap. This eliminates the shrinkage that would occur if the upper column bears directly on the wood girder. The same thing is accomplished by supporting the upper column on the lower column with wood corbels bolted to the side of the lower column to support the girders.

Where joist hangers are used, the top of the joist, when installed, should be above the top of the girder; otherwise, when the joist shrinks in the stirrup, the floor over the girder will be higher than that bearing upon the joist.

Heavy planking used for flooring should be near 12 percent in moisture content to minimize openings between boards as they approach moisture equilibrium. When 2- or 3-inch joists are nailed together to provide a laminated floor of greater depth for heavy design loads, the joist material should be somewhat below 12 percent moisture content if the building is to be heated.

Interior Finish

The normal seasonal changes in the moisture content of interior finish are not enough to cause serious dimensional change if the woodwork is carefully designed. Large members, such as ornamental beams, cornices, newel posts, stair stringers, and handrails, should be built up from comparatively small pieces. Wide door and window trim and base should be hollow-backed. Backband trim, if mitered at the corners, should be glued and splined before erection; otherwise butt joints should be used for the wide faces. Large, solid pieces, such as wood paneling, should be so designed and installed that the panels are free to move across the grain. Narrow widths are preferable.

Flooring

Flooring is usually dried to a suitable moisture content so that special design considerations are not necessary for installation in ordinary rooms. When used in basement, large hall, or gymnasium floors, however, enough space should be left around the edges to allow for some expansion.

WOOD CARE AND SCHEDULING DURING CONSTRUCTION

Lumber and Sheathing

Lumber and sheathing received at the building site should be protected from wetting and other damage. Construction lumber in place in a structure before it is enclosed may be wet during a storm, but the wetting is mostly on the exposed surface, and the lumber can dry out quickly. Dry lumber may be solid piled at the site, but the piles should be at least 6 inches off the ground and covered with canvas or waterproof paper laid to shed water from the top, sides, and ends of the pile.

Lumber that is green or nearly green, and lumber or plywood that has been used for concrete forms, should be piled on stickers under a roof for more thorough drying before it is built into the structure. The same procedure is required for preservative-treated lumber that has not been fully redried.

If framing lumber has higher moisture content when installed than that recommended in table 14–1, some shrinkage may be expected. Framing lumber, even thoroughly air-dried stock, will generally have a moisture content higher than that recommended when it is delivered to the building site. If carelessly handled in storage at the site, it may take up more moisture. Builders may schedule their work so an appreciable amount of seasoning can take place during the early stages of construction. This minimizes the effects of further drying and shrinkage after completion.

When the house has been framed, sheathed, and roofed, the framing is so exposed that in time it can dry to a lower moisture content than would ordinarily be expected in yard-dried lumber. The application of the wall and ceiling finish is delayed while wiring and plumbing are installed. If the delay is for about 30 days in warm, dry weather, framing lumber should lose enough moisture so that any further drying in place will be relatively unimportant. In cool, damp weather, or if unseasoned lumber is used, the period of exposure should be extended. Checking moisture content of door and window headers and floor and ceiling joists at this time with an electric moisture meter is good practice. When these members approach an average of 12 percent moisture content, interior finish and trim can normally be installed. Closing the house and using the heating system will hasten the rate of drying.

Before wall finish is applied, the frame should be examined and any defects that may have developed during drying, such as warped or distorted studs, shrinkage of lintels over openings, or loosened joints, should be corrected.

Exterior Trim and Millwork

Exterior trim such as cornice and rake moldings, fascia boards, and soffit material is normally installed before the shingles are laid. Trim, siding, and window and door frames should be protected on the site by storing in the house or garage if they are received some time before the contractor can use them. While items such as window frames and sash are usually treated with some type of water-repellent preservative to resist absorption of water, they should be stored in a protected area if they cannot be installed soon after delivery. Wood siding is often received in packaged form and can ordinarily remain in the package until it is applied.

Finish Floor

Cracks develop in flooring if it absorbs moisture either before or after it is laid and then shrinks when the building is heated. Such cracks can be greatly reduced by observing the following practices: (1) Specify flooring manufactured according to association rules and sold by dealers that protect it properly during storage and delivery; (2) do not allow the flooring to be delivered before the masonry and plastering are completed and fully dry, unless a dry storage space is available; (3) have the heating plant installed before the flooring is delivered; (4) break open the flooring bundles and expose all sides of the flooring to the atmosphere inside the structure; (5) close up the house at night and raise the temperature about 15° F. above the outdoor temperature for about 3 days before laying the floor; (6) if the house is not occupied immediately after the floor is laid, keep the house closed at night or during damp weather and supply some heat if necessary.

Better and smoother sanding and finishing can be done when the house is warm and the wood has been kept dry.

Interior Finish

In a building under construction, the relative humidity will average higher than it will in an occupied house because of the moisture that evaporates from wet concrete, brickwork, and plaster, and even from the structural wood members. The average temperature will be lower, because workmen prefer a lower temperature than is common in an occupied house. Under such conditions the finish tends to have a higher moisture content during construction than it will have during occupancy.

Before any interior finish is delivered, the outside doors and windows should be hung in place so that they may be kept closed at night; in this way conditions of the interior can be held as close as possible to the higher temperature and lower humidity that ordinarily prevail during the day. Such protection may be sufficient during dry summer weather, but during damp or cool weather it is highly desirable that some heat be maintained in the house, particularly at night. Whenever possible, the heating plant should be placed in the house before the interior trim goes in, to be available for supplying the necessary heat. Portable heaters also may be used. The temperatures during the night should be maintained about 15° F. above outside temperatures and not be allowed to drop below about 70° F. during the summer or 62° F. when outside temperatures are below freezing.

After buildings have thoroughly dried, there is less need for heat, but unoccupied houses, new or old, should not be allowed to stand without some heat during the winter. A temperature of about 15° F. above outside temperatures and above freezing at all times will keep the woodwork, finish, and other parts of the house from being affected by dampness or frost.

Plastering

During a plastering operation in a moderate-sized six-room house approximately 1,000 pounds of water are used, all of which must be dissipated before the house is ready for the interior finish. Adequate ventilation to remove the evaporated moisture will avoid that moisture being adsorbed by the framework. In houses plastered in cold weather the excess moisture may also cause paint to blister on exterior finish and siding. During warm, dry, summer weather with the windows wide open, the moisture will be gone within a week after the final coat of plaster is applied. During damp, cold weather, the heating system or portable heaters are used to prevent freezing of plaster and to hasten its drying. Adequate ventilation should be provided at all times of the year, because a large volume of air is required to carry away the amount of water involved. Even in the coldest weather, the windows on the side of the house away from the prevailing winds should be opened 2 or 3 inches, preferably from the top.

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Chapter 15

FIRE RESISTANCE OF WOOD CONSTRUCTION

FIRE RESISTANCE OF WOOD CONSTRUCTION

Wood construction for many years has been classified in building codes under three standard types—heavy timber, ordinary, and light-frame. Heavy timber and ordinary types have been used widely in educational, recreational, religious, industrial, commercial, and assembly buildings. However, light frame accounts for about 80 percent of the Nation's dwellings and some of the smaller commercial, educational, and industrial buildings. General principles of design of these types of construction, particularly as they affect fire prevention and control, are presented here.

The self-insulating qualities of wood, particularly in the large wood sections used in heavy timber construction, are an important factor in providing a good degree of fire resistance in wood construction. Good structural details, such as elimination of concealed spaces, also assure improved fire durability.

Light wood-frame construction can be protected to provide a high degree of fire performance through use of conventional gypsum board interior finish. Fire-resistance ratings of 1 hour or 2 hours are readily attained for such walls.

Treatment of wood with fire-retardant chemicals or fire-retardant coatings is also an effective means of preventing flame spread. Partitions and roof assemblies constructed of fire-retardant chemically treated wood framing are being accepted in "fire resistive" and "noncombustible" types of buildings.

HEAVY TIMBER CONSTRUCTION

Before the advent of glued-laminated construction, the sizes of solid sawn timbers that were available limited heavy timber construction. Even so, heavy timber construction was used extensively in multistory buildings. These have exterior walls of masonry, and interior columns, beams, and floors of wood in solid masses, with straight members of relatively short span and a minimum of surface or projections exposed to fire.

Glue-laminating techniques have since provided the means of manufacturing solid wood structural members with extremely long spans and of a variety of shapes. Thus, laminating has permitted the construction of heavy timber buildings with larger unobstructed areas (figs. 15–1 and 15–2) and given the architect a wood product that he can use in ways never before possible.

Heavy timber construction is generally defined in building codes and standards by the following minimum sizes for the various members or portions of a building:

	Inches, nominal
Columns:	
Supporting floor loads	8 x 8
Supporting roof and ceiling loads only	6 x 8
Floor framing:	
Beams and girders	6 wide x 10 deep
Arches and trusses	8 in any dimension
Roof framing—not supporting floor loads:	
Arches springing from grade	6 x 8 lower half 6 x 6 upper half
Arches, trusses, other framing springing from top of walls, etc.	4 x 6
Floor (covered with 1-inch nominal flooring, ½-inch plywood, or other approved surfacing):	
Splined or tongue-and-groove plank	3
Planks set on edge	4
Roof decks:	
Splined or tongue-and-groove plank	2
Plank set on edge	3
Tongue-and-groove plywood	1⅛

Roof arches and truss members may be spaced members—3 inches thick when blocked solidly throughout the intervening spaces, or when spaces are tightly closed by a continuous wood cover plate 2 inches thick secured to the underside of the members.

Although building code requirements vary somewhat for walls in heavy timber construction, they generally require that exterior and interior bearing walls be of 2-hour fire-resistive noncombustible construction. Also, use of fire-retardant-treated wood in exterior 2-hour fire-resistive bearing walls is permitted in some codes. However, 3-hour fire-resistive noncombustible construction is required for exterior walls when the distance from other buildings or the property line is 3 feet or less. This also applies to nonbearing walls, except that for a building or property line separation between 20 and 30 feet the fire resistance may be 1 hour and beyond 30 feet there is no fire resistance requirement. Consequently, today there is much heavy timber construction

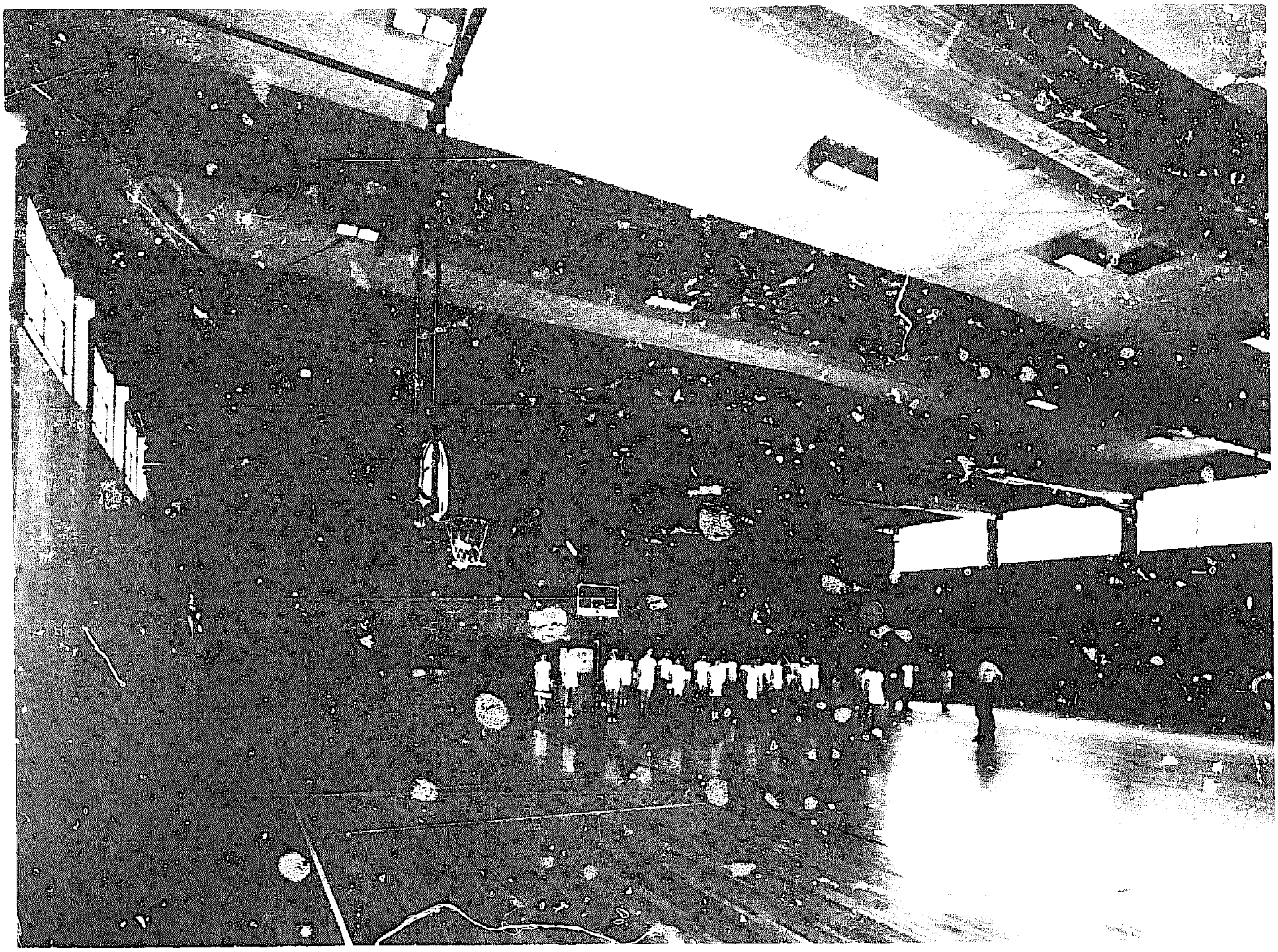

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Figure 15–1.—Use of glued-laminated beam construction provides large unobstructed floor area in school gymnasium.

in combination with glass or other nonrated exterior wall material when there is adequate separation from other buildings. Such construction is widely used for educational, religious, supermarket, and other buildings not built close to property lines.

Heavy timber construction is fire resistant because of the slow rate of burning of wood in massive form. The average rate of penetration of char under ASTM Designation E 119 time-temperature fire conditions is about 1½ inches per hour. When wood is first exposed to fire, there is some delay as it chars and eventually flames. Heating to ignition takes about 2 minutes under the ASTM standard fire test conditions, and then charring proceeds at a rate of approximately $\frac{1}{30}$ inch per minute for the next 8 minutes. Thereafter, the char layer has an insulative effect, and the rate decreases to $\frac{1}{40}$ inch per minute.

Considering the initial ignition delay, fast initial charring, and then slowing down to a constant rate, the average constant charring rate is about $\frac{1}{40}$ inch per minute (or 1½ in. per hr.) for wood species of about 0.48 specific gravity at a moisture content of 7 percent. The rate of char penetration is inversely related to the wood's density and moisture content. The temperatures at the inner zone of char are approximately 550° F., and ¼ inch inward from that a maximum of 360° F. Therefore, when the surfaces of large wood members are directly exposed to fire for periods as long as 1 hour, the low thermal conductivity and slow penetration of fire by charring allow the members to maintain a high percentage of their original strength.

The overall fire resistance of heavy timber construction obviously varies depending on the sizes of timber used. Most building codes, however, recognize that heavy timber construction performs similarly to noncombustible construction with a 1-hour fire resistance, and permit its use in all fire districts for all types of occupancy. This acceptance is based on experience with the performance of heavy timber construction in actual fires, the lack of concealed spaces, and the high fire resistance of walls in this type of construction.

Fire-fighting operations at buildings of heavy timber construction are facilitated by the fact that the structural integrity of wood is well understood by firemen. Through long experience of observing wood under fire conditions, they can approximate the time wood will carry its load without the fear of sudden collapse and are familiar with the warning it gives before it loses its structural integrity. In addition, heavy timber construction simplifies fire-fighting operations because concealed spaces in which fire can begin and spread unnoticed are kept to a minimum.

The fire resistance of glued-laminated structural members, such as arches, beams, and columns, is approximately equal to the fire resistance of solid members of similar sizes. Available information indicates that laminated members glued with phenol, resorcinol, or melamine adhesives are at least equal in fire resistance to a one-piece member of the same size, and laminated members glued with casein have only slightly less fire resistance.

In tests at the Forest Products Laboratory, when the edges of the laminations in sections of laminated members bonded with casein glue were exposed to a gas fire, slightly deeper charring resulted at the glue joints than between the glue joints. When the broad face of a lamination was exposed to the fire, the outer lamination adhered to the rest of the member until the zone of char penetrated to the depth of the glueline. Available data indicate that a casein-glued member with $^3\!/_4$-inch-thick laminations will be penetrated by the char zone as much as 10 percent deeper than a solid beam of the same size after exposure to ASTM E 119 fire for 1 hour. The appearance of the casein-glued joints and the results of shear tests indi-

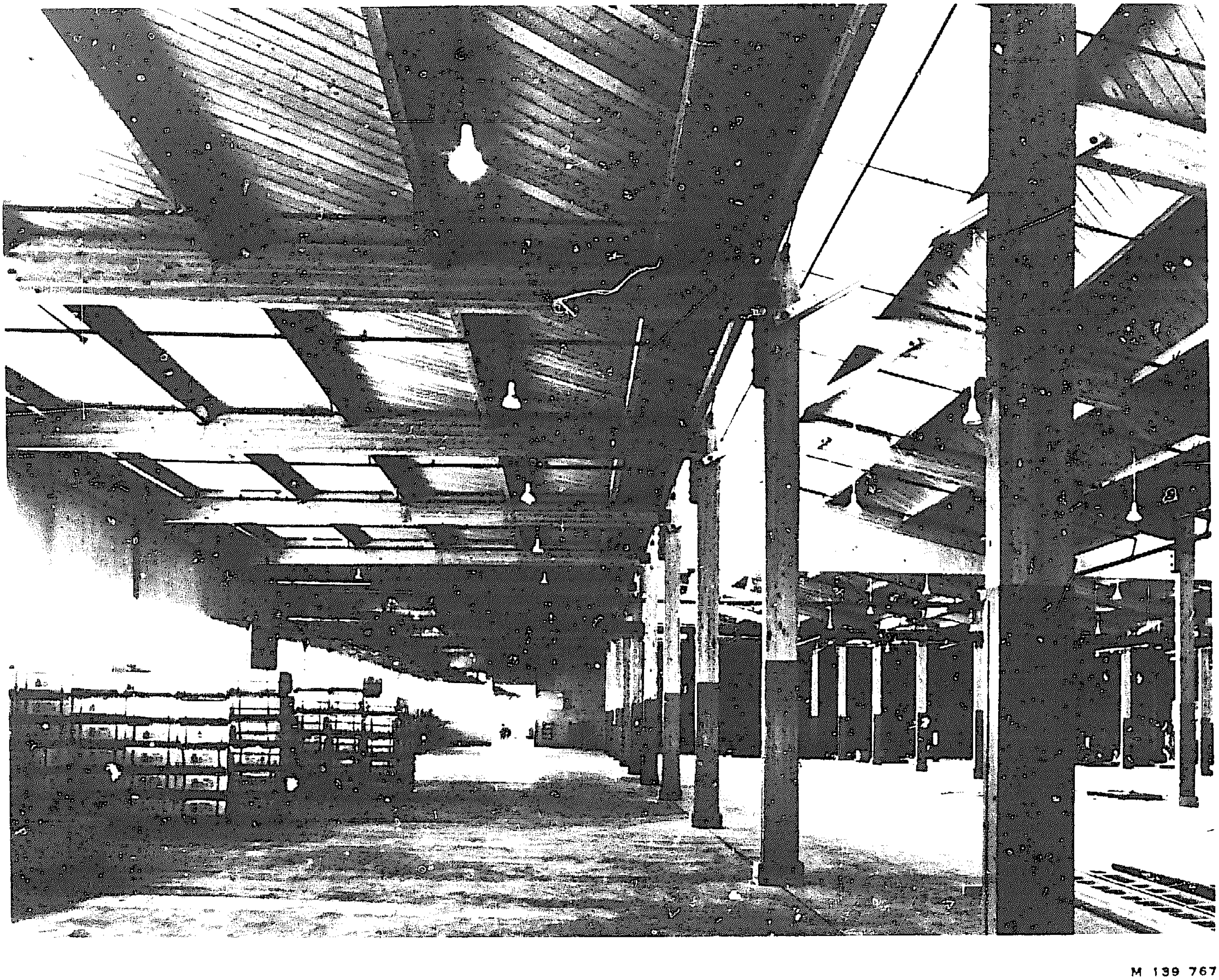
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Figure 15–2.—Heavy timber construction in a warehouse.

cated, however, that little if any weakening of the glue joints occurred beyond the charred depth as a result of the fire exposure. Also, the performance of casein-glued-laminated members in actual fires is reported to demonstrate the integrity of casein-glued joints beyond the zone of char.

When the fire endurance required of a wood member is less than the time required for the zone of char to penetrate through the outer laminations, the type of adhesive is unimportant. At 1½ inches per hour penetration, laminated material with outer laminations not less than 1½ inches thick (such as nominal 2-in. lumber laminations) would be equivalent in fire resistance to solid members of the same actual size with a fire resistance up to 1 hour.

Thus, for use in the heavy-timber-construction classification, laminated members glued with phenol, resorcinol, or melamine adhesives or laminated members glued with casein and having nominal 2-inch outer laminations are considered equivalent to solid sawn members of the same actual size.

ORDINARY CONSTRUCTION

The term "ordinary construction" defines buildings with exterior walls of masonry and interior wood-joist frames with members not less than 2 inches (nominal) thick. This type of construction has been widely employed in commercial or public buildings up to five or six stories high. Ordinary construction differs from heavy timber construction in that exterior walls generally are not as heavy and interior framing is less massive. These differences are reflected in smaller heights and areas allowed. Ordinary construction differs from light-frame construction in its larger allowable heights and areas, its self-supporting masonry walls, and in a number of interior requirements appropriate to the occupancy. There are detailed code requirements for firestops (nominal 2-inch-thick wood or the equivalent) in concealed spaces in walls or ceilings through which fire might spread. Large attic spaces are divided by "draft stops," partitions made of ½-inch plywood or gypsum board, or the equivalent.

LIGHT-FRAME CONSTRUCTION

Most residential and some commercial, institutional, industrial, and assembly buildings of wood are of light-frame construction. Originally restricted to the conventional type of building with stud walls, joisted floors and ceilings, and raftered roofs, light-frame construction has been diversified by the introduction of prefabricated, panelized, or stressed-skin structural elements.

A type of wood construction known as "protected light frame," in which elements are designed to have a fire resistance of 1 hour, is commonly used. Based on the areas allowed, codes rate the fire performance of this type as intermediate between ordinary and heavy timber construction. There are many recognized assemblies involving wood framed walls, floors, and roofs that provide a 1-hour, and even a 2-hour, fire resistance.

Unprotected light-frame wood buildings do not have the natural fire resistance of the heavier wood frames. In these, as in all buildings, attention to good construction details is important to minimize fire hazards. Of particular importance are firestops, separation of wood from masonry around chimneys and fireplaces, and design of walls, ceilings, floors, roofs, stairways, and doors.

HEIGHT AND AREA LIMITATIONS

The model codes develop some fire safety in structures by limiting building areas and heights, dependent primarily upon the type of building construction. The occupancy, fire zone, sprinkler protection, fire-retardant treatment, distance to other structures, and availability to fronting on streets also are considered in establishing the height and area limitations. The National Building Code, which is fairly representative in this respect, establishes a maximum limit on height of 65 feet for heavy timber, 45 feet for ordinary construction, and 35 feet for wood frame. Maximum floor areas per story are 12,000 square feet (one story) and 8,000 square feet (multistory) for heavy timber; 9,000 and 6,000 square feet, respectively, for ordinary; and 6,000 and 4,000 square feet, respectively, for wood frame. This compares to 35 feet, 9,000 and 6,000 square feet, for unprotected noncombustible construction.

Some modifications include floor areas increased by 200 percent when the building is equipped with automatic sprinkler protection; an increase of 100 percent when all sides face toward public streets; and an increase of 50 percent for one-story heavy timber and ordinary construction located outside fire limits and with fire-retardant treatment. For wood-frame construction outside fire limits with fire-retardant treatment, the increase is $33\frac{1}{3}$ percent. There are many variations of these limitations among the model codes, and careful consideration should be given to the specific code requirements.

IMPROVING FIRE RESISTANCE THROUGH DESIGN

The fire resistance of wood constructions, particularly that of light-frame construction, may be considerably improved by good design and construction details. Some of the more important details are covered in the following sections.

Firestops

Firestops are obstructions provided in concealed air spaces and are designed to interfere with the passage of flames up or across a building. Fire in buildings spreads by the movement of high-temperature air and gases through open channels. In addition to halls, stairways, and other large spaces, heated gases also follow the concealed spaces between floor joists, between studs in partitions and walls of frame construction, and between the plaster and the wall where the plaster is carried on furring strips. Obstruction of these hidden channels provides an effective means of restricting fire from spreading to other parts of the structure.

Wood of 2-inch nominal thickness or some noncombustible insulating material not less than 1 inch thick are effective firestops. Platform frame construction, which is commonly used in single family house construction, provides the firestopping. For balloon frame construction, good practice includes the use of: Firestops in exterior walls at each floor level, and at the level where the roof connects with the wall; firestops at each floor level in partitions that are continuous through two or more stories; headers at the top and bottom of the space between stair carriages; mineral wool asbestos, or an equivalent material, packed tightly around pipes or ducts that pass through a floor or a firestop; and self-closing doors on vertical shafts, such as clothes chutes. Figure 15–3 shows applications of firestops in an exterior wall in balloon frame construction.

Around Chimneys and Fireplaces

Good practice in the protection of wood from ignition by heat conducted through chimneys and fireplaces includes the following details:

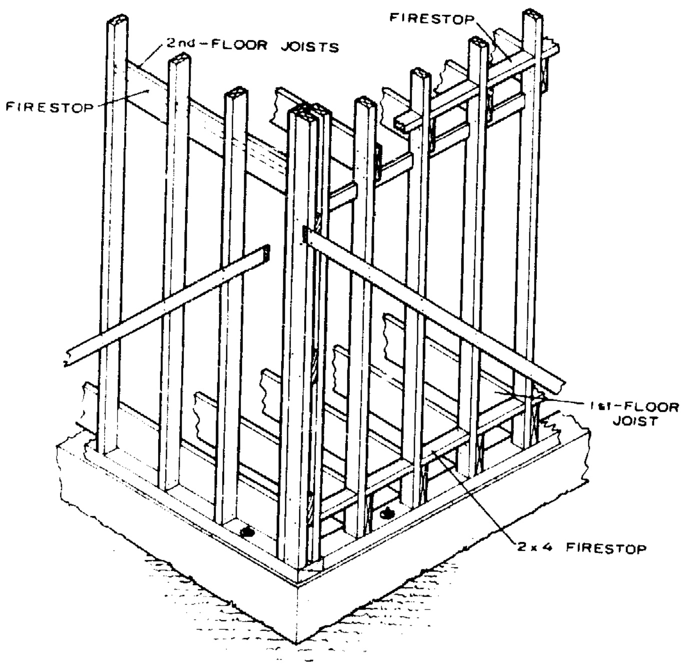

Figure 15–3.—Firestops in balloon frame construction.

1. If smoke pipes from furnaces pass through walls, they are protected by thimbles at least 8 inches larger in diameter than the pipe.
2. Smoke pipes do not pass through floors or ceilings, but join the chimney on the same floor where they originate.
3. Wood beams, joists, or rafters are separated from any chimney by a 2-inch space.
4. Wood furring strips placed around chimneys to support base or other trim are insulated from the masonry by asbestos paper at least $\frac{1}{8}$ inch thick, and metal wall plugs or approved noncombustible nail-holding devices attached to the wall surface are used for nailing.
5. Wood construction is separated at least 4 inches from the back wall of any fireplace and at least 2 inches from the sides. The space between the walls of the fireplace and the wood construction should be filled with loose noncombustible material and suitably firestopped. Supporting wood header beams are placed at least 20 inches away from the face of the fireplace. A wood mantel or other woodwork is placed not less than 6 inches from either side nor less than 12 inches from the top of any fireplace opening. Fireplace hearths are of noncombustible material, not less than 18 inches wide measured from the face of the opening.
6. All spaces between the masonry of chimneys and wood joists, beams, headers, or trimmers are filled with noncombustible material.

Partitions

A fire starting in one room of a building will be confined to that room for a variable period of time, depending on the amount and distribution of combustible contents in the room, and the fire resistance of the walls, partitions, and doors, as well as the ceilings and floors. The fire resistance of wood frame walls and partitions depends to a considerable extent upon the materials used for faces, method of fastening facings to frame, the method of joining wall and partition units, the quality of workmanship, the type and quantity of any insulation that may be used, and the structural load that the element is supporting.

The following tabulation gives the fire resistance under ASTM Designation E 119 conditions of some typical bearing or nonbearing built-up wood partitions:

	Fire-resistance rating (Min.)
Hollow 2- by 4-inch wood stud wall panels, 16 inches on center, firestopped, with faces of:	
¼-inch plywood, exterior glue [1]	10
⅜-inch plywood, exterior glue [1]	20
½-inch plywood, exterior glue [1]	25
⅝-inch plywood, exterior glue [1]	35
¾-inch tongue-and-groove sheathing boards	20
¾-inch tongue-and-groove sheathing boards plus mineral wool filling	35
⅜-inch gypsum wallboard	25
⅜-inch gypsum wallboard (two layers)	60
½-inch gypsum wallboard	40
½-inch gypsum wallboard (two layers)	90
⅝-inch gypsum (type X) wallboard	60
¾-inch gypsum sand plaster 1:2, on metal lath	60
¾-inch gypsum sand plaster 1:2, on metal lath, plus mineral wool filling	90
½-inch gypsum sand plaster 1:2 on ⅜-inch perforated gypsum lath	60
Solid nonbearing partitions of 2- by 4-inch tongue-and-groove wood boards placed vertically	10
Solid nonbearing partitions of ¾-inch boards, 2½ to 6 inches wide, grooved, joined together with wood splines, nailed:	
Two board layers	15
Same, with 30-pound asbestos paper between layers	25
Three board layers	40
Solid nonbearing partitions of 3/16-inch plywood glued to 2-inch-thick wood core of glued tongue-and-groove construction	60

Basement Ceilings

Since fires may start from heating plants located in basements, a fire-resistant separation of the furnace from the remainder of the building is desirable. Gypsum board, plaster on metal or gypsum lath placed on the basement joists affords an effective means of increasing the fire resistance of the basement ceiling and of retarding the rapid spread of flames. Particular attention should be given to the wood floor members directly above and near the furnace. With current improvements in furnace fuels, design, and control, the importance of ceiling protection has been reduced.

If, as is common, a basement stairway is directly under the stairway leading from the first to the second floor, it is good practice to protect the underside of the upper stairway with fire-resistant coverings, as suggested for basement ceilings, and to place firestops between the wood carriages at the top and bottom.

Floors

The conventional floor construction of joists, subfloor, and finish floor offers considerable resistance to the penetration of fire and will retain its load-carrying capacity in severe fire exposures up to 15 minutes. Prefabricated floor panels, in which the load-carrying capacity depends upon stressed covers, and floor systems supported by box girders with thin plywood webs may have more or less fire resistance depending on the dimensions of the elements, presence or absence of protective coverings, and other details.

Doors and Stairways

If a fire-resistant ceiling is placed on the basement joists, it is also desirable to have a self-closing door leading to the basement with fire resistance equal to the combined resistance of the ceiling and floor over the basement.

Enclosed stairways retard rapid spread of fire from floor to floor. If the interior design calls for an open stairway below, it can often be closed at the top with a solid-core wood flush door. Solid wood core or particleboard core wood flush doors provide up to 30 minutes endurance to fire penetration. Hollow-core flush doors offer less resistance to the penetration of fire unless the hollow spaces in the door are packed with an insulating material.

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[1] Values obtained on walls with 1- by 3-inch wood studs.

Wood Roof Coverings

The better grades of wood shingles are edge grained and thick butted with five butts measuring at least 2 inches. Edge-grained shingles warp or curl less than flat-grained ones, thick-butted shingles less than thin ones, and narrow shingles less than wide ones. The use of good quality products and the accepted rules of good practice in laying shingles and shakes not only provides a long-lived economical roof but markedly reduces fire hazards. For improved fire performance, shingles or shakes treated with leach-resistant fire-retardants can be used. Installation of the shingles or shakes with asbestos paper interlay, underlay, or both, or gypsum between rafters and sheathing will further improve fire-resistance.

In modern building construction with efficient heating systems, better separation of structures, and improved fire protection, only 0.5 percent of all fires are attributed to sparks on roof covering of all types. Therefore, insurance penalties against the use of wood shingles and shakes have been eliminated in most states. For structures in frequently dry bushy areas, crowded areas, areas where it is difficult to supply fire protection, or within certain fire zones, restrictions are sometimes imposed requiring fire-retardant treatments of wood shingles and shakes. A limited number of leach-resistant fire-retardant treatments are available for this purpose.

Interior Finishes

The interior finish commonly referred to for building constructions includes the exposed interior surfaces where the surface is an integral part of the building or affixed thereto; examples are the materials for walls and ceilings, interior partitions, interior trim, paint, and wallpaper. Decorations and furnishings which are not affixed to the structure are not considered interior finish, and are not limited by building codes, even though they may furnish the primary source of fuel to an incipient fire.

The model building codes and the National Fire Protection Association Life Safety Code generally specify maximum flame-spread characteristics for interior finish, based on the building occupancy, location within building, and whether or not automatic sprinkler protection is available.

The flame-spread characteristics specified by these codes are generally based on results obtained in tests by the 25-foot tunnel furnace method (ASTM Designation E 84). This method involves the use of a 20-inch by 25-foot-long specimen exposed horizontally as the cover to a tunnel furnace operated under a forced-draft condition. A gas flame is introduced against the test surface at one end of the furnace. The time for the flames to reach the other end of the specimen or the distance traveled in 10 minutes of exposure is recorded. This flame spread is then compared to the flame travel over a red oak lumber specimen, which requires about 5½ minutes for travel over the entire length of the specimen. The red oak specimen is arbitrarily assigned a flame-spread index value of 100, and asbestos-cement board an index of 0. The values for other materials are then determined relative to the time or distances of the flame travel as compared to the red oak standard. For example, if flames reach the end of the specimen in one-half the time required on red oak, the flame-spread index is 200.

Materials are usually classified into groups based on their flame-spread index values—in Class A from 0 to 25, Class B from 26 to 75, Class C from 76 to 200, Class D from 201 to 500, and Class E over 500.

The requirements for surface flammability of interior finish generally prescribe Class A in the exitways of unsprinklered buildings intended for large assembly and institutional purposes, and Class B for school, small assembly, mercantile, and hotel buildings. In general, the next higher class (greater flammability) is permitted for the interior finish used in other areas of the building which are not considered exitways. Also, the next higher flame-spread classification is permitted for materials when they are protected by automatic sprinkler devices, except that Class C finish is usually the highest permitted in any area.

These requirements frequently exempt interior trim or permit up to 10 perecent of the total wall and ceiling surface areas in any use area or occupancy group to be materials with flame-spread classification as high as Class C. The exposed portions of structural members of heavy timber construction are also exempt from these flame-spread requirements in several types of occupancies. Furthermore, wall paper, paint, and floor coverings may be exempt from these requirements, unless they are judged to be unusual fire hazards. Generally, the common paints and varnishes have only a slight effect on the flame-spread ratings of wood, usually lowering the values.

Most of the wood species have flame-spread index values of 90 to 160 by the ASTM E 84 method, and therefore are accepted for interior finish only for those applications requiring Class C interior finish. A few species have flame-spread index values of slightly less than 75, and these can be used for Class B applications. The Underwriters Laboratories, Inc., Card Data Service C60, U.L. 527, lists the flamespread index for various wood species.

Therefore, fire-retardant treatments are usually necessary for wood interior finish when Class A, and sometimes Class B, flame-spread performance is required.

FIRE-RETARDANT TREATMENTS

Two general methods are available for improving the fire performance of wood by the use of fire-retardant chemicals. One method consists of impregnating the wood with waterborne salts, using conventional vacuum-pressure methods, such as used in the wood-preserving industry. The second method involves the application of fire-retardant chemical paint coatings on the wood surface. The impregnation methods are usually the more effective and lasting and are intended for use on new wood construction. For wood in existing constructions, the surface application of the fire-retardant paints offers the principal means for increasing fire-retardant characteristics.

Chemical Impregnation

In the impregnation treatments, wood is pressure impregnated with water-soluble chemical solutions using full cell pressure processes similar to those used for chemical preservative treatments. Retentions of the fire-retardant salts must be fairly high (2½ to 5 lb. of dry salt per cubic foot of wood) to be effective.

The salts used in the current fire-retardant formulations are principally the same ones which have been known for their fire-retardant characteristics for over 50 years—monoammonium and diammonium phosphate, ammonium sulfate, zinc chloride, sodium tetraborate, and boric acid. These salts are combined in formulations to develop optimum fire performance characteristics and still have acceptable characteristics with regard to hygroscopicity, strength, corrosivity, machinability, surface appearance, gluability, paintability, and cost.

Some typical formulations as given in the American Wood-Preservers' Association Standard P10 are:

	Percent
Type B	
Zinc chloride	65.2
Ammonium sulfate	10.0
Boric acid	10.0
Sodium dichromate	14.8
Type C	
Diammonium phosphate	10.0
Ammonium sulfate	60.0
Sodium tetraborate (anhydrous)	10.0
Boric acid	20.0
Type D	
Zinc chloride	35.0
Ammonium sulfate	35.0
Boric acid	25.0
Sodium dichromate	5.0

Other commercial formulations of undisclosed composition are also available.

These formulations in water solutions at 10 to 18 percent concentration are impregnated into the wood under full-cell pressure treatment. American Wood-Preservers' Association Standards C20 and C27 prescribe recommended treating conditions for lumber and plywood. The wood is usually treated in the air- dried or kiln-dried condition, but certain species may be treated green if the wood is first given a steam treatment for periods up to 4 hours.

The treating characteristics of wood species vary considerably, as do sapwood and heartwood. Complete impregnation of the wood is necessary to obtain classification by some codes as being equivalent to "noncombustible." However, to reduce the surface flammability of thicker members, partial impregnation is the more common practice. For large wood members, impregnations of at least 0.5 inch are usually recommended. For some wood species, it is necessary to incise prior to treatment to consistently obtain this depth of treatment. Plywood sheets are treated without any need for incising as the knife checks and end-grain at panel edges improve the ease of impregnation. However, care should be taken that only exterior plywood is used so the plies will not delaminate as a result of the water penetration.

After the treated wood is removed from the treating solution, the wood must be carefully dried. Proper quality control may be obtained by following AWPA Standards C20 and C27, procuring under Military Specification MIL–L–19140C, or by obtaining a product evaluated, listed, and labeled by a rating laboratory such as the Underwriters Laboratories, Inc. The recent wider acceptance of fire-retardant-treated wood by code and insurance authorities has been largely atttributed to the fact that a quality product is insured, based on the inspection and labeling service of a recognized inspection agency.

The proper fire-retardant treatment of wood improves fire performance by greatly reducing the amount of flammable products released, thus reducing the rate at which flames spread over the surfaces. Treatment also reduces the amount of heat available or released in the volatiles during the initial stages of fire, and also results in the wood being self-extinguishing once the primary source of heat and fire is removed or exhausted.

The fire-retardant treatment of wood does not prevent the wood from decomposing and charring under fire exposure, and the rate of fire penetration through treated wood is approximately the same as for untreated wood. Slight improvement is obtained in the fire endurance of doors and walls where fire-retardant-treated wood is used. Most of this improvement is associated with the reduction in surface flammability, rather than any changes in charring rates. However, when walls or doors are improperly constructed or faulty, the use of fire-retardant wood can reduce the effect of the faults on fire endurance.

For most rating purposes, the surface flame-spread characteristics of interior finish materials are evaluated by ASTM Designation E 84 (25-ft. tunnel furnace method). Effective fire-tardant treatment can reduce the flame-spread index of lumber and most wood products to 25 or less by this method as compared to 100 for untreated red oak lumber.

Fire-retardant-treated wood and plywood is currently being used for interior finish and trim in rooms, auditoriums, and corridors where codes require materials with low surface flammability. In addition, many codes, including the model building codes, have accepted the use of fire-retardant-treated wood and plywood in fire-resistive and noncombustible constructions for the framing of nonload-bearing walls and roof assemblies, including decking. Fire-retardant-treated wood is also used for such special purposes as wood scaffolding, and for the framing and rails used in wooden fire doors. The use of fire-retardant treatment for all wood used in buildings over 150 feet high is also prescribed in New York City. Some building codes also permit increased floor area limits in heavy timber, ordinary, and wood-frame constructions when the structural wood members have been given fire-retardant treatment.

Durability

The chemicals used as fire retardants are inorganic salts, generally thermally stable at temperatures up to 330° F. Therefore, under normal interior conditions, the fire-retardant-treated wood remains durable and effective. This has been proven in fire tests of treated wood which has been in service for over 40 years.

The salts generally used as fire retardants are water soluble, and therefore, if exposed to exterior conditions or repeated washing, the effectiveness of the treatment will be diminished. Further, the treated wood is more hygroscopic than untreated wood; under prolonged exposure at relative humidities higher than 80 percent, the treated wood may actually exude moisture and chemical, thus slowly reducing the effectiveness. The use of a sealer topcoat can improve the resistance of leaching and the durability when treated wood is subjected to adverse moisture conditions.

New types of fire-retardant treatments have been developed for wood shingles and shakes and other exterior uses. These treatments have improved leach-resistance and do not add to the hygroscopic properties of the wood. Plywood sidings treated with such exterior fire-retardants have been recognized by code bodies for wall constructions where only noncombustible materials have been previously accepted.

Strength

Fire-retardant treatment results in some reduction of the strength properties of wood, but the reductions are not great. Current treatments have been observed, in tests at the Forest Products Laboratory, to decrease the modulus of elasticity values by 5 to 10 percent and modulus of rupture values by 10 to 20 percent as compared to untreated, matched controls. These values were obtained when both treated and untreated samples were conditioned at the same relative humidity conditions. As the hygroscopic characteristics of the treated wood are slightly greater, the wood density of equivalent cross sections of the treated sample was slightly less. This could account for an appreciable amount of the reduction in strength properties. Fire-retardant-treated wood is more brash than untreated wood. While this reduced resistance to impact is not usually considered in design, the work-to-maximum load, which measures brashness, may be decreased 30 percent or more.

There is no evidence that fire-retardant treatment will cause any further or progressive decrease in strength under temperature and humidity conditions in normal use.

As evidence indicates that there is some reduction in the strength properties of fire-retardant-treated wood, the national design specification for wood has reduced the allowable unit stress for design by 10 percent as compared to untreated wood.

Hygroscopicity

Wood treated with the inorganic fire-retardant salts is usually more hygroscopic than untreated wood, particularly at high relative humidities. For treated wood, increases in equilibrium moisture content will also depend upon the type of chemical, level of chemical retention, and size and species of wood involved. For wood treated with most fire-retardant formulations, the increase in equilibrium moisture content at 80° F. and 30 to 50 percent relative humidity is negligible. At 80° F. and 65 percent relative humidity, increases in moisture content for fire-retardant-treated wood are 2 to 8 percent. At 80° F. and 80 percent relative humidity, increases in moisture content range from 5 to 15 percent and may result in the exuding of chemical solution from the wood. Most current fire-retardant formulations are developed to be used at conditions up to 80 percent relative humidity without significant exuding of chemical solution. However, some of the new leach-resistant fire-retardant treatments are nonhygroscopic.

Corrosivity

Individually, some fire-retardant salts are quite corrosive to metals. However, combinations of these chemicals result in more neutral formulations. The addition of corrosion inhibitors, such as sodium dichromate, has generally reduced the corrosive action of the current types of fire-retardants for wood to an insignificant level.

Machinability

The presence of salt crystals in wood has an abrasive effect on cutting tools. Increased tool life can be obtained by using cutting and shaping tools tipped with tungsten carbide or similar abrasion-resistant alloys. When it is necessary to use regular high-speed steel tools, economy of cutting is practical only when a few hundred feet of the fire-retardant-treated wood is involved. The usual practice in preparing fire-retardant-treated wood for use in trim and moldings is to cut the material to approximate finish size before treatment so a minimum of machining after treatment is necessary.

Gluing Characteristics

Certain phases of the gluing of fire-retardant-treated woods still remain a problem. However, untreated veneer facings can be satisfactorily glued over treated plywood cores with the conventional hot-press phenolic adhesives. For assembly gluing of fire-retardant-treated wood for nonstructural purposes, adhesives such as casein, urea, and resorcinol types can be used. The major problem is in the structural bonding of fire-retardant-treated wood to provide bonds, in both interior and exterior performance tests, which are equivalent to those obtainable for the untreated wood. Special resorcinol-resin adhesives, which employ a high formaldehyde content hardener, have been developed for gluing fire-retardant-treated wood. Improved bonding can be obtained with this type of adhesive, when curing is done at temperatures of 150° F. or higher.

Paintability

The fire-retardant treatment of wood does not generally interfere with the adhesion of decorative paint coatings, unless the treated wood has extremely high moisture content because of its increased hygroscopicity. Moisture content of the treated wood should be at 12 percent or less at the time of the application of the paint coating. Natural finishes are not generally used for fire-retardant-treated wood as the treatment and subsequent drying often causes darkening and irregular staining. Decorative fire-retardant plywoods are usually prepared by treating the plywood core and then bonding a thin, untreated decorative veneer facing to these cores. This eliminates the stained surfaces, which may be difficult to finish properly to a natural wood finish. Crystals may appear on the surface of paint coatings applied over wood having high salt retentions, but only when the wood is exposed to high relative humidity for prolonged periods.

Fire-Retardant Coatings

Many commercial paint coating products are available to provide varying degrees of protection of wood against fire. These paint coatings generally have low surface flammability characteristics and "intumesce" to form an expanded low-density film upon exposure to fire, thus insulating the wood surface below from pyrolysis reactions. They have added ingredients to restrict the flaming of any released combustible vapors. Chemicals may also be present in these paints to promote the rapid decomposition of the wood surface to charcoal and water rather than forming intermediate volatile flammable products.

Fire-retardant paints include those based on water-soluble silicates, urea resins, carbohydrates and alginates, polyvinyl emulsions and oil-base alkyd, and pigmented types. In many of the water-soluble paints, ammonium phosphate or sodium borate is used in the formulation to obtain fire-retardant characteristics. The oil-base paints frequently make use of chlorinated paraffins and alkyds plus antimony trioxide to limit the flammability of any pyrolysis products produced. Inert materials, such as zinc borate, mica, kaolin, and inorganic pigments are also used in these formulations. Intumescence is obtained by the natural characteristics of some of the organic ingredients or special materials, such as isano oil, may be used. A limited number of clear fire-retardant finishes are available. Generally they do not have the effectiveness of the fire-retardant paints, as pigmentation and opaque chemical additives are usually necessary to gain greater effectiveness.

Many of the commercial formulations have been evaluated by ASTM Designation E 84 (25-ft. tunnel furnace) when applied over a substrate of Douglas-fir lumber. These coatings, when properly applied to lumber and wood products, can reduce the surface flame-spread index to 25 or less. To obtain this reduction in surface flammability, it is necessary to apply these coatings to much greater thicknesses (100 to 175 sq. ft. per gal.) than for conventional decorative coatings. Also, because of the added ingredients in these paints, many of them do not have as good brushing characteristics as the decorative paints.

Most of the fire-retardant coatings are intended for interior use, although some products on the market can be used on the exterior of a structure. The application of thin coatings of conventional paint products over the fire-retardant coatings has been one method to improve their durability. Most conventional decorative paint coating products will in themselves slightly reduce the flammability of wood products when applied in conventional film thicknesses.

More and more, fire-retardant coatings are being applied to panel products at the factory. Such application has been common for ceiling tile made of fiberboard.

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Chapter 16

PAINTING AND FINISHING

PAINTING AND FINISHING[1]

Wood and wood products in a variety of species, grain patterns, textures, and colors can be finished effectively by several different methods. Painting, which totally obscures the wood grain with a coating, achieves a particular color decor. Penetrating preservatives and pigmented stains permit some or all of the wood grain and texture to show and provide a special color effect as well as natural or rustic appearance. Selection of a type of finish, painted or penetrating, depends on the appearance desired and substrate employed.

FACTORS AFFECTING FINISH PERFORMANCE

Satisfactory performance of finishes is achieved when full consideration is given to the many factors that affect finishes. These factors include the effect of the wood substrate, the properties of the finishing material, details of application, and severity of exposure to elements of the weather. This chapter reviews some of the more important considerations. Sources of more detailed information are given in the Bibliography at the end of this chapter.

Wood Properties

Wood surfaces that shrink and swell the least are best for painting. For this reason, vertical- or edge-grained surfaces are far better than flat-grained surfaces of any species, especially for exterior use where wide ranges in relative humidity and periodic wetting can produce wide ranges in swelling and shrinking.

Also, because the swelling of wood is directly proportional to density, low-density species are preferred over high-density species. However, even high-swelling and dense wood surfaces with flat grain can be stabilized with a resin-treated paper overlay (overlaid exterior plywood and lumber) to provide excellent surfaces for painting. Medium-density, stabilized fiberboard products with a uniform, low-density surface or paper overlay are also a good substrate for exterior use. Vertical-grained western redcedar and redwood, however, are probably the species most widely used as exterior siding to be painted. These species are classified in group I, those woods easiest to keep painted (table 16–1). Vertical-grain surfaces of all species actually are considered excellent for painting, but most species are generally available only as flat-grain lumber.

Species that are normally cut as flat-grained lumber, are high in density and swelling, or have defects such as knots or pitch, are classified in groups II through V, depending upon their general paint-holding characteristics. Many species in groups II through IV are commonly painted, particularly the pines, Douglas-fir, and spruce. These species generally require more care and attention than the group I species with vertical-grain surfaces. Exterior paint will be more durable on vertical-grain boards than on flat-grain boards for any species with marked differences in density between earlywood and latewood, even if the species is rated in group I. Flat-grain boards that are to be painted should be installed in areas protected from rain and sun.

Plywood for exterior use nearly always has a flat-grain surface. In addition, cycles of swelling and shrinking tend to check the face veneer of plywood much more than lumber. This checking extends through paint coatings to detract from their appearance and durability. Plywood with a resin-treated paper overlay, however, has excellent paintability and would be equal to or better than vertical-grain lumber surfaces of group I.

Before painting, resinous species should be thoroughly kiln dried at temperatures that will effectively set the pitch to reduce problems of resin exudation.

Such wood properties as high density, flat grain, and tight knots detract from paintability of boards but do not necessarily affect their finishing with penetrating preservatives and stains. These finishes penetrate into wood without forming a continuous film on the surface. Therefore, they will not blister or peel even if excessive moisture penetrates into wood.

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[1] Mention of a chemical in this chapter does not constitute a recommendation; only those chemicals registered by the U.S. Environmental Protection Agency may be recommended, and then only for uses as prescribed in the registration and in the manner and at the concentration prescribed. The list of registered chemicals varies from time to time; prospective users, therefore, should get current information on registration status from the Environmental Protection Agency, Washington, D.C.

Table 16–1.—*Characteristics of woods for painting and finishing (omissions in the table indicate inadequate data for classification)*

Wood	Ease of keeping well painted; I—easiest, V—most exacting [1]	Weathering		Appearance	
		Resistance to cupping; 1—best, 4—worst	Conspicuousness of checking; 1—least, 2—most	Color of heartwood (sapwood is always light)	Degree of figure on flat-grained surface
SOFTWOODS					
Cedar:					
Alaska-	I	1	1	Yellow	Faint
California incense-	I			Brown	Do.
Port-Orford-	I		1	Cream	Do.
Western redcedar	I	1	1	Brown	Distinct
White-	I	1		Light brown	Do.
Cypress	I	1	1	do	Strong
Redwood	I	1	1	Dark brown	Distinct
Products [2] overlaid with resin-treated paper	I		1		
Pine:					
Eastern white	II	2	2	Cream	Faint
Sugar	II	2	2	do	Do.
Western white	II	2	2	do	Do.
Ponderosa	III	2	2	do	Distinct
Fir, commercial white	III	2	2	White	Faint
Hemlock	III	2	2	Pale brown	Do.
Spruce	III	2	2	White	Do.
Douglas-fir (lumber and plywood)	IV	2	2	Pale red	Strong
Larch	IV	2	2	Brown	Do.
Lauan (plywood)	IV	2	2	do	Faint
Pine:					
Norway	IV	2	2	Light brown	Distinct
Southern (lumber and plywood)	IV	2	2	do	Strong
Tamarack	IV	2	2	Brown	Do.
HARDWOODS					
Alder	III			Pale brown	Faint
Aspen	III	2	1	do	Do.
Basswood	III	2	2	Cream	Do.
Cottonwood	III	4	2	White	Do.
Magnolia	III	2		Pale brown	Do.
Yellow-poplar	III	2	1	do	Do.
Beech	IV	4	2	do	Do.
Birch	IV	4	2	Light brown	Do.
Cherry	IV			Brown	Do.
Gum	IV	4	2	Brown	Do.
Maple	IV	4	2	Light brown	Do.
Sycamore	IV			Pale brown	Do.
Ash	V or III	4	2	Light brown	Distinct
Butternut	V or III			do	Faint
Chestnut	V or III	3	2	Light brown	Distinct
Walnut	V or III	3	2	Dark brown	Do.
Elm	V or IV	4	2	Brown	Do.
Hickory	V or IV	4	2	Light brown	Do.
Oak, white	V or IV	4	2	Brown	Do.
Oak, red	V or IV	4	2	do	Do.

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[1] Woods ranked in group V for *ease of keeping well painted* are hardwoods with large pores that need filling with wood filler for durable painting. When so filled before painting, the second classification recorded in the table applies.

[2] Plywood, lumber, and fiberboard with overlay or low-density surface.

Many wood products of lumber, plywood, shingles, and fiberboard are prepared with a roughsawn and absorptive surface that enhances the durability of stains by providing for better penetration.

Construction Details

House construction features that will minimize water damage of outside paint are: (a) Wide roof overhang, (b) wide flashing under shingles at roof edges, (c) effective vapor barriers, (d) adequate eave troughs and properly hung downspouts, (e) exhaust fans to remove excessive moisture, and (f) adequate insulation and ventilation of the attic. If these features are lacking in a new house, persistent paint blistering and peeling may occur and the structure then would best be finished with penetrating pigmented stains.

The proper application and nailing of wood siding does much to improve the appearance and durability of both wood and paint by reducing the tendency of the siding to split, crack, and cup with changes in moisture content. When possible, depending on the siding pattern, siding boards should be fastened so boards are free to shrink and swell, thereby reducing the tensile stresses that develop at fasteners.

Exterior siding and millwork should be installed with corrosion-resistant nails. Aluminum, hot-dipped galvanized, or stainless steel nails should be used for this purpose. Common iron nails or poor-quality galvanized nails corrode easily and will cause unsightly staining of the wood and paint. When the wood is to be left unfinished to weather or finished naturally with light-colored penetrating stains or water-repellent preservatives, only aluminum or stainless steel nails should be used.

Nails should be long enough to penetrate into studs and sheathing at least 1½ inches. Threaded nails should be used when nailing into plywood or lumber sheathing. When nails are near the end or edge of a board, nail holes should be predrilled or the tips of the nails blunted slightly to prevent splitting.

Recommended nailing practices for siding vary with the type of siding pattern and thickness and width of siding (fig. 16–1).

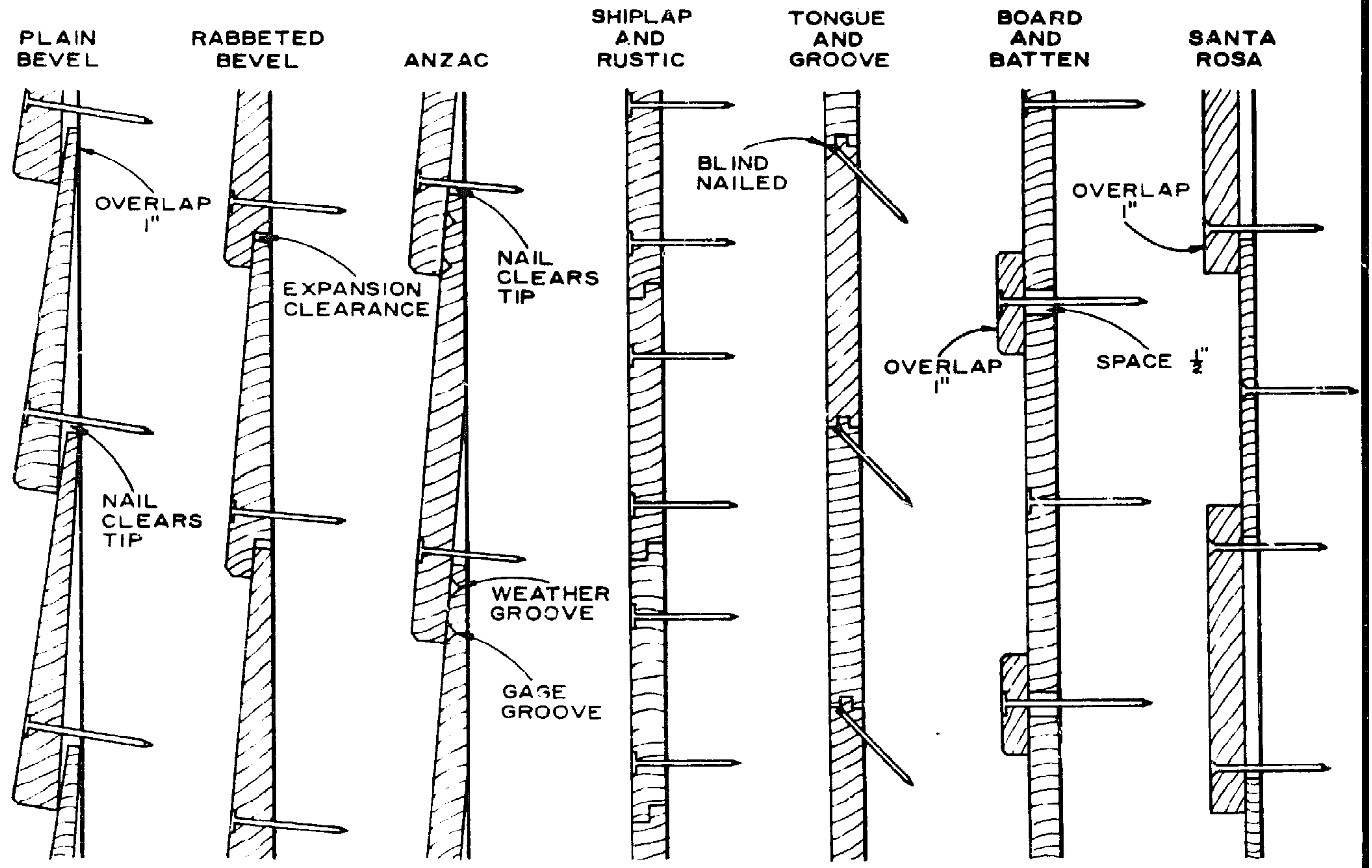

Figure 16–1.—Recommended nailing methods for various types of wood siding.

For plain bevel patterns, the siding should be face nailed, one nail per bearing, so that the nail clears the edge of the under course. Eightpenny or tenpenny nails are recommended for 1-inch-thick siding and sixpenny to eightpenny nails for thinner material.

Shiplap siding in 4- and 6-inch widths is face nailed with one nail per bearing a distance of 1 inch from the overlapping edge. Siding boards 8 inches or more in width should be nailed with two nails. Again, eightpenny nails should be used for siding 1 inch thick.

Tongued-and-grooved siding, 6 inches or less in width, is either face nailed with one eightpenny nail per bearing or blind nailed with one sixpenny finish nail through the tongue. Boards 6 inches or more in width are face nailed with two eightpenny nails.

In board-and-batten patterns, the under boards are spaced ½ inch apart and nailed with one eightpenny or ninepenny siding nail at the center of the board. The batten strip, 2½ inches wide, is nailed at the center with one tenpenny or twelvepenny nail. In board-on-board siding (fig. 16–1, Santa Rosa), the under board also is nailed with one nail at the center of the board. The outer boards, positioned to lap the under boards by 1 inch, are face nailed with two tenpenny or twelvepenny nails 1¼ inches from the edges.

Extractives and Impregnated Preservatives

Water-soluble color extractives occur naturally in western redcedar and redwood. It is to these substances that the heartwood of these species owes its attractive color, good stability, and natural decay resistance. Discoloration of paint occurs when the extractives are dissolved and leached from the wood by water. When the solution of extractives reaches the painted surface, the water evaporates, leaving the extractives as a reddish-brown stain. The water that gets behind the paint and causes moisture blisters also causes migration of extractives. The discoloration produced by water wetting siding from the back frequently forms a rundown or streaked pattern.

The latex paints and the so-called "breather" or low-luster oil paints are more porous than conventional oil paints. If these porous paint systems are used on new wood without a nonporous primer or a primer specifically designed to resist staining, or if any paint is applied too thinly on new wood (a skimpy two-coat paint job, for example), rain or even heavy dew can penetrate the coating and reach the wood. When the water dries from the wood, the extractives are brought to the surface of the paint. Discoloration of paint by this process forms a diffused pattern which coincides with the dew and rain pattern of wetting.

On rough surfaces, such as shingles, machine-grooved shakes, and rough-sawn lumber sidings, it is difficult to obtain a uniformly thick coating on ridges and high points in the surface. Therefore, extractive staining is more likely to occur on such surfaces by water penetrating through defects in the coating.

Wood pressure-treated with waterborne chemicals, such as copper, chromium, and arsenic salts which react with the wood or form an insoluble residue, presents no major problems in painting if the wood is redried after treating. However, certain chemicals, which are not fixed in the wood but remain soluble, will diffuse to the surface under moist conditions to discolor paint.

Wood treated with solvent or oilborne preservative chemicals, such as pentachlorophenol, is not considered paintable until all the solvents have been removed. When heavy oil solvents with low volatility are used to treat wood under pressure, successful painting is usually impossible. Even special drying procedures for wood pressure-treated with the water-repellent preservative formulas that employ highly volatile solvents do not restore complete paintability.

Water-repellent preservatives introduced into wood by a vacuum-pressure process (NWMA Industry Standard 4–70) are paintable.

Coal-tar creosote or other dark oily preservatives tend to stain through paint, especially light-colored paint, unless the treated wood has weathered for many years before painting.

When it is necessary to finish pressure-treated wood, a dark-colored pigmented stain which penetrates the wood surface and forms no coating is recommended.

Moisture-Excluding Effectiveness of Finishes

The protection afforded by coatings in excluding moisture from wood depends on a great number of variables. Among them are film thickness, absence of defects and voids in the film, type of pigment, chemical composition of the vehicle, volume ratio of pigment to vehicle, vapor-pressure gradient across the film, and length of exposure period.

The relative effectiveness of several typical treating and finishing systems for wood in retarding adsorption of water vapor at 97 percent relative humidity is compared in table 16–2. Perfect protection, or no adsorption of water, would be represented by 100 percent effectiveness; complete lack of protection (as with unfinished wood) by 0 percent.

Values in table 16–2 are only representative and indicate the range in protection against moisture for some conventional finish systems. The degree of protection provided also depends on the kind of exposure. For example, the water-repellent preservative treatment, which may have 0 percent effectiveness after 2 hours at 80° F. and 97 percent relative humidity, would have an effectiveness of over 60 percent when tested after immersion in water for 30 minutes. The high degree of protection provided by a water-repellent preservative to short periods of wetting by water is the major reason they are recommended for exterior finishing.

Paints which are porous, such as the latex paints and low-luster or breather-type oil-base paints formulated at a pigment volume concentration usually above 40 percent, afford little protection against moisture. These paints permit rapid entry of water and so provide little protection against dew and rain unless applied over a nonporous primer.

FINISHING EXTERIOR WOOD

Weathering

The simplest of natural finishes for wood is weathering. Without paint or treatment of any kind, wood surfaces gradually change in color and texture and then may stay almost unaltered for a long time if the wood does not decay. Generally, the dark-colored woods become lighter and the light-colored woods become darker. As weathering continues, all woods become gray, accompanied by photodegradation of the wood cells at the surface. Exposed unfinished wood will wear away at the rate of about ¼ inch in 100 years.

The appearance of weathered wood exposed outdoors is usually affected by dark-colored spores and mycelia of fungi or mildew on the surface, which give the wood a dark gray, blotchy, and unsightly appearance. Highly colored wood extractives in such species as western redcedar and redwood also influence the color of weathered wood. The dark brown color may persist for a long time in areas not exposed to the sun and where the extractives are not removed by rain.

Table 16–2.—*Some typical values of moisture-excluding effectiveness of finishes. Wood was initially conditioned to 80° F. and 65 percent relative humidity and then exposed for 2 weeks to 80° F. and 97 percent relative humidity*

Coatings	Effectiveness
INTERIOR FINISHES	*Pct.*
Uncoated wood	0
3 coats of phenolic varnish	73
2 coats of phenolic varnish	49
1 coat of phenolic varnish (sealer)	5
3 coats of shellac	87
3 coats of cellulose lacquer	73
3 coats of lacquer enamel	76
3 coats of furniture wax	8
3 coats of linseed oil	21
2 coats of linseed oil	5
1 coat of linseed oil (sealer)	1
2 coats of latex paint	0
2 coats of semigloss enamel	52
2 coats of floor seal	0
2 coats of floor seal plus wax	10
EXTERIOR FINISHES	
1 coat water-repellent preservative [1]	0
1 coat of FPL natural finish (penetrating stain)	0
1 coat house paint primer	20
1 coat of house primer plus 2 coats of latex paint	22
1 coat of house primer plus 1 coat of TZ [2] linseed oil paint, 30 percent PVC [3]	60
1 coat of house primer plus 1 coat of TL [2] linseed oil paint, 30 percent PVC	65
1 coat of T-alkyd-oil, 30 percent PVC	45
1 coat of T-alkyd-oil, 40 percent PVC	3
1 coat of T-alkyd-oil, 50 percent PVC	0
2 coats of exterior latex paint	3
1 coat aluminum powder in long oil phenolic varnish	39
2 coats aluminum powder in long oil phenolic varnish	88
3 coats aluminum powder in long oil phenolic varnish	95

[1] The same product measured by immersing in water for 30 min. would have a water-repellency effectiveness of over 60 pct.

[2] The letters *T*, *L*, and *Z* denote paint's pigment with titanium dioxide, basic carbonated white lead, and zinc oxide, respectively.

[3] PVC denotes pigment volume concentration which is the volume percent of pigment in the nonvolatile portion of the paint.

Water-Repellent Preservatives

The natural weathering of wood may be modified by treatment with water-repellent finishes that contain a fungicide (usually pentachlorophenol), a small amount of resin, and a very small amount of water repellent which frequently is wax or waxlike in nature. The treatment, which penetrates the wood surface, retards the growth of fungi (mildew), reduces water staining of the ends of boards to a minimum, reduces warping, and protects species that have a low natural resistance to decay. A clear, golden tan color can be achieved on such sidings as smooth or rough-sawn western redcedar and redwood.

The preservative solution can be easily applied by dipping, brushing, or spraying. All lap and butt joints, edges, and ends of boards and panels should be liberally treated. Rough surfaces will absorb more solution than smoothly planed surfaces and the treatment will be more durable on them. Repeated brush and spray applications to the point of refusal will enhance durability and performance.

Because of the toxicity of pentachlorophenol, the commonly used fungicide in water-repellent preservative solutions, care should be exercised to avoid excessive contact with the solution or vapor, especially when spraying. Shrubs and plants should also be protected from contamination.

The initial application to smooth surfaces is usually short-lived. When a surface starts to show a blotchy discoloration due to extractives or mildew, it should be cleaned with detergent solution and retreated after drying. During the first few years, the finish may have to be applied every year or so. After sufficient time has elapsed so that the wood has weathered to a uniform color, however, the treatments are more durable and need refinishing only when the surface starts to become unevenly colored by fungi.

Inorganic pigments also can be added to the water-repellent preservative solutions to provide special color effects, and the mixture is then classified as a pigmented penetrating stain. Two to six fluid ounces of colors-in-oil or tinting colors can be added to each gallon of treating solution. Colors which match the natural color of the wood and extractives are usually preferred. The addition of pigment to the finish helps to stabilize the color and increases the durability of the finish.

Inorganic preservative chemicals which are soluble in water show promise as natural exterior finishes for wood. Such treatments retard the growth of fungi and also inhibit photodegradation of the surface fibers.

Pigmented Penetrating Stains

The pigmented penetrating stains are semitransparent, permitting much of the grain pattern to show through, and penetrate into the wood without forming a continuous film on the surface. Therefore, they will not blister or peel even if excessive moisture enters the wood. Stains are made from both solvent resin and latex systems. Latex stains are a relatively new product.

Penetrating stains are suitable for both smooth and rough-textured surfaces; however, their performance is markedly improved if applied to rough-sawn, weathered, or rough-textured wood. They are especially effective on lumber and plywood that does not hold paint well, such as flat-grained surfaces of dense species. One coat of penetrating stain applied to smooth surfaces may last only 2 to 4 years; but the second application, after the surface has roughened by weathering, will last 8 to 10 years. A finish life of close to 10 years can be achieved initially on rough surfaces by applying two coats of stain. Two-coat staining also minimizes problems related to uneven stain application and lap marks. In two-coat staining, the second coat should always be applied before the first dries, usually within 30 to 60 minutes, so that both coats will penetrate.

Pigmented penetrating stains can be used effectively to finish such exterior surfaces as siding, trim, exposed decking, and fences.

One stain of this type is the Forest Products Laboratory natural finish. The finish has a linseed oil vehicle; a fungicide, pentachlorophenol, to protect the oil from mildew; and a water repellent, paraffin, wax, to protect the wood from excessive penetration of water. Durable red and brown iron oxide pigments simulate the natural colors of redwood and cedar. A variety of other colors also can be achieved with this type of finish; however, a pure white is not possible. Durability depends primarily on how much pigment penetrates into the wood surface.

Commercial finishes known as heavy-bodied or opaque stains are really considered to be more like a paint because of their film-forming characteristics. Such stains are finding wide success on textured surfaces and panel products. They should not be confused with the typical shake and shingle paints that are prone to check and peel.

Transparent Coatings

Clean coatings of conventional spar or marine varnishes, which are film-forming finishes, are not generally recommended for exterior use. Such coatings, embrittled by exposure to sunlight, develop severe cracking and peeling of the finish in less than 2 years. Areas that are protected from direct sunlight by overhang or are on the north side of the structure can be finished with exterior-grade varnishes. Even in protected areas, a minimum of three coats of varnish is recommended and the wood should be treated with water-repellent preservative before finishing. The use of pigmented stains and sealers as undercoats also will contribute to the life of the clear finish.

Expected major breakthroughs in polymer research will greatly enhance the longevity and use of exterior clear coatings. These developments will likely involve the use of new polymers which do not absorb ultraviolet light, such as certain vinyl fluoride, silicone, and acrylic polymers. Without the absorption of ultraviolet, the coating will undergo little photodegradation, and presumably could remain serviceable for many years. The use of coatings which are transparent to ultraviolet light will necessitate, however, the treating of wood surfaces with ultraviolet absorbers or the use of improved stable absorbers in the clear coating to protect the wood substrate from photodegradation. Treating the wood surface with salts of copper and chromium has been effective in protecting against photodegradation of the wood surface.

Painting Systems

Of all the finishes, paints provide the most protection for wood against surface erosion and offer the widest selection of colors. A nonporous paint film retards penetration of moisture and reduces the problem of discoloration by wood extractives, paint peeling, and checking and warping of the wood. Paint, however, is not a preservative; it will not prevent decay if conditions are favorable for fungal growth. Original and maintenance costs are usually higher for a paint finish than for a water-repellent preservative or penetrating stain finish.

The durability of paint coatings on exterior wood is affected both by variables in the wood surface and the type of paint.

Application of Paint

Wood to be painted should be handled like other building and finishing material to prevent contamination of surfaces from dirt, oil, and other foreign substances, and to avoid excessive wetting. Weathering of the wood surface before painting can detract from paintability and performance. It is therefore advisable to paint the surface promptly after installation.

Exterior wood surfaces can be very effectively painted by following a simple three-step procedure:

Step 1. Water-repellent-preservative treatment.—Wood siding and trim should be treated with water-repellent preservative to protect them against the entrance of rain and dew at joints. If treated exterior wood was not installed, the wood can be treated in place by brushing, dipping, or spraying. Care should be taken to brush well into lap and butt joints, especially treating ends of boards and panels. Two warm, sunny days should be allowed for adequate drying of the treatment before painting.

Care should be exercised in applying water-repellent preservatives, especially by spraying. The common fungicide used in these products is pentachlorophenol, which is toxic to both people and plants. The volatile solvents that are used are also toxic.

Step 2. Primer.—New wood should be given three coats of paint. The first, or prime, coat is the most important. It should be free of zinc-oxide pigment to reduce the tendency of the paint to blister, nonporous to prevent excessive entry of rain and dew, and flexible and thick enough to cover the wood grain so swelling stresses which develop on the wood surface are uniformly distributed. The primer should be applied soon after the wood is in place and treated; topcoats should be applied within 2 days to 2 weeks after the primer. Enough primer should be applied to obscure the wood grain. Many painters tend to spread primer too thinly. For best results, the spreading rates recommended by the manufacturer should be followed, or approximately 400 to 450 square feet should be covered per gallon with a paint that is about 85 percent solids by weight. A properly applied coat of a nonporous house paint primer will greatly reduce moisture blistering, peeling, and staining of paint by wood extractives.

For woods such as redwood and cedar, which contain water-soluble extractives, the best primers are good quality oil and alkyd-oil paints. For species free of extractives, such as the pines and Douglas-fir, high-quality acrylic latex paints (used for both primer and topcoat) hold great promise.

Primers effective on wood are not considered best for galvanized iron. Galvanized surfaces should be allowed to weather for several months and then primed with an appropriate primer, such as a linseed oil or resin-oil vehicle pigmented with metallic zinc dust (about 80 pct.) and zinc oxide (about 20 pct.)

Step 3. Finish coats.—Two coats of a good-quality latex, alkyd, or oil-base house paint should be applied over the nonporous primer. Two finish coats are particularly important for areas on east, south, and west sides of a structure that are exposed to maximum weather conditions, and not protected by overhang. One coat of a good house paint over a properly applied primer (a conventional two-coat paint system) will last only 4 or 5 years, but two coats should last 8 to 10 years.

High-quality acrylic latex paints and heavy-bodied stains are currently considered the best film-forming type finish for plywood panel products. These finishes are generally used without a primer.

To avoid future separation between coats of oil-base paint, or intercoat peeling, the first topcoat should be applied within 2 weeks after the primer and the second within 2 weeks of the first.

To avoid temperature blistering, oil-base paints should not be applied on a cool surface that will be heated by the sun within a few hours. Temperature blistering is most common with thickly applied paints of dark colors applied in cool weather. The blisters usually show up in the last coat of paint and occur within a few hours to 1 or 2 days after painting. They do not contain water.

To avoid wrinkling, fading, or loss of gloss of oil-base paints, and streaking of latex paints, paint should not be applied in the evenings of cool spring and fall days when heavy dews form before the surface of the paint has thoroughly dried.

Porches and Decks

Exposed flooring on porches and decks is commonly painted. The recommended procedure of treating with water-repellent preservative and primer is the same as for wood siding. After the primer, an undercoat and matching coat of porch and deck enamel should be applied.

Many fully exposed rustic-type decks are effectively finished with only water-repellent preservative or a penetrating-type pigmented stain. Because these finishes penetrate and form no film on the surface, they do not crack and peel. They may need more frequent refinishing than painted surfaces, but this is easily done because there is no need for laborious surface preparation as when painted surfaces start to peel.

RENEWING EXTERIOR PAINT SYSTEMS

Exterior wood surfaces need be repainted only when the old paint has worn thin and no longer protects the wood. In repainting with oil paint, one coat may be adequate if the old paint is in good condition. Dirty paint can often be freshened by washing with detergent. Paint in protected areas also should be washed well before repainting. Wood surfaces exposed by weathering, sanding, or scraping should be spot primed with a zinc-free oil-base primer before the finish coat is applied. Too-frequent repainting with oil-base systems produces an excessively thick film that is likely to crack abnormally across the grain of the wood. Complete paint removal is the only cure for cross-grain cracking. Latex films, based on either vinyl or acrylic polymers, have not been known to fail by cross-grain cracking.

When repainting with water-emulsion or latex paint, good adhesion of the latex to the badly chalked oil paint, is most important in preventing peeling. Vinyl and acrylic latexes are best for exterior exposure on wood.

This can be accomplished in several ways. The chalk layer can be removed by thorough washing and scrubbing with detergent solution. Or after mild steel wooling, the surface can be coated with a good oil-base primer. If the chalk layer is not excessively thick, certain latex paints can have adequate adhesion because of their modification with oil or alkyd-oil resins.

Porous latex paints, like porous low-luster oil-base paints, allow rain and dew to readily pass through the coating film. This can lead to problems of discoloration of the paint by wood extractives and peeling of old paint unless these paints are applied over a nonporous oil-base primer paint.

Avoiding Intercoat Peeling

To avoid intercoat peeling of oil-base paint, which indicates a weak bond between coats of paint, the old painted surface should be well cleaned and no more than 2 weeks allowed between coats in two-coat repainting. Sheltered areas, such as eaves and porch ceilings, need not be repainted every time the weathered body of the house is painted. Before repainting the sheltered areas where intercoat peeling frequently develops, the old paint surface should be washed with trisodium phosphate or detergent solution to remove surface contaminants that interfere with adhesion of the new coat of paint. After washing, the sheltered areas should be rinsed with large amounts of water and allowed to dry thoroughly before repainting. When intercoat peeling does occur, complete paint removal is the only satisfactory procedure to avoid future problems. Latex paints are less likely to fail by intercoat peeling than oil-base paints.

Blistering and Peeling

When too much water gets into paint or into the wood beneath the paint, the paint may either blister or peel.

Moisture blistering usually includes all of the paint down to the wood surface and indicates that the wood behind the paint is excessively wet. Blistering occurs in early spring and will occur first on only specific areas in heated buildings. These are areas that may enclose rooms with a high relative humidity in the winter or are areas wet because of ice dams and plugged gutters. If the blistering is severe, the paint may peel.

Moisture blistering is more likely in new, thin coatings of oil-base paint containing zinc-oxide pigment than in flat-alkyd or latex paints pigmented with titanium dioxide. Older and thicker coatings also are usually too rigid to swell enough to form blisters; instead, they are more prone to crack and peel after excessive wetting.

Peeling is a common type of water damage to paint and does not necessarily involve the formation of distinct blisters. Failure can occur both from interior and exterior source of moisture. Both heated and unheated buildings can peel where rain and dew wet the paint. Such failures are frequently associated with porous, flat, oil-alkyd, and latex paint systems which hold water on the surface, and so provide time for water to penetrate into the layers of paint. Peeling can occur at the wood interface or at some weak bond between layers of paint.

Cracking failures, followed by peeling at the ends of boards and the lower portion of horizontal siding, also indicate that rain and dew have been penetrating through paint or through cracks in paint. Such failures will occur on all sides of houses and also on unheated buildings. On the other hand, peeling failure or paint discoloration at localized areas, such as gable ends of heated buildings, indicates that the moisture is coming from within the building.

FINISHING INTERIOR WOOD

Interior finishing differs from exterior chiefly in that interior woodwork usually requires much less protection against moisture but more exacting standards of appearance and cleanability. Good finishes used indoors should last much longer than paint coatings on exterior surfaces. Veneered panels and plywood, however, present special finishing problems because of the tendency of these wood constructions to surface check.

Opaque Finishes

Interior surfaces may be easily painted by procedures similar to those for exterior surfaces. As a rule, however, smoother surfaces, better color, and a more lasting sheen are demanded for interior woodwork, especially wood trim; therefore, enamels or semigloss enamels rather than paints are used.

Before enameling, the wood surface should be sanded extremely smooth. Imperfections such as planer marks, hammer marks, and raised grain are accentuated by enamel finish. Raised grain is especially troublesome on flat-grained surfaces of the denser softwoods. It may occur because the hard bands of latewood have been crushed into the soft earlywood in planing, and later are pushed up again when the wood changes in moisture content. Before enameling, sponge softwoods with water, allow them to dry thoroughly, and then rub them lightly with new sandpaper. In new buildings, woodwork should be allowed adequate time to come to its equilibrium moisture content before finishing.

To effectively finish hardwoods with large pores, such as oak and ash, the pores must be filled with wood filler (see section on Fillers). After filling and sanding, successive applications of interior primer and sealer, undercoat, and enamel are used. Knots in the white pines, ponderosa pine, or southern pine should be sealed with shellac or a special knot sealer before priming. A coat of pigmented shellac or special knot sealer is also sometimes necessary over white pines and ponderosa pine to retard discoloration of light-colored enamels by colored matter present in the resin of the heartwood of these species.

One or two coats of enamel undercoat are applied; this should completely hide the wood and also present a surface that easily can be sandpapered smooth. For best results, the surface should be sandpapered before applying the finishing enamel; however, this step is sometimes omitted. After the finishing enamel has been applied, it may be left with its natural gloss, or rubbed to a dull finish. When wood trim and paneling are finished with a flat paint, the surface preparation is not nearly as exacting.

Transparent Finishes

Transparent finishes are used on most hardwood and some softwood trim and paneling, according to personal preference. Most finishing consists of some combination of the fundamental operations of staining, filling, sealing, surface coating, or waxing. Before finishing, planer marks and other blemishes on the wood surface that would be accentuated by the finish should be removed.

Stains

Both softwoods and hardwoods are often finished without staining, especially if the wood has a pleasing and characteristic color. When used, however, stain often provides much more than color alone because it is absorbed unequally by different parts of the wood; therefore, it accentuates the natural variations in grain. With hardwoods, such emphasis of the grain is usually desirable; the best stains for the purpose are dyes dissolved either in water or solvent. The water stains give the most pleasing results but raise the grain of the wood and require an extra sanding operation after the stain is dry.

The most commonly used stains are the "non-grain-raising" ones in solvents which dry quickly, and often approach the water stains in clearness and uniformity of color. Stains on softwoods color the earlywood more strongly than the latewood, reversing the natural gradation in color unless the wood has been sealed with a wash coat. Pigment-oil stains (essentially, thin paints) are less subject to this variation, and are therefore more suitable for softwoods. Alternatively, the softwood may be coated with clear sealer before applying the pigment-oil stain to give more nearly uniform coloring.

Fillers

If a smooth coating is desired in hardwoods with large pores, the pores must be filled (usually after staining) before varnish or lacquer is applied. The filler may be transparent and without effect on the color of the finish, or it may be colored to contrast with the surrounding wood.

For finishing purposes, the hardwoods may be classified as follows:

Hardwoods with large pores

- Ash
- Butternut
- Chestnut
- Elm
- Hackberry
- Hickory
- Khaya (African mahogany)
- Lauans
- Mahogany
- Oak
- Sugarberry
- Walnut

Hardwoods with small pores

- Alder, red
- Aspen
- Basswood
- Beech
- Cherry
- Cottonwood
- Gum
- Magnolia
- Maple
- Sycamore
- Yellow-poplar

Birch has pores large enough to take wood filler effectively when desired, but small enough as a rule to be finished satisfactorily without filling.

Hardwoods with small pores may be finished with paints, enamels, and varnishes in exactly the same manner as softwoods.

A filler may be paste or liquid, natural or colored. It is applied by brushing first across the grain and then by brushing with the grain. Surplus filler must be removed immediately after the glossy wet appearance disappears. Wipe first across the grain to pack the filler into the pores; then complete the wiping with a few light strokes with the grain. Filler should be allowed to dry thoroughly and sanded lightly before the finish coats are applied.

Sealers

Sealers are thinned varnish or lacquer and are used to prevent absorption of surface coatings and prevent the bleeding of some stains and fillers into surface coatings, especially lacquer coatings. Lacquer sealers have the advantage of being very fast drying.

Surface Coats

Transparent surface coatings over the sealer may be gloss varnish, semigloss varnish, nitrocellulose lacquer, or wax. Wax provides protection without forming a thick coating and without greatly enhancing the natural luster of the wood. Coatings of a more resinous nature, especially lacquer and varnish, accentuate the natural luster of some hardwoods and seem to permit the observer to look down into the wood. Shellac applied by the laborious process of French polishing probably achieves this impression of depth most fully, but the coating is expensive and easily marred by water. Rubbing varnishes made with resins of high refractive index for light (ability to bend light rays) are nearly as effective as shellac. Lacquers have the advantages of drying rapidly and forming a hard surface, but require more applications than varnish to build up a lustrous coating.

Varnish and lacquer usually dry with a highly glossy surface. To reduce the gloss, the surfaces may be rubbed with pumice stone and water or polishing oil. Waterproof sandpaper and water may be used instead of pumice stone. The final sheen varies with the fineness of the powdered pumice stone, coarse powders making a dull surface and fine powders a bright sheen. For very smooth surfaces with high polish, the final rubbing is done with rottenstone and oil. Varnish and lacquer made to dry to semigloss are also available.

Flat oil finishes commonly called Danish oils are currently very popular. This type of finish penetrates the wood and forms no noticeable film on the surface. Two coats of oil are usually applied, which may be followed with a paste wax. Such finishes are easily applied and maintained but are more subject to soiling than a film-forming type of finish.

Finishes for Floors

Wood possesses a variety of properties that make it a highly desirable flooring material for homes and industrial and public structures. A variety of wood flooring products permits a wide selection of attractive and serviceable wood floors. Selection is available not only from a variety of different wood species and grain characteristics, but also from a considerable number of distinctive flooring types and patterns.

The natural color and grain of wood floors make them inherently attractive and beautiful. Floor finishes enhance the natural beauty of wood, protect it from excessive wear and abrasion, and make the floors easier to clean. A complete finishing process may consist of four steps: Sanding the surface, applying a filler for certain woods, applying a stain to achieve a desired color effect, and applying a finish. Detailed procedures and specified materials depend largely on the species of wood used and individual preference in type of finish.

Careful sanding to provide a smooth surface is essential for a good finish because any irregularities or roughness in the wood surface will be magnified by the finish. Development of a top-quality surface requires sanding in several steps with progressively finer sandpaper, usually with a machine unless the area is small. The final sanding is usually done with a 2/0 grade paper. When sanding is complete, all dust must be removed with a vacuum cleaner or tack rag. Steel wool should not be used on floors unprotected by finish because minute steel particles left in the wood may later cause staining or discoloration.

A filler is required for wood with large pores, such as oak and walnut, if a smooth, glossy, varnish finish is desired.

Stains are sometimes used to obtain a more nearly uniform color when individual boards vary too much in their natural color. Stains may also be used to accent the grain pattern. If the natural color of the wood is acceptable, staining is omitted. The stain should be an oil-base or a non-grain-raising stain. Stains penetrate wood only slightly; therefore, the finish should be carefully maintained to prevent wearing through the stained layer. It is difficult to renew the stain at worn spots in a way that will match the color of the surrounding area.

Finishes commonly used for wood floors are classified either as sealers or varnishes. Sealers, which are usually thinned varnishes, are widely used in residential flooring. They penetrate the wood just enough to avoid formation of a surface coating of appreciable thickness. Wax is usually applied over the sealer; however, if greater gloss is desired, the sealed floor makes an excellent base for varnish. The thin surface coat of sealer and wax needs more frequent attention than varnished surfaces. However, rewaxing or resealing and waxing of high-traffic areas is a relatively simple maintenance procedure.

Varnish may be based on phenolic, alkyd, epoxy, or polyurethane resins. Varnish forms a distinct coating over the wood and gives a lustrous finish. The kind of service expected usually determines the type of varnish. Varnishes especially designed for homes, schools, gymnasiums, or other public buildings are available. Information on types of floor finishes can be obtained from the flooring associations or the individual flooring manufacturers.

Durability of floor finishes can be improved by keeping them waxed. Paste waxes generally give the best appearance and durability. Two coats are recommended and, if a liquid wax is used, additional coats may be necessary to get an adequate film for good performance.

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Chapter 17

PROTECTION FROM ORGANISMS THAT DEGRADE WOOD

PROTECTION FROM ORGANISMS THAT DEGRADE WOOD[1]

Under proper conditions, wood will give centuries of service. Where conditions permit development of organisms that can degrade wood, however, protection must be provided in milling, merchandising, and building to insure maximum service life.

The principal organisms that can degrade wood are fungi, insects, bacteria, and marine borers.

Molds, most sapwood stains, and decay are caused by fungi, which are microscopic, threadlike plants that must have organic material to live. For some of them, wood offers the required food supply. The growth of fungi depends on suitably mild temperatures, dampness, and air (oxygen). Chemical stains, although they are not caused by organisms, are mentioned in this chapter because they resemble stains caused by fungi.

Insects also may damage wood, and in many situations must be considered in protective measures. Termites are the major insect enemy of wood, but, on a national scale, they are a less serious threat than fungi.

Bacteria in wood ordinarily are of little consequence, but some may make the wood excessively absorptive. Additionally, some may cause strength losses.

Marine borers are a fourth general type of wood-degrading organism. They can attack susceptible wood rapidly, and in salt-water harbors are the principal cause of damage to piles and other wood marine structures.

Wood degradation by organisms has been studied extensively and many preventive measures are well known and widely practiced. By taking ordinary precautions with the finished product, the user can contribute substantially to insuring a long service life.

FUNGUS DAMAGE AND CONTROL

Fungus damage to wood may be traced to three general causes: (1) Lack of suitable protective measures when storing logs or bolts; (2) improper seasoning, storing, or handling of the raw material produced after storage; and (3) failure to take ordinary simple precautions in using the final product. The incidence and development of molds, decay, and stains caused by fungi depend heavily on temperature and moisture conditions.

Molds and Fungus Stains

Molds and fungus stains are confined largely to sapwood and are of various colors. The principal fungus stains are usually referred to as "sap stain" or "blue stain." The distinction between molding and staining is made largely on the basis of the depth of discoloration; with some molds and the lesser fungus stains there is no clear-cut differentiation. Typical sap stain or blue stain penetrates into the sapwood and cannot be removed by surfacing. Also, the discoloration as seen on a cross section of the wood often tends to exhibit some radial alinement corresponding to the direction of the wood rays. The discoloration may completely cover the sapwood or may occur as specks, spots, streaks, or patches of varying intensities of color. The so-called "blue" stains, which vary from bluish to bluish-black and gray to brown, are the most common, although various shades of yellow, orange, purple, and red are sometimes encountered. The exact color of the stain depends on the infecting organisms and the species and moisture condition of the wood. The brown stain mentioned here should not be confused with chemical brown stain.

Mold discolorations usually first become noticeable as largely fuzzy or powdery surface growths, with colors ranging from light shades to black. Among the brighter colors, green and yellowish hues are common. On softwoods—through the fungus may penetrate deeply—the discoloring surface growth often can easily be brushed or surfaced off. On hardwoods, however, the wood beneath the surface growth is commonly stained too deeply to be surfaced off. The staining tends to occur in spots of varying concentration and size, depending on the kind and pattern of the superficial growth.

Under favorable moisture and temperature conditions, staining and molding fungi may become established and develop rapidly in the sapwood of logs shortly after they are cut. In

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[1] Mention of a chemical in this chapter does not constitute a recommendation; only those chemicals registered by the U.S. Environmental Protection Agency may be recommended, and then only for uses as prescribed in the registration and in the manner and at the concentration prescribed. The list of registered chemicals varies from time to time; prospective users, therefore, should get current information on registration status from the Environmental Protection Agency, Washington, D.C.

addition, lumber and such products as veneer, furniture stock, and millwork may become infected at any stage of manufacture or use if they become sufficiently moist. Freshly cut or unseasoned stock that is piled during warm, humid weather may be noticeably discolored within 5 or 6 days. Recommended moisture control measures are given in chapter 14.

Stains and molds should not be considered stages of decay as the causal fungi ordinarily do not attack the wood substance appreciably. Ordinarily, they affect the strength of the wood only slightly; their greatest effect is usually confined to strength properties that determine shock resistance or toughness (ch. 4).

Stain- and mold-infected stock is practically unimpaired for many uses in which appearance is not a limiting factor and a small amount of stain may be permitted by standard grading rules. Stock with stain and mold may not be entirely satisfactory for siding, trim, and other exterior millwork because the infected wood has greater water absorptiveness. Also, incipient decay may be present—though inconspicuous—in the discolored areas. Both of these factors increase the possibility of decay in wood that is rained on unless the wood has been treated with a suitable preservative.

Chemical Stains

One type of stain in unseasoned sapwood may resemble blue stain but is not caused by a fungus. This is called chemical stain or sometimes oxidation stain because it is brought about by a reaction between oxygen in the air and certain constituents of the exposed wood. Chemical brown stain is the only one of this type that is particularly serious in softwoods; however, many hardwoods are degraded by such stain. Chemical staining is largely a problem of seasoning; it can usually be prevented by rapid drying at low temperatures (ch. 14).

Decay

Decay-producing fungi may, under conditions that favor their growth, attack either heartwood or sapwood; the result is a condition variously designated as decay, rot, dote, or doze. Fresh surface growths of decay fungi may appear as fan-shaped patches, strands, or rootlike structures, usually white or brown. Sometimes fruiting bodies are produced that take the form of toadstools, brackets, or crusts. The fungus, in the form of microscopic, threadlike strands, permeates the wood and uses parts of it as food. Some fungi live largely on the cellulose; others use the lignin as well as the cellulose.

Certain decay fungi attack the heartwood (causing "heartrot"), and rarely the sapwood of living trees, whereas others confine their activities to logs or manufactured products, such as sawed lumber, structural timbers, poles, and ties. Most of the tree-attacking groups cease their activities after the trees have been cut, as do the fungi causing brown pocket (peck) in baldcypress or white pocket in Douglas-fir. Relatively few continue their destruction after the trees have been cut and worked into products, and then only if conditions remain favorable for their growth.

Most decay can progress rapidly at temperatures that favor growth of plant life in general. For the most part decay is relatively slow at temperatures below 50° F. and much above 90° F. Decay essentially ceases when the temperature drops as low as 35° F. or rises as high as 100° F.

Serious decay occurs only when the moisture content of the wood is above the fiber saturation point (average 30 pct.). Only when previously dried wood is contacted by water, such as provided by rain, condensation, or contact with wet ground, will the fiber saturation point be reached. The water vapor in humid air alone will not wet wood sufficiently to support significant decay, but it will permit development of some mold. Fully air-dry wood usually will have a moisture content not exexceeding 20 percent, and should provide a reasonable margin of safety against fungus damage. Thus wood will not decay if it is kept air dry—and decay already present from infection incurred earlier will not progress.

Wood can be too wet for decay as well as too dry. If it is water-soaked, there may be insufficient access of air to the interior of a piece to support development of typical decay fungi. For this reason, foundation piles buried beneath the water table and logs stored in a pond or under a suitable system of water sprays are not subject to decay by typical wood-decay fungi.

The early or incipient stages of decay are often accompanied by a discoloration of the wood, which is more evident on freshly exposed surfaces of unseasoned wood than on dry wood. Abnormal mottling of the wood color—with either unnatural brown or "bleached" areas—is often evidence of decay infection. Many fungi that cause heartrot in the standing tree produce incipient decay that differs only slightly from the normal color of the wood or gives a somewhat water-soaked appearance to the wood.

Typical or late stages of decay are easily recognized, because the wood has undergone definite changes in color and properties, the character of the changes depending on the organism and the substances it removes.

Two kinds of major decay are recognized—"brown rot" and "white rot." With brown rot, only the cellulose is extensively removed, the wood takes on a browner color, and it tends to crack across the grain and to shrink and collapse. With white rot, both lignin and cellulose usually are removed; the wood may lose color and appear "whiter" than normal, it does not crack across the grain, and until severely degraded it retains its outward dimensions and does not shrink or collapse.

Brown, crumbly rot, in the dry condition, is sometimes called "dry rot," but the term is incorrect because wood must be damp to decay, although it may become dry later. A few fungi, however, have water-conducting strands; such fungi are capable of carrying water (usually from the soil) into buildings or lumber piles, where they moisten and rot wood that would otherwise be dry. They are sometimes referred to technically as "dry rot fungi" or "water-conducting fungi." The latter term better describes the true situation as these fungi, like the others, must have water.

A third and generally less important kind of decay is known as soft rot. Soft rot is caused by fungi related to the molds rather than those responsible for brown and white rot. Soft rot typically is relatively shallow; the affected wood is greatly degraded and often soft when wet, but immediately beneath the zone of rot the wood may be firm. Because soft rot usually is rather shallow it is most likely to damage relatively thin pieces such as slats in cooling towers. It is favored by wet situations but is also prevalent on surfaces that have been alternately wet and dry over a substantial period. Heavily fissured surfaces—familiar to many as "weathered" wood—generally have been considerably degraded by soft rot fungi.

Decay Resistance of Wood

For a discussion of the natural resistance of wood to fungi and a grouping of species according to decay resistance, see chapter 3. Among decay-resistant domestic species, only the heartwood has significant resistance, because the natural preservative chemicals in wood that retard the growth of fungi are essentially restricted to the heartwood. Natural resistance of species to fungi is important only where conditions conducive to decay exist or may develop.

Effect of Decay on Strength of Wood

Incipient decay induced by some fungi is reflected immediately in pronounced weakening of the wood, whereas other fungi reduce strength much less. For example, white pocket (produced by *Fomes pini*) results in little or no loss in strength in its incipient stages. On the other hand, another cause of heartrot in standing softwoods, *Polyporus schweinitzii*, greatly reduces the strength of wood at a very early stage. In the later stages of decay any wood-damaging fungus will seriously reduce the strength of wood.

Control of Mold, Stain, and Decay

Logs, Poles, Piles, and Ties

The wood species, section of the country, and time of the year determine what precautions must be taken to avoid serious damage from fungi in poles, piles, ties, and similar thick products during seasoning or storage. In dry climates, rapid surface seasoning of poles and piles will retard development of mold, stains, and decay. First the bark is peeled from the pole and the peeled product is decked on high skids or piled on high, well-drained ground in the open to dry. In humid regions, such as the Gulf States, these products often do not air dry fast enough to avoid losses from fungi. Preseasoning treatments with approved preservative solutions can be helpful in these circumstances.

For logs, rapid conversion into lumber, or storage in water or under a water spray is the surest way to avoid fungus damage. Preservative sprays promptly applied in the woods will protect most timber species during storage for 2 to 3 months. For longer storage, an end coating is needed to prevent seasoning checks, through which infection can enter the log.

Lumber

Growth of decay fungi can be prevented in lumber and other wood products by rapidly drying them to a moisture content of 20 percent or less and keeping them dry. Standard air-drying practices will usually dry the wood fast enough to protect it, particularly if the protection afforded by drying is supplemented by surface treatment of the stock with an approved fungicidal solution. However, kiln drying is the most reliable method of rapidly reducing moisture content.

Dip or spray treatment of freshly cut lumber with suitable preservative solutions will prevent fungus infection during air drying. Successful control by this method depends not only upon immediate and adequate treatment but also upon the proper handling of the lumber after treatment.

Air drying yards should be kept as sanitary and as open as possible to air circulation. Recommended practice includes locating yards and sheds on well-drained ground; removing debris, which serves as a source of infection, and weeds, which reduce air circulation; and employing piling methods that permit rapid drying of the lumber and protect against wetting. Storage sheds should be constructed and maintained to prevent significant wetting of the stock; an ample roof overhang on open sheds is desirable. In areas where termites or water-conducting fungi may be troublesome, stock to be held for long periods should be set on foundations high enough so it can be inspected from beneath.

The user's best assurance of receiving lumber free from decay or other than light stain is to buy stock marked by a lumber association in a grade that eliminates or limits such quality-reducing features. Surface treatment for protection at the drying yard is only temporarily effective. Except for temporary structures, lumber to be used under conditions conductive to decay should be all heartwood of a naturally durable species or should be adequately treated with a wood preservative (ch. 18).

Buildings

The lasting qualities of properly constructed wood buildings are apparent in all parts of the country. Serious decay problems are almost always a sign of faulty design or construction or of lack of reasonable care in the handling of the wood.

Construction principles that assure long service and avoid decay in buildings include: (1) Build with dry lumber, free of incipient decay and not exceeding the amounts of mold and blue stain permitted by standard grading rules; (2) use designs that will keep the wood dry and accelerate rain runoff; (3) for parts exposed to above-ground decay hazards, use wood treated with a preservative or heartwood of a decay-resistant species; and (4) for the high-hazard situation associated with ground contact, use pressure-treated wood.

A building site that is dry or for which drainage is provided will reduce the possibility of decay. Stumps, wood debris, stakes, or wood concrete forms frequently lead to decay if left under or near a building.

Unseasoned or infected wood should not be enclosed until it is thoroughly dried. Unseasoned wood may be infected because of improper handling at the sawmill or retail yard, or after delivery on the job.

Untreated wood parts of substructures should not be permitted to contact the soil. A minimum of 8 inches clearance between soil and framing and 6 inches between soil and siding is recommended. An exception may be made for certain temporary constructions. If contact with soil is necessary, the wood should be pressure treated (ch. 18).

Sill plates and other wood resting on a concrete-slab foundation generally should be pressure treated, and additionally protected by installing beneath the slab a moisture-resistant membrane of heavy asphalt roll roofing or polyethylene. Girder and joist openings in masonry walls should be big enough to assure an air space around the ends of these wood members; if the members are below the outside soil level, moistureproofing of the outer face of the wall is essential.

In the crawl space of basementless buildings on damp ground, wetting of the wood by condensation during cold weather may result in serious decay damage. However, serious condensation leading to decay can be prevented by providing openings on opposite sides of the foundation walls for cross ventilation or by laying heavy roll roofing or polyethylene on the soil; both provisions may be helpful in very wet situations. To facilitate inspection and ventilation of the crawl space, at least an 18-inch clearance should be left under wood joists.

Porches, exterior steps, and platforms present a decay hazard that cannot be fully avoided by construction practices. Therefore, in the wetter climates the use of preservative-treated wood (ch. 18) or heartwood of a durable species usually is advisable for such items.

Protection from entrance or retention of rainwater or condensation in walls and roofs will prevent the development of decay in these areas. A fairly wide roof overhang (2 ft.) with gutters and downspouts that are never permitted to clog is very desirable. Sheathing papers under the siding should be of a "breathing" or vapor-permeable type (asphalt paper not exceeding 15-lb. weight). Vapor barriers should be near the warm face of walls and ceilings. Roofs must be kept tight, and cross ventilation in attics is desirable. The use of sound, dry lumber is important in all parts of buildings.

Where service conditions in a building are such that the wood cannot be kept dry, as in textile mills, pulp and paper mills, and cold-storage plants, lumber properly treated with an approved preservative or lumber containing all heartwood of a naturally decay-resistant species should be used.

In making repairs necessitated by decay, every effort should be made to correct the moisture condition leading to the damage. If the condition cannot be corrected, all infected parts should be replaced with treated wood or with all-heartwood lumber of a naturally decay-resistant wood species. If the sources of moisture that caused the decay are entirely eliminated, it is necessary only to replace the weakened wood with dry lumber.

Other Structures and Products

In general, the principles underlying the prevention of mold, stain, or decay damage to veneer, plywood, containers, boats, and other wood products and structures are similar to those described for buildings—dry the wood rapidly and keep it dry or treat it with approved protective and preservative solutions. Interior grades of plywood should not be used where the plywood will be exposed to moisture; the adhesives, as well as the wood, may be damaged by fungi and bacteria as well as being degraded by moisture. With either plywood or fiberboard of the exterior type, joint construction should be carefully designed to prevent the entrance of rainwater.

Wood boats present certain problems that are not encountered in other uses of wood. The parts especially subject to decay are the stem, knighthead, transom, and frameheads; these are reached by rainwater from above or condensation moisture from below. Faying surfaces are more liable to decay than exposed surfaces, and in salt-water service hull members just below the weather deck are more vulnerable than those below the waterline. Recommendations for avoiding decay include: (1) Use only heartwood of durable species, free of infection, and preferably below 20 percent in moisture content; (2) provide and maintain ventilation in the hull and all compartments; (3) keep water out as much as is practicable, especially fresh water; and (4) where it is necessary to use sapwood or nondurable heartwood, impregnate the wood with an approved preservative or treat the fully cut, shaped, and bored wood before installation by soaking it for a short time in preservative solution. Where such mild soaking treatment is used, the wood most subject to decay should also be flooded with an approved preservative at intervals of 2 or 3 years. When retreating, the wood should be dry so that joints are relatively loose.

BACTERIA

Most wood that has been wet for any considerable length of time probably will contain bacteria. The sour smell of logs that have been held under water for several months—or of lumber cut from them—manifests bacterial action. Usually bacteria have little effect on wood properties, except over long periods of time, but some may make the wood excessively absorptive. This effect has been a problem in the sapwood of millwork cut from pine logs that have been stored in ponds. There also is evidence that bacteria developing in pine veneer bolts held under water or water spray may cause noticeable changes in the physical character of the veneer—including some strength loss. Additionally, mixtures of different bacteria, and probably fungi also, were found capable of accelerating decay of treated cooling tower slats and mine timbers.

INSECT DAMAGE AND CONTROL

The more common types of degrade caused by wood-attacking insects are shown in table 17–1. Methods of controlling and preventing insect attack of wood are described in the following paragraphs.

Table 17-1.—*Common types of degrade caused by wood-attacking insects*

Type of degrade	Description	How and where made	Condition of degraded timber
Pinholes	Holes with dark streak in surrounding wood, 1/100 to ¼ inch in diameter, usually circular and open (not grouped in given space):		
	Hardwoods:		
	Stained area 1 inch or more long	By ambrosia beetles in living trees.	Wormholes, no living worms.
	Stained area less than 1 inch long	By ambrosia beetles in recently felled trees and green logs.	Do.
	Softwoods:		
	Stained area less than 1 inch long	By ambrosia beetles in sapwood of peeled trees, green logs, and green lumber.	Do.
	Holes usually without streak in surrounding wood of both softwoods and hardwoods (usually grouped in given space):		
	Holes darkly stained, less than ⅛ inch in diameter.	By ambrosia beetles in felled trees, green logs, and green lumber.	Do.
	Holes unstained, open, and variable in diameter:		
	Lined with a substance the color of wood: from 1/100 to ¼ inch in diameter (hardwoods rarely with streaks in surrounding wood).	By timberworms in living and felled trees and green logs.	Do.
	Unlined, less than ⅛ inch in diameter (not grouped in given space).	By ambrosia beetles in green logs and green lumber.	Do.
Grub holes	Holes ⅜ to 1 inch in diameter, variable in shape, open or with boring dust:		
	Holes stained, usually open	By wood-boring grubs in living trees.	Do.
	Holes unstained, usually with boring dust present:		
	Borings fine, granular, or fibrous	do	Do.
	Borings variable in character, sometimes absent.	By adults and larvae of beetles and other wood-boring insects in recently felled softwoods and hardwoods.	Do.
Powder-post	Holes mostly 1/16 to ¼ inch in diameter, circular to broadly oval, filled with granular or powdery boring dust, and unstained:		
	Hardwoods	By roundheaded borers and powder-post beetles in green or seasoned wood.	Wormholes.
	Softwoods	By flathead borers in living, recently felled, and dead trees.	Do.
		By roundheaded borers, weevils, and Anobium powder-post beetles in seasoned wood.	Do.
Pitch pocket		By various insects in living trees.	Wormholes, no living worms.
Black check		By the grubs of various insects in living trees.	Do.
Bluing	Stained area over 1 inch long	By fungus following insect wounds in living trees and recently felled sawlogs.	Do.
Pith fleck		By the maggots of flies or adult weevils in living trees.	Do.
Gum spot		By the grubs of various insects in living trees.	Do.
Ring distortions		By defoliating larvae or flathead cambium miners in living trees.	Do.

Beetles

Bark beetles may damage the components of log and other rustic structures on which the bark is left. They are reddish-brown to black and vary in length from about 1/16 to 1/4 inch. They bore through the outer bark to the soft inner part, where they make tunnels in which they lay their eggs. In making tunnels, bark beetles push out fine brownish-white sawdust-like particles. If many beetles are present, their extensive tunneling will loosen the bark and permit it to fall off in large patches, making the structure unsightly.

To avoid bark beetle damage, logs may be stored in water or under a water spray, or cut during the dormant season (October or November, for instance). If cut during this period, logs should immediately be piled off the ground where there will be good air movement, to promote rapid drying of the inner bark before the beetles begin to fly in the spring. Drying the bark will almost always prevent damage by insects that prefer freshly cut wood. Another protective measure is to thoroughly spray the logs with an approved insecticidal solution.

Ambrosia beetles, roundheaded and flatheaded borers, and some powder-post beetles that get into freshly cut timber can cause considerable damage to wood in rustic structures and some manufactured products. Certain beetles may complete development and emerge a year or more after the wood is dry, often raising a question as to the origin of the infestation. Proper cutting practices and spraying the material with an approved chemical solution, as recommended for bark beetles, will control these insects. Damage by ambrosia beetles can be prevented in freshly sawed lumber by dipping the product in a chemical solution. The addition of one of the sap-stain preventives approved for controlling molds, stains, and decay will keep the lumber bright.

Powder-post beetles attack both hardwoods and softwoods, and both freshly cut and seasoned lumber and timber. The powder-post beetles that cause most damage to dry hardwood lumber belong to the *Lyctus* species. They attack the sapwood of ash, hickory, oak, and other hardwoods as it begins to season. Eggs are laid in pores of the wood, and the larvae burrow through the wood, making tunnels from 1/16 to 1/12 inch in diameter, which they leave packed with a fine powder. Powder-post damage is indicated by holes left in the surface of the wood by the winged adults as they emerge and by the fine powder that may fall from the wood.

Susceptible hardwood lumber used for manufacturing purposes should be protected from powder-post beetle attack as soon as it is sawed and also when it arrives at the plant. An approved insecticide applied in water emulsion to the green lumber will provide protection. Such treatment may be effective even after the lumber is kiln dried—until it is surfaced.

Good plant sanitation is extremely important in alleviating the problem of infestations. Proper sanitation measures can often eliminate the necessity for other preventative steps. Damage to manufactured items frequently is traceable to infestations that occur before the products are placed on the market, particularly if a finish is not applied to the surface of the items until they are sold. Once wood is infested, the larvae will continue to work, even though the surface is subsequently painted, oiled, waxed, or varnished.

When selecting hardwood lumber for building or manufacturing purposes, any evidence of powder-post infestation should not be overlooked, for the beetles may continue to be active long after the wood is put to use. Sterilization of green wood with steam at 130° F. or sterilization of wood with a lower moisture content at 180° F. under controlled conditions of relative humidity for about 2 hours is effective for checking infestation or preventing attack of 1-inch lumber. Thicker material requires a longer time. A 3-minute soaking in a petroleum oil solution containing an insecticide is also effective for checking infestation or preventing attack of lumber up to 1 inch thick. Small dimension stock also can be protected by brushing or spraying with approved chemicals. For infested furniture or finished woodwork in a building, the same insecticides may be used but they should be dissolved in a refined petroleum oil, like mineral spirits.

As the *Lyctus* beetles lay their eggs in the open pores of wood, infestation can be prevented by covering the entire surface of each piece of wood with a suitable finish.

A roundheaded powder-post beetle, commonly known as the "old house borer," causes damage to seasoned pine floor joists. The larvae reduce the sapwood to a powdery or granular consistency and make a ticking sound while at work. When mature, the beetles make an oval hole about 1/4 inch in diameter in the surface of the wood and emerge. Anobiid powder-post beetles, which make holes 1/16 to 1/8 inch in diameter, also cause damage to pine joists. Infested wood should be drenched with a solution of one of the currently recommended insecticides in a highly penetrating solvent. Beetles working in wood behind plastered or paneled walls can be eliminated by having a licensed operator fumigate the building.

Termites

Termites superficially resemble ants in size, general appearance, and habit of living in colonies. About 56 species are known in the United States. From the standpoint of their methods of attack on wood, they can be grouped into two main classes: (1) The ground-inhabiting or subterranean termites; and (2) the wood-inhabiting or nonsubterranean termites.

Subterranean Termites

Subterranean termites are responsible for most of the termite damage done to wood structures in the United States. This damage can be prevented. Subterranean termites are more prevalent in the southern states than in the northern states, where low temperatures do not favor their development (fig. 17–1). The hazard of infestation is greatest (1) beneath basementless buildings erected on a concrete-slab foundation or over a crawl space that is poorly drained and ventilated, and (2) in any substructure wood close to the ground or an earth fill (e.g. an earth-filled porch).

The subterranean termites develop their colonies and maintain their headquarters in the ground. They build their tunnels through earth and around obstructions to get at the wood they need for food. They also must have a constant source of moisture. The worker members of the colony cause destruction of wood. At certain seasons of the year male and female winged forms swarm from the colony, fly a short time, lose their wings, mate, and, if successful in locating a suitable home, start new colonies. The appearance of "flying ants," or their shed wings, is an indication that a termite colony may be near and causing serious damage. Not all "flying ants" are termites; therefore suspicious insects should be identified before money is spent for their eradication (fig. 17–2).

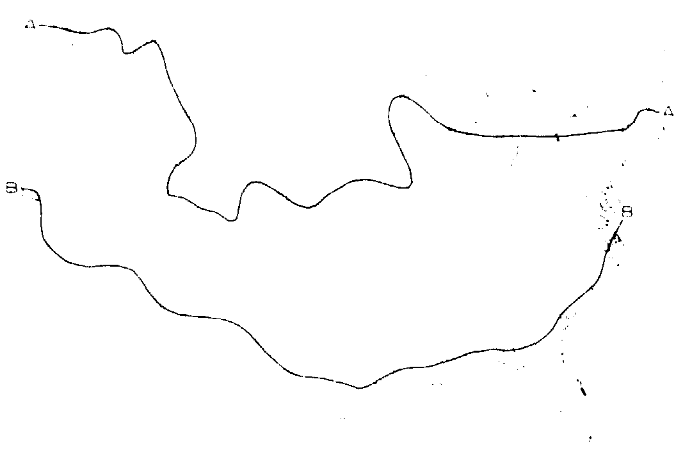

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Figure 17–1.—*A*, The northern limit of recorded damage done by subterranean termites in the United States; *B*, the northern limit of damage done by dry-wood or nonsubterranean termites.

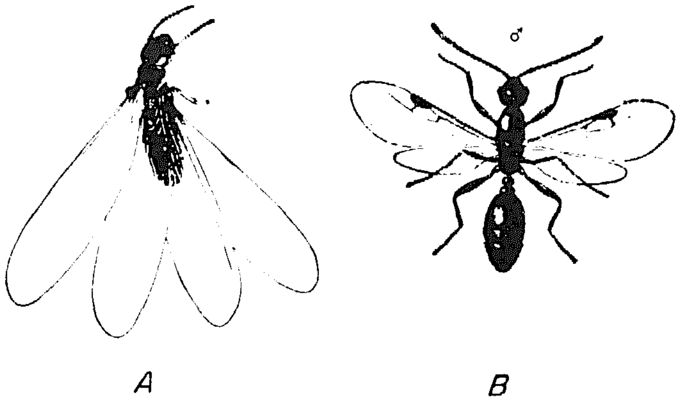

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Figure 17–2.—*A*, Winged termite; *B*, winged ant (both greatly enlarged). The wasp waist of the ant and the long wings of the termite are distinguishing characteristics.

Subterranean termites do not establish themselves in buildings by being carried there in lumber, but enter from ground nests after the building has been constructed. Telltale signs of their presence are the earthern tubes or runways built by these insects over the surfaces of foundation walls to reach the wood above. Another sign is the swarming of winged adults early in the spring or fall. In the wood itself, the termites make galleries that generally follow the grain, leaving a shell of sound wood to conceal their activities. As the galleries seldom show on the wood surfaces, probing with an ice pick or knife is advisable if the presence of termites is suspected.

The best protection where subterranean termites are prevalent is to prevent them from gaining access to the building. The foundations should be of concrete or other solid material through which the termites cannot penetrate. With brick, stone, or concrete blocks, cement mortar should be used, for termites can work through some other kinds of mortar.

Also, it is a good precaution to cap the foundation with about 4 inches of reinforced concrete. Posts supporting first-floor girders should, if they bear directly on the ground, be of concrete. If there is a basement, it should be floored with concrete. Untreated posts in such a basement should rest on concrete piers extending a few inches above the basement floor. However, pressure-treated posts can rest directly on the basement floor. With the crawl-space type of foundation, wood floor joists should be kept at least 18 inches and girders 12 inches from the earth and good ventilation provided beneath the floor.

Moisture condensation on the floor joists and subflooring, which may cause conditions favorable to decay and contribute to infestation by termites, can be avoided by covering the soil below with a moisture barrier. When concrete-slab floors are laid directly on the ground, all soil under the slab should be treated with an approved insecticide before the concrete is poured. Furthermore, insulation containing cellulose that is used as a filler in expansion joints should be impregnated with an approved chemical toxic to termites. Sealing the top $\frac{1}{2}$ inch of the expansion joint with roofing-grade coal-tar pitch also provides effective protection from ground-nesting termites.

All concrete forms, stakes, stumps, and waste wood should be removed from the building site, for they are possible sources of infestation. In the main, the precautions effective against subterranean termites are also helpful against decay.

The principal method of protecting buildings in high termite hazard areas is to throughly treat the soil adjacent to the foundation walls and piers beneath the building with a soil insecticide. New modifications in soil treatment are currently under investigation and appear promising. Current references to termite control should be consulted.

To control termites already in a building, break any contact between the termite colony in the soil and the woodwork. This can be done by blocking the runways from soil to wood, by treating the soil, or both. Guard against possible reinfestations by frequent inspections for telltale signs that were listed previously.

Recently, the Formosan termite has become established in the United States. It is more active and voracious than the subterranean termites native to the United States. However, the conventional methods of protection seem to be effective.

Nonsubterranean Termites

Nonsubterranean termites have been found only in a narrow strip of territory extending from central California around the southern edge of continental United States to Virginia (fig. 17–1) and also in the West Indies and Hawaii. Their principal damage is confined to an area in southern California, to parts of southern Florida, notably Key West, and to the islands of Hawaii.

The nonsubterranean termites, especially the dry-wood type, do not multiply as rapidly as the subterranean termites, and have somewhat different colony life and habits. The total amount of destruction they cause in the United States is much less than that caused by the subterranean termites. The ability of dry-wood termites to live in dry wood without outside moisture or contact with the ground, however, makes them a definite menace in the regions where they occur. Their depredations are not rapid, but they can thoroughly riddle timbers with their tunnelings if allowed to work unmolested for a few years.

In constructing a building in localities where the dry-wood type of nonsubterranean termite is prevalent, it is good practice to inspect the lumber carefully to see that it was not infested before arrival at the building site. If the building is constructed during the swarming season, the lumber should be watched during the course of construction, because infestation by colonizing pairs can easily take place. Because paint is a good protection against the entrance of dry-wood termites, exposed wood (except that which is preservative treated) should be kept adequately painted. Fine screen should be placed over any openings through which access might be gained to the interior unpainted parts of the buildings. As in the case of ground-nesting termites, old stumps, posts, or wood debris of any kind that could serve as sources of infestation should be removed from the premises.

If a building is infested with dry-wood termites, badly damaged wood should be replaced. If the wood is only slightly damaged or difficult to replace, further termite activity can be arrested by forcing a teaspoonful of an approved pesticide dust into each nest. Also effective are approved liquid insecticides. Current recommendations for such formulations should be consulted.[2] Detached houses

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[2] See footnote, p. 17–2.

heavily infested with nonsubterranean termites have been fumigated with success. This method is quicker and often cheaper than the use of poisonous liquids and dusts, but it does not prevent the termites from returning because no poisonous residue is left in the tunnels. Fumigation is very dangerous and should be conducted only by licensed professional fumigators.

In localities where dry-wood termites do serious damage to posts and poles, the best protection for these and similar forms of outdoor timbers is full-length pressure treatment with a preservative.

Naturally Termite-Resistant Woods

Only a limited number of woods grown in the United States offer any marked degree of natural resistance to termite attack. The close-grained heartwood of California redwood has some resistance, especially when used above ground. Very resinous heartwood of southern pine is practically immune, but wood of this type is not available in large quantities or suitable for many uses.

Carpenter Ants

Carpenter ants are black or brown. They occur usually in stumps, trees, or logs but sometimes damage poles, structural timbers, or buildings. One form is easily recognized by its giant size relative to other ants. Carpenter ants use wood for shelter rather than for food, usually preferring wood that is naturally soft or has been made soft by decay. They may enter a building directly, by crawling, or may be carried there in fuel wood. If left undisturbed they can, in a few years, enlarge their tunnels to the point where replacement or extensive repairs are necessary. The parts of dwellings they frequent most often are porch columns, porch roofs, window sills, and sometimes the wood plates in foundation walls. The logs of rustic cabins are also attacked.

Precautions that prevent attack by decay and termites are usually effective against carpenter ants. Decaying or infested wood, such as logs or stumps, should be removed from the premises, and crevices present in the foundation or woodwork of the building should be sealed. Particularly, leaks in porch roofs should be repaired, because the decay that may result makes the wood more desirable to the ants.

When carpenter ants are found in a structure, any badly damaged timbers should be replaced. Because the ant needs high humidity in its immature stages, alterations in the construction may also be required to eliminate moisture from rain or condensation. In wood not sufficently damaged to require replacement, the ants can be killed by dusting with an approved insecticide.

MARINE BORER DAMAGE AND CONTROL

Damage by marine-boring organisms to wood structures in salt or brackish waters is practically worldwide. Slight attack is sometimes found in rivers even above the region of brackishness. The rapidity of attack depends upon local conditions and the kinds of borers present. Along the Pacific, Gulf, and South Atlantic coasts of the United States attack is rapid, and untreated piling may be completely destroyed in a year or less. Along the coast of the New England States the rate of attack is slower but still sufficiently rapid, generally, to require protection of wood where long life is desired.

The principal marine borers from the standpoint of wood damage in the United States are described here. Control measures discussed in this section are those in use at the time this handbook was prepared. Regulations should be reviewed at the time control treatments are being considered so that approved practices will be followed.[3]

Shipworms

Shipworms are the most destructive of the marine borers. They are mollusks of various species that superficially are wormlike in form. The group includes several species of *Teredo* and several species of *Bankia*, which are especially damaging. These are readily distinguishable on close observation but are all very similar in several respects. In the early stages of their life they are minute, free-swimming organisms. Upon finding suitable lodgement on wood they quickly develop into a new form and bury themselves in the wood. A pair of boring shells on the head grows rapidly in size as the boring progresses, while the tail part or siphon remains at the original entrance. Thus, the animal grows in length and diameter within the wood but remains a prisoner in its burrow, which it lines with

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[3] See footnote, p. 17–2.

a shell-like deposit. It lives on the wood borings and the organic matter extracted from the sea water that is continuously being pumped through its system. The entrance holes never grow large, and the interior of a pile may be completely honeycombed and ruined while the surface shows only slight perforations. When present in great numbers, the borers grow only a few inches before the wood is so completely occupied that growth is stopped, but when not crowded they can grow to lengths of 1 to 4 feet according to species.

Pholads

Another group of wood-boring mollusks is *pholads*, which clearly resemble clams and therefore are not included with the shipworms. These are entirely encased in their double shells. The *Martesia* are the best-known species, but a second group is the *Xylophaga*. Like the shipworms, the *Martesia* enter the wood when very small, leaving a small entrance hole, and grow larger as they burrow into the wood. They generally do not exceed 2½ inches in length and 1 inch in diameter, but are capable of doing considerable damage. Their activities in the United States appear to be confined to the Gulf of Mexico.

Limnoria and Sphaeroma

Another distinct group of marine borers are crustaceans, which are related to lobsters and shrimp. The principal ones are species of *Limnoria* and *Sphaeroma*. Their attack differs from that of the shipworms and the *Martesia* in that it is quite shallow; the result is that the wood gradually is thinned through erosion by the combined action of the borers and water. Also, the *Limnoria* and *Sphaeroma* do not become imprisoned in the wood but may move freely from place to place.

Limnoria are small, about ⅛ to ⅙ inch long, and bore small burrows in the surface of piles. Although they can change their location, they usually continue to bore in one place. When great numbers are present, their burrows are separated by very thin walls of wood that are easily eroded by the motion of the water or damaged by objects floating upon it. This erosion causes the *Limnoria* to burrow continually deeper; otherwise the burrows would probably not become more than 2 inches long or more than ½ inch deep. As erosion is greatest between tide levels, piles heavily attacked by *Limnoria* characteristically wear within such levels to an hourglass shape. Untreated piling can be destroyed by *Limnoria* within a year in heavily infested harbors.

Sphaeroma are somewhat larger, sometimes reaching a length of ½ inch and a width of ¼ inch. They resemble in general appearance and size the common sow bug or pill bug that inhabits damp places. *Sphaeroma* are widely distributed but not as plentiful as *Limnoria* and do much less damage. Nevertheless piles in some structures have been ruined by them. Occasionally they have been found working in fresh water. In types of damage, *Sphaeroma* action resembles that of *Limnoria*.

The average life of well-creosoted structures is many times the average life that could be obtained from untreated structures. However, even thorough creosote treatment will not always stop *Martesia*, *Sphaeroma*, and especially *Limnoria*.

Shallow or erratic creosote penetration affords but slight protection. The spots with poor protection are attacked, and from them the borers spread inward and destroy the untreated interior of the pile. Low retention fails to provide a reservoir of surplus preservative to compensate for depletion by evaporation and leaching.

When wood is to be used in salt water, avoidance of cutting or injuring the surface after treatment is even more important than when wood is to be used on land. No cutting or injury of any kind for any purpose should be permitted in the underwater part of the pile. Where piles are cut to grade above the waterline, the exposed surfaces should, of course, be protected from decay.

Resistance to Marine Borers

No wood is immune to marine-borer attack, and no commercially important wood of the United States has sufficient marine-borer resistance to justify its use untreated in any important structure in areas where borers are active. The heartwood of several foreign species, such as turpentine, greenheart, jarrah, azobe, totara, kasikasi, manbarklak, and several others, has shown resistance to marine-borer attack. Service records on these woods, however, do not always show uniform results and are affected by local conditions.

Protection of Permanent Structures

The best practical protection for piles in sea water where borer hazard is moderate is heavy treatment with coal-tar creosote or creosote-coal tar solution. Where severe borer hazard exists, dual treatment (copper arsenate[4] containing waterborne preservatives followed by coal-tar creosote) is recommended. The treatment must be thorough, the penetration as deep as possible, and the retention high to give satisfactory results in heavily infested waters. It is best to treat such piles by the full-cell process "to refusal;" that is, to force in all the preservative the piles can hold without using treatments that cause serious damage to the wood. The retentions recommended in chapter 18 are minimum values; when maximum protection against marine borers is desired, as much more preservative as is practicable should be injected. For highest retentions it is necessary to air dry the piling before treatment. Details of treatments are discussed in chapter 18.

The life of treated piles is influenced by the thoroughness of the treatment, the care and intelligence used in avoiding damage to the treated shell during handling and installation, and the severity of borer attack. Differences in exposure conditions, such as water temperature, salinity, dissolved oxygen, water depth, and currents, tend to cause wide variations in the severity of borer attack even within limited areas. The San Francisco Bay Marine Piling Committee has estimated a range of 15 to 30 years for the life of creosoted piles on the Pacific Coast. More recent service records show average-life figures of from 22 to 48 years on well-treated Douglas-fir piles in San Francisco Bay waters. In South Atlantic and Gulf of Mexico waters, creosoted piles are estimated to last 10 to 12 years, and frequently much longer. On the North Atlantic Coast, even longer life is to be expected.

Metal armor and concrete jacketing have been used with varying degrees of success for the protection of marine piles. The metal armor may be in the form of sheets, wire, or nails. Scupper-nailing with iron or steel furnishes some protection, particularly against *Limnoria*. Sheathing of piles with copper or muntz metal has been only partially successful, owing to difficulty in maintaining a continuous armor. Theft, damage in driving, damage by storm or driftwood, and corrosion have sooner or later let in the borers, and in only a few cases has long life been reported. Attempts during World War II to electroplate wood piles with copper were not successful. Concrete casings are now in greater use than metal armor and appear to provide better protection when high-quality materials are used and are carefully applied. Unfortunately, they are readily damaged by ship impact. For this reason, concrete casings are less practical for fender piles than for foundation piles that are protected from mechanical damage.

Jacketing piles by wrapping them with heavy polyvinyl plastic is one of the most recent forms of supplementary protection. If properly applied, it will kill any borers that may have already become established, by rendering stagnant the water in contact with the piles. Like other materials, the plastic jacket is subject to mechanical damage.

Protection of Boats

Wood barges and lighters have been constructed with planking or sheathing pressure treated with creosote to provide hull protection from marine borers, and the results have been favorable. Although coal-tar creosote is an effective preservative for protecting wood against marine borers in areas of moderate borer hazard, it has disadvantages in many types of boats. Creosote adds considerably to the weight of the boat hull, and its odor is objectionable to boat crews. In addition, antifouling paints are difficult to apply over creosoted wood.

Some copper bottom paints protect boat hulls against marine-borer attack, but the protection continues only while the coating remains unbroken. As it is difficult to maintain an unbroken coating of antifouling paint, the U.S. Navy has found it desirable to impregnate the hull planking of some wood boats with certain copper-containing preservatives.[4] Such preservatives, when applied with high retentions (1.5 to 2.0 p.c.f.), have some effectiveness against marine borers and should help to protect the hull of a boat during intervals between renewals of the antifouling coating. These copper preservatives do not provide protection equivalent to that furnished by coal-tar creosote; their effectiveness in protecting boats is therefore best assured if the boats are dry docked at regular and frequent intervals and the antifouling coating

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[4] See footnote, p. 17-2.

maintained. However, the leach-resistant wood preservatives containing copper arsenates[5] have shown superior performance (at a retention of 2.5 p.c.f.) to creosote in tests conducted in areas of severe borer hazard.

Plywood as well as plank hulls can be protected against marine borers by preservative treatment. The plywood hull presents a surface that can be covered successfully with a protective membrane of reinforced plastic laminate. Such coverings should not be attempted on wood that has been treated with a preservative carried in oil, because the bond will be unsatisfactory.

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[5] See footnote, p. 17–2.

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Chapter 18

WOOD PRESERVATION

WOOD PRESERVATION[1]

Wood can be protected from the attack of decay fungi, harmful insects, or marine borers by applying selected chemicals as wood preservatives. The degree of protection obtained depends on the kind of preservative used and on achieving proper penetration and retention of the chemicals. Some preservatives are more effective than others, and some are more adaptable to certain use requirements. The wood can be well protected only when the preservative substantially penetrates it, and some methods of treatment assure better penetration than others. There is also a difference in the treatability of various species of wood, particularly of their heartwood, which generally resists preservative treatment more than sapwood.

Good wood preservatives, applied with standard retentions and with the wood satisfactorily penetrated, substantially increase the life of wood structures, often by five or more times. On this basis the annual cost of treated wood in service is greatly reduced below that of similar wood without treatment. In considering preservative treatment processes and wood species, the combination must provide the required protection for the conditions of exposure and life of the structure.

WOOD PRESERVATIVES

Wood preservatives fall into two general classes: Oils, such as creosote and petroleum solutions of pentachlorophenol; and waterborne salts that are applied as water solutions.

Preservative Oils

The wood does not swell from the preservative oils, but it may shrink if it loses moisture during the treating process. Creosote and solutions with the heavier, less volatile petroleum oils often help protect the wood from weathering outdoors, but may adversely influence its cleanliness, odor, color, paintability, and fire resistance in use. Preservative oils sometimes travel from treated studs or subflooring along nails and discolor adjacent plaster or finish flooring. Volatile oils or solvents with oil-borne preservatives, if removed after treatment, leave the wood somewhat cleaner than the heavier oils but may not provide as much protection. Wood treated with preservative oils can be glued satisfactorily, although special processing or cleaning may be required to remove surplus oils from surfaces before spreading the adhesive.

Coal-Tar Creosote

Coal-tar creosote, a black or brownish oil made by distilling coal tar, is one of the more important and useful wood preservatives. Its advantages are: (1) High toxicity to wood-destroying organisms; (2) relative insolubility in water and low volatility, which impart to it a great degree of permanence under the most varied use conditions; (3) ease of application; (4) ease with which its depth of penetration can be determined; (5) general availability and relative low cost (when purchased in wholesale quantities); and (6) long record of satisfactory use.

The character of the tar used, the method of distillation, and the temperature range in which the creosote fraction is collected all influence the composition of the creosote. The composition of the various coal-tar creosotes available, therefore, may vary to a considerable extent. Small differences in composition, however, do not prevent creosotes from giving good service; satisfactory results in preventing decay may generally be expected from any coal-tar creosote that complies with the requirements of standard specifications.

Although coal-tar creosote or creosote-coal tar solutions are well qualified for general outdoor service in structural timbers, they have properties that are disadvantageous for some purposes.

The color of creosote and the fact that creosote-treated wood usually cannot be painted satisfactorily make this preservative unsuitable for finish lumber or other lumber used where appearance and paintability are important.

The odor of creosoted wood is unpleasant to some persons. Also, creosote vapors are

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[1] Mention of a chemical in this chapter does not constitute a recommendation; only those chemicals registered by the U.S. Environmental Protection Agency may be recommended, and then only for uses as prescribed in the registration and in the manner and at the concentration prescribed. The list of registered chemicals varies from time to time; prospective users, therefore, should get current information on registration status from the Environmental Protection Agency, Washington, D.C.

harmful to growing plants, and foodstuffs that are sensitive to odors should not be stored where creosote odors are present. Workmen sometimes object to creosoted wood because it soils their clothes and because it burns the skin of the face and hands of some individuals. With normal precautions to avoid direct dermal contact with creosote, there appears to be no danger to the health of workmen handling or working near the treated wood or on the health of the occupants of buildings in which the treated wood is used.

Freshly creosoted timber can be ignited easily and will burn readily, producing a dense smoke. However, after the timber has seasoned some months, the more volatile parts of the oil disappear from near the surface, and the creosoted wood usually is little, if any, easier to ignite than untreated wood. Until this volatile oil has evaporated, ordinary precautions should be taken to prevent fires. On the other hand, timber that has been kept sound by creosote treatment is harder to ignite than untreated wood that has started to decay. A preservative other than creosote should be used where fire hazard is highly important, unless the treated wood is also protected from fire.

A number of specifications prepared by different organizations are available for creosote oils of different kinds. Although the oil obtained under most of these specifications will probably be effective in preventing decay, the requirements of some organizations are more exacting than others. Federal Specification TT–C–645 for coal-tar creosote, adopted for use by the U.S. Government, will generally prove satisfactory; under normal conditions, this specification can be met without difficulty by most creosote producers. The requirements of this specification are similar to those of the American Wood-Preservers' Association (AWPA) Standard P1 for creosote, which is equally acceptable.

Federal Specification TT–C–645 provides for three classes of coal-tar creosote. Class I is for poles; class II is for ties, lumber, structural timbers, land or fresh water piles, and posts; and class III is for piles, lumber, and structural timbers for use in coastal waters.

Some pole users, to reduce bleeding in poles with high retentions of creosote, have specified lower retentions of coal-tar creosote fortified with 2 percent pentachlorophenol. Corrosion problems to treating plant equipment have accompanied the use of this preservative and are under investigation.

Coal-Tar Creosotes for Nonpressure Treatments

Special coal-tar creosotes are available for nonpressure treatments. They differ somewhat from regular commercial coal-tar creosote in (1) being crystal-free to flow freely at ordinary temperatures and (2) having low-boiling distillation fractions removed to reduce evaporation in thermal (hot-and-cold) treatments in open tanks. Federal Specification TT–C–655 covers coal-tar creosote for brush, spray, or open-tank treatments.

Other Creosotes

Creosotes distilled from tars other than coal tar are used to some extent for wood preservation, although they are not included in current Federal or AWPA specifications. These include wood-tar creosote, oil-tar creosote, and water-gas-tar creosote. These creosotes protect wood from decay and insect attack but are generally less effective than coal-tar creosote.

Tars

Coal tars are seldom used alone for preserving wood because good penetration is usually difficult to obtain and because they are less poisonous to wood-destroying fungi than the coal-tar creosotes. Service tests have demonstrated that surface coatings of tar are of little value. Coal tar has been used in the pressure treatment of crossties, but it has been difficult to get the highly viscous tar to penetrate wood satisfactorily. When good absorptions and deep penetrations are obtained, however, it is reasonable to expect a satisfactory degree of effectiveness from treatment with coal tar. The tar has been particularly effective in reducing checking in crossties in service.

Water-gas-tar is used less extensively than coal tar, but, in certain cases where the wood was thoroughly impregnated, the results were good.

Creosote Solution

For many years, either coal tar or petroleum oil has been mixed with coal-tar creosote, in various proportions, to lower preservative costs. These creosote solutions have a satisfactory record of performance, particularly for crossties where they have been most commonly used.

Federal Specification TT–C–650, "Creosote-Coal-Tar Solution," covers five classes of creosote-coal-tar solution. These classes contain not less than 80, 70, 60, 50, and 65 percent coal-tar distillate (creosote) (by volume), for classes I, II, III, IV, and V, respectively. Classes I and II are for land and fresh-water piles, posts, lumber, structural timber, and bridge ties. Classes III and IV are for crossties and switch ties. Class V, which has a 60 to 75 percent level of distillate, is for piles, lumber, and structural timber used in coastal waters.

AWPA Standard P2 includes four creosote-coal-tar solutions that must contain, respectively, not less than 80, 70, 60, or 50 percent by volume of coal-tar distillate and must also meet requirements as to physical and chemical properties. AWPA Standard P12 covers a creosote-coal-tar solution for the treatment of marine (coastal waters) piles and timbers. Federal Specification TT–W–568 and AWPA Standard P3 stipulate that creosote-petroleum oil solutions shall contain not less than 50 percent (by volume) of coal-tar creosote and the petroleum oil shall meet the requirements of AWPA's Standard P4.

Creosote-coal-tar solutions, compared to straight creosote, tend to reduce weathering and checking of the treated wood. The solutions may have a greater tendency to accumulate on the surface of the treated wood (bleed) and may penetrate the wood with greater difficulty, particularly because they generally are more viscous than straight creosote. Higher temperatures and pressures during treatment, when they can safely be used, will often improve penetration of solutions of high viscosity.

Even though petroleum oil and coal tar are less toxic to wood-destroying organisms than straight creosote, and their mixtures with creosote are also less toxic in laboratory tests, a reduction in toxicity does not imply less preservative protection. Creosote-petroleum solutions and creosote coal-tar solutions help to reduce checking and weathering of the treated wood. Frequently posts and ties treated with these solutions of standard formulation have shown better service than those similarly treated with straight coal-tar creosote.

Pentachlorophenol Solutions

Water-repellent solutions containing chlorinated phenols, principally pentachlorophenol, in solvents of the mineral spirits type, were first used in commercial treatments of wood by the millwork industry about 1931. Commercial pressure treatment with pentachlorophenol in heavy petroleum oils started on poles about 1941, and considerable quantities of various products were soon pressure treated. AWPA Standard P8 and Federal Specification TT–W–570 define the properties of pentachlorophenol and AWPA Standard P9 covers solvents for oil-borne preservatives. A commercial process using pentachlorophenol dissolved in liquid petroleum gas was introduced in 1961.

Pentachlorophenol solutions for wood preservation generally contain 5 percent (by weight) of this chemical although solutions with volatile solvents may contain lower or higher concentrations. The performance of pentachlorophenol and the properties of the treated wood are influenced by the properties of the solvent used. The heavy petroleum solvent included in AWPA Standard P9A is preferable for maximum protection, particularly where the wood treated with pentachlorophenol is used in contact with the ground, but further evaluation of newer volatile solvents is needed.

The heavy oils remain in the wood for a long time and do not usually provide a clean or paintable surface. The volatile solvents, such as liquefied petroleum gas and methylene chloride, are used with pentachlorophenol when the natural appearance of the wood must be retained and the treated wood requires a paint coating or other finish. Because of the toxicity of pentachlorophenol, care is necessary to avoid excessive personal contact with the solution or vapor in handling and using it.

A "bloom" preventive, such as ester gum or oil-soluble glycol, is generally required with volatile solvents to prevent crystals of pentachlorophenol from forming on the surface of the treated wood. Brushing or washing the surface with hot water or an alkaline solution has been used to remove the crystalline deposits.

The results of pole service and field tests on wood treated with 5 percent pentachlorophenol in a heavy petroleum oil are similar to those with coal-tar creosote. This similarity has been recognized in the preservative retention requirements of treatment specifications. Pentachlorophenol is ineffective against marine borers and is not recommended for the treatment of marine piling or timbers used in coastal waters.

Water-Repellent Preservatives

Preservative systems containing water-repellent components are sold under various trade names, principally for the dip or equivalent treatment of window sash and other millwork. Federal Specification TT–W–572 stipulates that such preservatives consist of volatile solvents, such as mineral spirits, that do not cause appreciable swelling of the wood, and that the treated wood be paintable and meet a performance test on water repellency. In pressure treatment with water-repellent preservative, however, considerable difficulty has been experienced in removing residual solvents and obtaining acceptable paintability.

The preservative chemicals in Federal Specification TT–W–572 may be not less than 5 percent of pentachlorophenol, not less than either 1 or 2 percent (for tropical conditions) of copper in the form of copper naphthenate, or not less than 0.045 percent copper in the form of copper-8-quinolinolate (for uses where foodstuffs will be in contact with the treated wood). Commercial Standard CS 262–63, covering the water-repellent preservative, nonpressure treatment for millwork, permits other preservatives provided their toxicity properties are as high as those of 5 percent (by weight) pentachlorophenol solution. Mixtures of other chlorinated phenols with pentachlorophenol meet this requirement according to tests by the National Woodwork Manufacturer's Association.

Water-repellent preservative containing copper-8-quinolinolate has been used in nonpressure treatment of wood containers, pallets, and other products for use in contact with foods. That preservative is also included in AWPA Standard P8. Here it is intended for use in volatile solvents to pressure-treat lumber for decking of trucks and cars or for related uses involving harvesting, storage, and transportation of foods.

Effective water-repellent preservatives will retard the ingress of water when wood is exposed above ground. They therefore help reduce dimensional changes in the wood due to moisture changes when the wood is exposed to rainwater or dampness for short periods. As with any wood preservative, their effectiveness in protecting wood against decay and insects depends upon the retention and penetration obtained in application.

Waterborne Preservatives

Standard wood preservatives used in water solution include acid copper chromate, ammoniacal copper arsenite, chromated copper arsenate (types I, II, and III), chromated zinc chloride, and fluor chrome arsenate phenol. These preservatives are often employed when cleanliness and paintability of the treated wood are required. The chromated zinc chloride and fluor chrome arsenate phenol formulations resist leaching less than preservative oils, and are seldom used where a high degree of protection is required for wood in ground contact or for other wet installations. Several formulations involving combinations of copper, chromium, and arsenic have shown high resistance to leaching and very good performance in service. The ammoniacal copper arsenite and chromated copper arsenate are now included in specifications for such items as building foundations, building poles, utility poles, marine piling, and piling for land and fresh water use.

Test results based on sea water exposure have shown that dual treatment (waterborne copper-containing salt preservatives followed by coal-tar-creosote) is possibly the most effective method of protecting wood against all types of marine borers. The AWPA standards have recognized this process as well as the treatment of marine piling with high retentions of ammoniacal copper arsenite or chromated copper arsenate. The recommended treatment and retention in pounds per cubic foot (p.c.f.) for round timber piles exposed to severe marine borer hazard are:

	Southern pine, red pine	Coastal Douglas-fir	AWPA standard
	(P.c.f.)	*(P.c.f.)*	
Severe borer hazard:			
Limnoria tripunctata only:			
Ammoniacal copper arsenite	2.5	2.5	C3 C18
Chromated copper arsenate	2.5	2.5	C3 C18
Limnoria tripunctata and Pholads (dual treatment):			
First treatment:			
Ammoniacal copper arsenite	1.0	1.0	C3 C18
Chromated copper arsenate	1.0	1.0	C3 C18
Second treatment:			
Creosote	20.0	20.0	C3 C18
Creosote-coal-tar	20.0	Not recommended	C3 C18

Waterborne preservatives leave the wood surface comparatively clean, paintable, and free from objectionable odor. With several exceptions, they must be used at low treating temperatures (100° to 150° F.) because they are unstable at the higher temperatures. This may involve some difficulty when higher temperatures are needed to obtain good treating results in such woods as Douglas-fir. Because water is added during treatment, the wood must be dried afterward to the moisture content required for use.

Waterborne preservatives, in the retentions normally specified for wood preservation, decrease the danger of ignition and rapid spread of flame, although formulations with copper and chromium stimulate and prolong glowing combustion in carbonized wood.

Acid Copper Chromate

Acid copper chromate (Celcure) contains, according to Federal Specification TT–W–546 and AWPA Standard P5, 31.8 percent copper oxide and 68.2 percent chromic acid. Equivalent amounts of copper sulfate, potassium dichromate, or sodium dichromate may be used in place of copper oxide. Tests on stakes and posts exposed to decay and termite attack indicate that wood well impregnated with Celcure gives good service. Tests by the Forest Products Laboratory and the U.S. Navy showed that wood thoroughly impregnated with at least 0.5 p.c.f. of Celcure has some resistance to marine borer attack. The protection against marine borers, however, is much less than that provided by a standard treatment with creosote.

Ammoniacal Copper Arsenite

According to Federal Specification TT–W–549 and AWPA Standard P5, ammoniacal copper arsenite (Chemonite) should contain approximately 49.8 percent copper oxide or an equivalent amount of copper hydroxide, 50.2 percent of arsenic pentoxide or an equivalent amount of arsenic trioxide, and 1.7 percent of acetic acid. The net retention of preservative is calculated as pounds of copper oxide plus arsenic pentoxide per cubic foot of wood treated within the proportions in the specification.

Service records on structures treated with ammoniacal copper arsenite show that this preservative provides very good protection against decay and termites. High retentions of preservative will provide extended service life to wood exposed to the marine environment, provided pholad-type borers are not present.

Chromated Copper Arsenate

Types I, II, and III of chromated copper arsenate are covered in Federal Specification TT–W–550 and AWPA Standard P5. The compositions of the three types according to that Federal specification are:

	Type I	Type II	Type III
		Parts by weight	
Chromium trioxide	61	35.3	47
Copper oxide	17	19.6	19
Arsenic pentoxide	22	45.1	34

The above types permit substitution of potassium or sodium dichromate for chromium trioxide; copper sulfate, basic copper carbonate, or copper hydroxide for copper oxide; and arsenic acid or sodium arsenate for arsenic pentoxide.

Type I (Erdalith, Greensalt, Tanalith, CCA)

Service data on treated poles, posts, and stakes installed in the United States since 1938 have shown excellent protection against decay fungi and termites. High retentions of copper chrome arsenate-treated wood have shown good resistance to marine borer attack when only Limnoria and teredo borers are present.

Type II (Boliden K–33)

This preservative has been used commercially in Sweden since 1950 and now throughout the world. It was included in stake tests in the United States in 1949 and commercial use in the United States started in 1964.

Type III (Wolman CCA)

Composition of this preservative was arrived at by AWPA technical committees in encouraging a single standard for chromated copper arsenate preservatives. Commercial preservatives of similar composition have been tested and used in England since 1954 and more recently in Australia, New Zealand, Malaysia, and in various countries of Africa and Central Europe and are performing very well.

Chromated Zinc Chloride

Chromated zinc chloride is covered in Federal Specification TT–W–551 and in AWPA Standard P5. Chromated zinc chloride (FR)[2]

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[2] Designation for fire retardant.

is included, as a fire-retarding chemical, in AWPA Standard P10.

Chromated zinc chloride was developed about 1934. The specifications require that it contain 80 percent of zinc oxide and 20 percent of chromium trioxide. Zinc chloride may be substituted for the zinc oxide and sodium dichromate for the chromium trioxide. The preservative is only moderately effective in contact with the ground or in wet installations but has performed well under somewhat drier conditions. Its principal advantages are its low cost and ease of handling at treating plants.

Chromated zinc chloride (FR) contains 80 percent of chromated zinc chloride, 10 percent of boric acid, and 10 percent of ammonium sulfate. Retentions of from 1½ to 3 p.c.f. of wood provide combined protection from fire, decay, and insect attack.

Fluor Chrome Arsenate Phenol

The composition of fluor chrome arsenate phenol (FCAP) is included in Federal Specification TT–W–535 and the AWPA Standard P5. The active ingredients of this preservative are:

	Percent
Fluoride	22
Chromium trioxide	37
Arsenic pentoxide	25
Dinitrophenol	16

To avoid objectionable staining of building materials, sodium pentachlorophenate is sometimes substituted in equal amounts for the dinitrophenol.

Sodium or potassium fluoride may be used as a source of fluoride. Sodium chromate or dichromate may be used in place of chromium trioxide. Sodium arsenate may be used in place of arsenic pentoxide.

FCAP type I (Wolman salts) and FCAP type II (Osmosalts) have performed well in above-ground wood structures and given moderate protection when used in contact with the ground.

PRESERVATIVE EFFECTIVENESS

Preservative effectiveness is influenced not only by the protective value of the preservative chemical itself, but also by the method of application and extent of penetration and retention of the preservative in the treated wood. Even with an effective preservative, good protection cannot be expected with poor penetration and substandard retentions. The species of wood, proportion of heartwood and sapwood, heartwood penetrability, and moisture content are among the important variables influencing the results of treatment. For various wood products, the preservatives and retentions listed in Federal Specification TT–W–571 are given in table 18–1.

Results of service tests on various treated products that show the effectiveness of different wood preservatives are published periodically in the proceedings of the American Wood-Preservers' Association and elsewhere. Few service tests, however, include a variety of preservatives under comparable conditions of exposure. Furthermore, service tests may not show a good comparison between different preservatives due to the difficulty in controlling the above-mentioned variables. Such comparative data under similar exposure conditions, with various preservatives and retentions, are included in Forest Products Laboratory stake tests on southern pine sapwood. A summary of these FPL results is included in table 18–2.

PENETRABILITY OF DIFFERENT SPECIES

The effectiveness of preservative treatment is influenced by the penetration and distribution of the preservative in the wood. For maximum protection it is desirable to select species for which good penetration is best assured. The heartwood is commonly difficult to treat. With round members such as poles, posts, and piling, the penetrability of the sapwood is important in achieving a protective outer zone around the heartwood.

Table 18–1.—*Preservatives and minimum retentions for various wood products*[1]

Product and service condition	Coal tar creosote	Creosote coal tar solution	Creosote petroleum solution	Pentachlorophenol in heavy AWPA P9 solvent	Acid copper chromate[2]	Ammoniacal copper arsenite[2]	Chromated copper arsenate[2] Types I, II, or III	AWPA Standard
	P.c.f.	*P.c.f.*	*P.c.f.*	*P.c.f.*	*P.c.f.*	*P.c.f.*	*P.c.f.*	
A. Ties (crossties, and switch ties)	8	8	8	0.4				C2 & C6
B. Lumber, plywood, and structural timbers (including glued laminated)								C2, C9, C14, C18 & C20
(1) For use in coastal waters:[3]								
Lumber (under 5 in. thick)	22	22						
Timbers (5 in. or thicker):								
Southern pine	22	22						
Coast Douglas-fir and western hemlock	22	6						
Plywood	25							
(2) For use in fresh water, in contact with ground, or for important structural members not in contact with ground or water	10	10	12	.5		0.60	0.60	
Glued laminated timbers or laminates	12	12	12	.6		.60	.60	
(3) For other uses not in contact with ground or water:[4]	8	8	8	.4	0.25	.25	.25	
C. Piles								C3, C14, & C18
(1) For use in coastal waters:[3]								
Southern pine		25				2.5	2.5	
Coast Douglas-fir	22					2.5		

(2) For land or fresh water use:								C3 & C14
Southern and other pines	12	12	12	.6		.8	.8	
Douglas-fir and western larch	17	17	17	.85		1.0	1.0	
Oak	6	6	6	.3				
D. Poles (utility)								C4
Southern and ponderosa pine	7.5 & 9.0			.38 & .45		.60	.60	
Red pine	10.5 & 13.5			.53 & .68		.60	.60	
Jack and lodgepole pine	12.0 & 16.0			0.6 & 0.8		.60	.60	
Coast Douglas-fir	12.0 & 15.0			0.6 & 0.75		.60	.60	
Interior Douglas-fir and western larch	15			.75		.60	.60	
Western redcedar	16			.8				
Western redcedar, northern white-cedar, Alaska-cedar, lodgepole pine ("thermal" or hot and cold process)	20			1.0				C7, C8, & C10
E. Poles (Building, round)	15			.75		.70	.70	C23
F. Posts (round)								C5 & C16
Fence	6	6	6	.3	.50	.40	.40	
Building	15			.75		.70	.70	C23

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[1] Retentions for lumber, timber, plywood, piles, poles, and fence posts are determined by assay of borings of a number and location as specified in Federal Specification TT-W-571 or in the Standards of the American Wood Preservers' Association referenced in last column.

[2] All waterborne preservatives retention are specified on an oxide basis.

[3] Dual treatments are recommended when marine borer activity is known to be high (see AWPA Standards C2, C3, C14, and C18 for details.)

[4] Additional preservatives recommended for this use, and their retention levels, include pentachlorophenol in AWPA P9 light or volatile solvent, 0.4 p.c.f.; plain chromated zinc chloride, 0.46 p.c.f.; and fluorchrome arsenate phenol, 0.22 p.c.f.

NOTE: Minimum retentions are those included in Federal Specification TT-W-571 and Standards of the American Wood Preservers' Association. The current issues of these specifications should be referred to for up-to-date recommendations and other details.

Table 18-2.—*Results of Forest Products Laboratory studies on stakes pressure-treated with commonly used wood preservatives—stakes 2 by 4 by 18 inches of southern pine sapwood, installed at Harrison Experimental Forest, Miss.*

Preservative	Average retention [1]	Average life or condition at last inspection
	P.c.f.	
Untreated stakes		1.8 to 3.6 years
Acid copper chromate	0.13	11.6 years
	.14	40 percent failed after 6 years
	.25	30 percent failed after 5 years
	.26	20 percent failed after 27 years
	.29	80 percent failed after 6 years
	.37	30 percent failed after 27 years
	.50	10 percent failed after 5 years
	.76	10 percent failed after 5 years
Ammoniacal copper arsenite	.24	30 percent failed after 28 years
	.51, 0.97, and 1.25	No failures after 28 years
Chromated copper arsenate	.15	60 percent failed after 27 years
Type I	.29 and 0.44	No failures after 27 years
Type II	.26, 0.37, 0.52, 0.79, and 1.04	No failures after 23 years
Chromated zinc chloride	.30	14.2 years
	.47	20.2 years
	.63	20.1 years
	.62	30 percent failed after 5 years
	.92	40 percent failed after 21 years
	1.78 and 3.67	No failures after 21 years
Copper naphthenate:		
0.11 percent copper in No. 2 fuel oil	10.3 solution	15.9 years
.29 percent copper in No. 2 fuel oil	10.2 solution	21.8 years
.57 percent copper in No. 2 fuel oil	10.6 solution	80 percent failed after 31 years
.86 percent copper in No. 2 fuel oil	9.6 solution	50 percent failed after 31 years
Copper-8-quinolinolate:		
0.1 percent in Stoddard solvent	.01	5.3 years
.2 percent in Stoddard solvent	.02	4.2 years
.6 percent in Stoddard solvent	.06	5.6 years
1.2 percent in Stoddard solvent	.12	7.8 years
.15 percent in AWPA P9 heavy oil	.01	No failures after 9 years
.3 percent in AWPA P9 heavy oil	.03	No failures after 9 years
.6 percent in AWPA P9 heavy oil	.59	No failures after 9 years
1.2 percent in AWPA P9 heavy oil	.12	No failures after 9 years
Creosote, coal-tar (regular type)	4.2	17.8 years
	8.0	40 percent failed after 32½ years
	8.3	No failures after 23 years
	11.8	10 percent failed after 32½ years
	16.5	No failures after 32½ years
	4.6	21.3 years
	10.0	60 percent failed after 32 years
	14.5	No failures after 32 years
	4.1	14.2 years
Creosote, coal-tar (special types):		
Low residue, straight run	8.0	17.8 years
Medium residue, straight run	8.0	18.8 years
High residue, straight run	7.8	20.3 years
Medium residue:		
Low in tar acids	8.1	19.4 years
Low in naphthalene	8.2	21.3 years
Low in tar acids and naphthalene	8.0	18.9 years
Low residue, low in tar acids and naphthalene	8.0	19.2 years
High residue, low in tar acids and naphthalene	8.2	20.0 years
English vertical retort	8.0	18.9 years
	5.3	60 percent failed after 22 years
	10.1	20 percent failed after 22 years
	15.0	No failures after 22 years
English coke oven	7.9	13.6 years
	4.7	16.3 years
	10.1	70 percent failed after 22 years
	14.8	70 percent failed after 22 years

Table 18-2.—*Results of Forest Products Laboratory studies on stakes pressure-treated with commonly used wood preservatives—stakes 2 by 4 by 18 inches of southern pine sapwood, installed at Harrison Experimental Forest, Miss.*—continued.

Preservative	Average retention [1]	Average life or condition at last inspection
	P.c.f.	
Fluor chrome arsenate phenol type I	.16	10.2 years
	.24	18.0 years
	.49	24.1 years
	.27, 0.38, and 0.57	No failures after 11 years
Pentachlorophenol (various solvents):		
Liquefied petroleum gas	.14	10 percent failed in 11½ years
	.19	30 percent failed in 11½ years
	.34	No failures in 11½ years
	.34	10 percent failed in 9 years
	.49	No failures in 9 years
	.58	No failures in 11½ years
	.65	No failures in 9 years
AWPA P9 (heavy petroleum)	.11	No failures in 11½ years
	.19	No failures in 11½ years
	.29	No failures in 11½ years
	.53	No failures in 9 years
	.67	No failures in 11½ years
Stoddard solvent (mineral spirits)	.14	30 percent failed in 11½ years
	.18	10 percent failed in 11½ years
	.38	No failures in 11½ years
	.67	No failures in 11½ years
	.2	13.7 years
	.2	9.5 years
	.4	15.5 years
Heavy gas oil (Mid-United States)	.2	22 percent failed in 22½ years
	.4	10 percent failed in 22½ years
	.6	10 percent failed in 22½ years
No. 4 aromatic oil (West Coast)	.2	60 percent failed in 21 years
	.4	20 percent failed in 21 years

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[1] All waterborne salt preservative retentions are based on oxides.

Examples of species with sapwood that is easily penetrated when it is well dried and pressure treated are the pines, coast Douglas-fir, western larch, Sitka spruce, western hemlock, western redcedar, northern white-cedar, and white fir (*A. concolor*). Examples of species with sapwood and heartwood somewhat resistant to penetration are red and white spruces and Rocky Mountain Douglas-fir. Cedar poles are commonly incised to obtain satisfactory preservative penetration.

The sapwood and heartwood of several hardwood species, such as black jack oak, some of the lowland red oaks, and aspen often present a problem in getting uniform preservative penetration.

The heartwood of most species resists penetration of preservatives although well-dried white fir, western hemlock, northern red oak, the ashes, and tupelo are examples of species with heartwood reasonably easy to penetrate. The southern pines, ponderosa pine, redwood, Sitka spruce, coast Douglas-fir, beech, maples, and birches are examples of species with heartwood moderately resistant to penetration.

PREPARING TIMBER FOR TREATMENT

For satisfactory treatment and good performance thereafter, the timber must be sound and suitably prepared. Except in specialized treating methods involving unpeeled or green material, the wood should be well peeled and either seasoned or similarly conditioned before treatment. It is also highly desirable that all machining be completed before treatment. Machining may include incising to improve the preservative penetration in woods that are resistant to treatment, as well as the operations of cutting, framing, or boring of holes.

Peeling

Peeling round or slabbed products is necessary to enable the wood to dry quickly enough to avoid decay and insect damage and to permit the preservative to penetrate satisfactorily. (Processes in which a preservative is forced or permitted to diffuse through green wood lengthwise do not require peeling of the timber.) Even strips of the thin inner bark may prevent penetration. Patches of bark left on during treatment usually fall off in time and expose untreated wood, thus permitting decay to reach the interior of the member.

Careful peeling is especially important for wood that is to be treated by a superficial method. In the more thorough processes some penetration may take place both lengthwise and tangentially in the wood, and consequently small strips of bark are tolerated in some specifications. Machines of various types have been developed for peeling round timbers, such as poles, piling, and posts (fig. 18–1).


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Figure 18–1.—Machine peeling of poles. Here the outer bark had been removed by hand and the inner bark is being peeled by machine. Frequently the bark is completely removed by machine.

Drying

For treatment with waterborne preservatives by certain diffusion methods, high moisture content may be permitted. For treatment by other methods, however, drying before treatment is essential. Drying the material permits adequate penetration and distribution of the preservative and reduces the risk of checking that would expose unpenetrated wood after treatment. Good penetration of preservative is possible with wood at a moisture content as high as 40 to 60 percent, but serious checking after treatment can result when wood at that moisture level dries.

Air drying, despite the greater time, labor, and storage space required, is a widely used method of conditioning and is generally the cheapest and most effective, even for pressure treatment. Under wet, warm climatic conditions it is difficult to adequately air-dry wood without objectionable infection by stain, mold, and decay fungi. Such infected wood is often highly permeable; in rainy weather it can absorb a large quantity of water, which in turn prevents satisfactory treatment.

How long the lumber must be air dried before treatment depends on the climate, location, and condition of the seasoning yard, methods of piling, season of the year, size, and species of the timbers. The most satisfactory seasoning practice for any specific case will depend on the individual drying conditions and the preservative treatment to be used. Treating specifications therefore are not always specific as to moisture content requirements.

To prevent decay and other forms of fungus infection during air drying, the wood should be cut and dried when conditions are less favorable for fungus development (see ch. 17). If this is impossible, chances for infection can be minimized by prompt conditioning of the green material, careful piling and roofing during air drying, and pretreating the green wood with preservatives to protect during air drying.

Lumber, as well as southern pine poles, are often kiln dried before treatment, particularly in the southern United States where proper air seasoning is difficult. Kiln drying has the important added advantage of quickly reducing moisture content and thereby reducing transportation charges on poles.

Plants that treat wood by pressure processes can condition green material by means other than air drying and kiln drying. Thus they avoid a long delay and possible deterioration of the timber before treatment.

Conditioning Green Products for Pressure Treatment

When green wood is to be treated under pressure, one of several methods for conditioning may be selected. The steaming-and-vacuum process is employed mainly for southern pine, while the Boulton or boiling-under-vacuum process is used for Douglas-fir and sometimes for hardwoods.

In the steaming process the green wood is steamed in the treating cylinder for several hours, usually at a maximum temperature of 245° F. When the steaming is completed, a vacuum is immediately applied. During the steaming period the outer part of the wood is heated to a temperature approaching that of the steam; the subsequent vacuum lowers the boiling point so part of the water is evaporated or is forced out of the wood by the steam produced when the vacuum is applied. The steaming and vacuum periods employed depend upon the size, species, and moisture content of the wood. The steaming and vacuum usually reduce the moisture content of green wood slightly, and the heating assists greatly in getting the preservative to penetrate. A sufficient steaming period will also sterilize the wood. In the Boulton or boiling-under-vacuum method of partial seasoning, the wood is heated in the oil preservative under vacuum, usually at temperatures of about 180° to 220° F. This temperature range, lower than that of the steaming process, is a considerable advantage in treating woods that are especially susceptible to injury from high temperatures. The Boulton method removes much less moisture from heartwood than from the sapwood.

A third method of conditioning known as "vapor drying" has been patented and is used for seasoning railroad ties and other products. In the treating cylinder, the green wood is subjected to the vapors produced by boiling an organic chemical, such as xylene. The resulting mixed vapors of water and the chemical are then removed from the drying chamber. A small quantity of chemical remains in the wood, but the balance is recovered and reused. The wood is treated by standard pressure methods after the conditioning is completed.

Incising

Wood that is resistant to penetration by preservatives is often incised before treatment to permit deeper and more uniform penetration. To accomplish this, sawed or hewed timbers are passed through rollers equipped with teeth that sink into the wood to a predetermined depth, usually ½ to ¾ inch. The teeth are spaced to give the desired distribution of preservative with the minimum number of incisions. A machine of different design is required for deep incising the butts of poles (fig. 18–2).

The effectiveness of incising depends on the fact that preservatives usually penetrate into wood much farther in a longitudinal direction than in a direction perpendicular to the faces of the timber. The incisions expose end-grain surfaces and thus permit longitudinal penetration. It is especially effective in improving penetration in the heartwood areas of sawed or hewed surfaces.

Incising is practiced chiefly on Douglas-fir, western hemlock, and western larch ties and timbers for pressure treatment and on poles of cedar and Douglas-fir.

Cutting and Framing

All cutting, framing, and boring of holes should be done before treatment. Cutting into the wood in any way after treatment will fre-

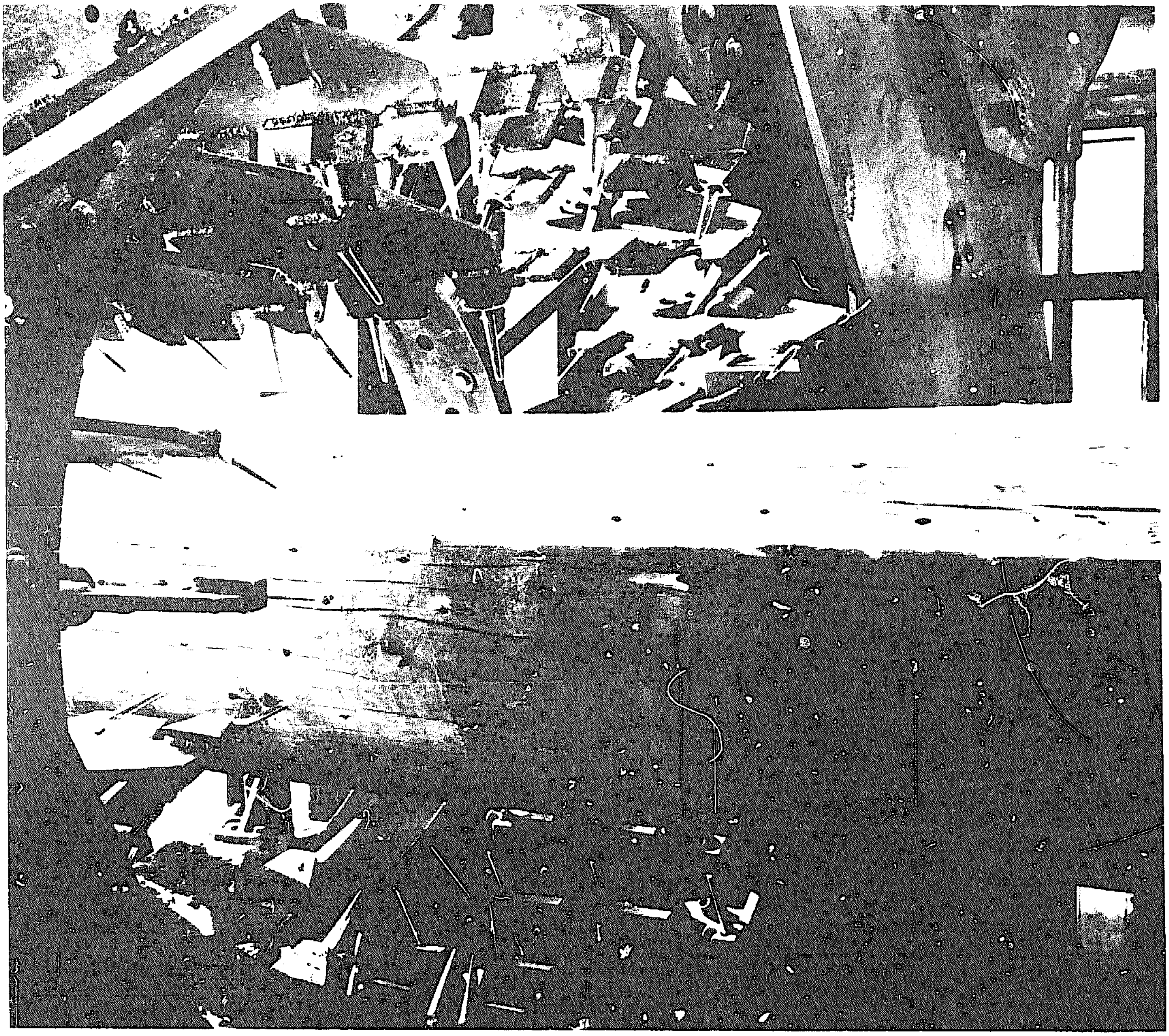

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Figure 18–2.—Deep incising permits better penetration.

quently expose the untreated interior of the timber and permit ready access to decay fungi or insects.

It is much more practical than is commonly supposed to design wood structures so all cutting and framing may be done before treatment. Railroads have followed the practice extensively and find it not only practical but economical. Many wood-preserving plants are equipped to carry on such operations as the adzing and boring of crossties; gaining, roofing, and boring of poles; and the framing of material for bridges and for specialized structures such as water tanks and barges.

Treatment of the wood with preservative oils involves little or no dimensional change. In the case of treatment with water-borne preservatives, however, some change in the size and shape may occur even though wood is redried to the moisture content it had before treatment. If precision fitting is necessary, the wood is cut and framed before treatment to its approximate final dimensions to allow for slight surfacing, trimming, and reaming of bolt holes. Grooves and bolt holes for timber connectors are cut before treatment and can be reamed out if necessary after treatment.

APPLYING PRESERVATIVES

Wood-preserving methods are of two general types: (1) Pressure processes, in which the wood is impregnated in closed vessels under pressures considerably above atmospheric, and (2) nonpressure processes, which vary widely as to procedures and equipment used. Pressure processes generally provide a closer control over preservative retentions and penetrations, and usually provide greater protection than nonpressure processes. Some nonpressure methods, however, are better than others and are occasionally as effective as pressure processes in providing good preservative retentions and penetrations.

Pressure Processes

In commercial practice, wood is most often treated by immersing it in preservative in high-pressure apparatus and applying pressure to drive the preservative into the wood. Pressure processes differ in details, but the general principle is the same. The wood, on cars, is run into a long steel cylinder (fig. 18–3), which is then closed and filled with preservative. Pressure forces preservative into the wood until the desired amount has been absorbed. Considerable preservative is absorbed, with relatively deep penetration. Two processes, the full-cell and empty-cell, are in common use.

Full-Cell

The full-cell (Bethel) process is used when the retention of a maximum quantity of preservative is desired. It is a standard procedure for timbers to be treated full-cell with creosote when protection against marine borers is required. Waterborne preservatives are generally applied by the full-cell process, and control over preservative retention is obtained by regulating the concentration of the treating solution.

Steps in the full-cell process are essentially:

1. The charge of wood is sealed in the treating cylinder, and a preliminary vacuum is applied for ½ hour or more to remove the air from the cylinder and as much as possible from the wood.

2. The preservative, previously heated to somewhat above the desired treating temperature, is admitted to the cylinder without admission of air.

3. After the cylinder is filled, pressure is applied until the required retention of preservative is obtained.

4. When the pressure period is completed, the preservative is withdrawn from the cylinder.

5. A short final vacuum may be applied to free the charge from dripping preservative.

When the wood is steamed before treatment, the preservative is admitted at the end of the vacuum period that follows steaming. When the timber has received preliminary conditioning by the Boulton or boiling-under-vacuum process, the cylinder can be filled and the pressure applied as soon as the conditioning period is completed.

A pressure treatment referred to commercially as the "Cellon" process usually employs the full-cell process. It uses a preservative such as pentachlorophenol in highly volatile liquefied petroleum gas, such as butane or propane, which are gases at atmospheric pressure and ordinary temperatures. A cosolvent is employed to obtain the required concentration of preservative in the treating liquid.

For closer control over preservative retention during the Cellon process, the empty-cell process may be used. If so, a noncombustible gas, such as nitrogen, is substituted for air during the initial air pressure in the conventional Rueping process.

Empty-Cell

The objective of empty-cell treatment is to obtain deep penetration with a relatively low net retention of preservative. For treatment with oil preservatives, the empty-cell process should always be used if it will provide the desired retention. Two empty-cell processes, the Rueping and the Lowry, are commonly employed; both use the expansive force of compressed air to drive out part of the preservative absorbed during the pressure period.

The Rueping empty-cell process has been widely used for many years, in both Europe and the United States. The following general procedure is employed:

1. Air under pressure is forced into the treating cylinder, which contains the charge of wood. The air penetrates some species easily, requiring but a few minutes' application of pressure. In the treatment of the more resistant species, common practice is to maintain air pressure from ½ to 1 hour before admitting the preservative, but the necessity for

long air-pressure periods does not seem fully established. The air pressures employed generally range between 25 and 100 p.s.i., depending on the net retention of preservative desired and the resistance of the wood.

2. After the period of preliminary air pressure, preservative is forced into the cylinder. As the preservative is pumped in, the air escapes from the treating cylinder into an equalizing or Rueping tank, at a rate that keeps the pressure constant within the cylinder. When the treating cylinder is filled with preservative, the treating pressure is raised above that of the initial air and is maintained until the wood will take no more preservative, or until enough has been absorbed to leave the required retention of preservative in the wood after the treatment.

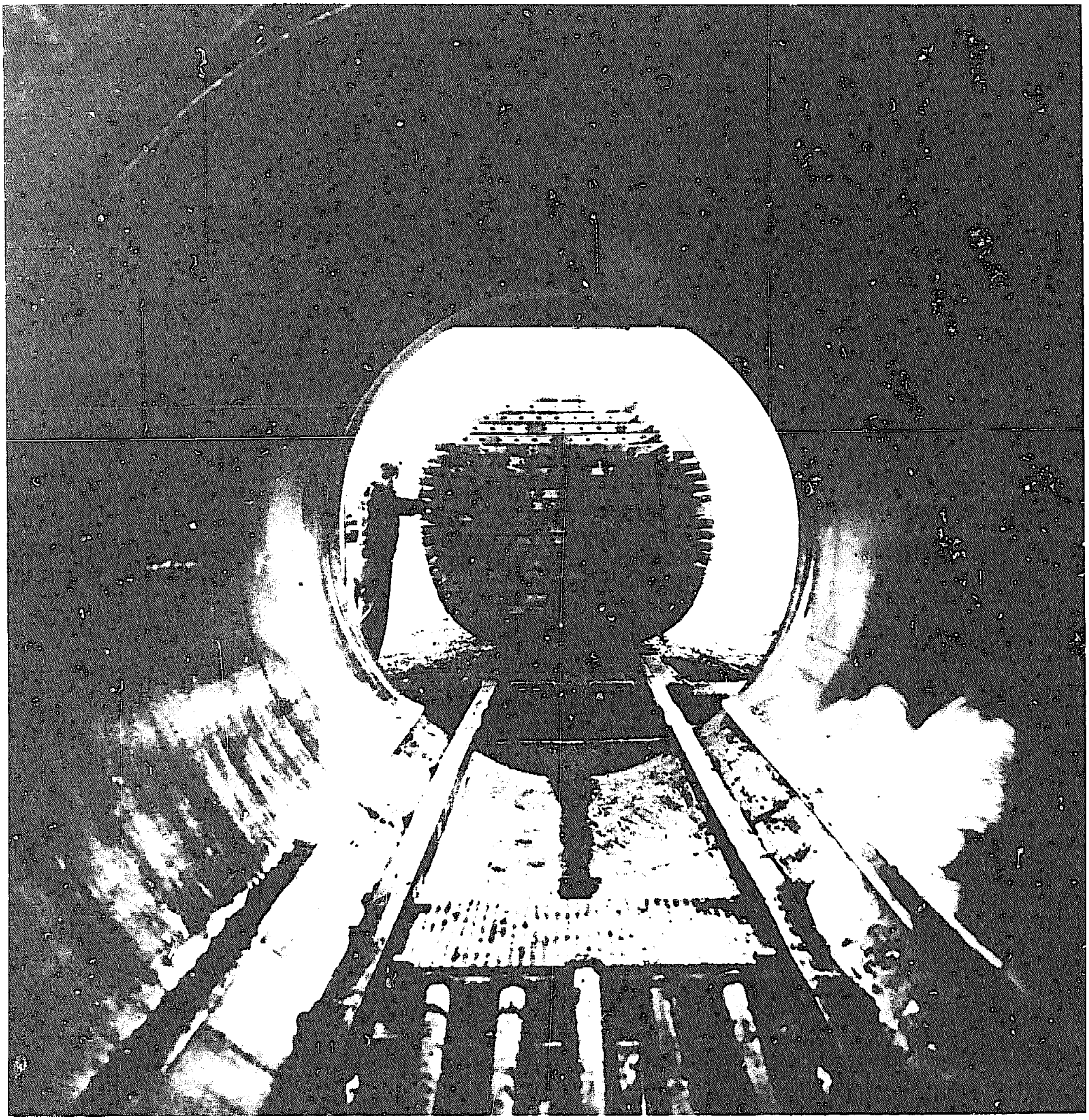

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Figure 18-3.—Interior view of treating cylinder at wood-preserving plant, with a load about to come in.

3. At the end of the pressure period the preservative is drained from the cylinder, and surplus preservative removed from the wood with a final vacuum. The amount recovered may be from 20 to 60 percent of the gross amount injected.

The Lowry is often called the empty-cell process without initial air pressure. Preservative is admitted to the cylinder without either an initial air pressure or a vacuum, and the air originally in the wood at atmospheric pressure is imprisoned during the filling period. After the cylinder is filled with the preservative, pressure is applied, and the remainder of the treatment is the same as described for the Rueping treatment.

The Lowry process has the advantage that equipment for the full-cell process can be used without other accessories; the Rueping process usually requires additional equipment, such as an air compressor and an extra cylinder or Rueping tank for the preservative, or a suitable pump to force the preservative into the cylinder against the air pressure. Both processes, however, have advantages, and both are widely and successfully used.

With poles and other products where bleeding of preservative oil is objectionable, the empty-cell process is followed by either heating in the preservative (expansion bath) at a maximum temperature of 220° F. or a final steaming, for a specified time limit at a maximum temperature of 240° F., prior to the final vacuum.

Treating Pressures and Preservative Temperatures

The pressures used in treatments vary from about 50 to 250 p.s.i., depending on the species and the ease with which the wood takes the treatment. Most commonly they are about 125 to 175 p.s.i. Many woods are sensitive to high treating pressures, especially when hot. AWPA standards, for example, permit a maximum pressure of 150 p.s.i. in the treatment of Douglas-fir, 125 p.s.i. for redwood, and 100 p.s.i. for western redcedar poles. In commercial practice even lower pressures are frequently used on such woods.

AWPA specifications commonly require that the temperature of creosote and creosote solutions during the pressure period shall not be more than 210° F. Pentachlorophenol solutions may be applied at somewhat lower temperatures. Since high temperatures are much more effective than low temperatures for treating resistant wood, it is common practice to use average temperatures between 190° and 200° F. with creosote and creosote solutions. With a number of waterborne preservatives, however, especially those containing chromium salts, maximum temperatures are limited to 120° to 150° F. to avoid premature precipitation of the preservative.

Preservative Penetration and Retention

Penetration and retention requirements are equally important in determining the quality of preservative treatment.

Penetrations vary widely, even in pressure-treated material. In most species, heartwood is more difficult to penetrate than sapwood. In addition, species differ greatly in the degree to which their heartwood may be penetrated. Incising tends to improve penetration of preservative in many refractory species, but those highly resistant to penetration will not have deep or uniform penetration even when incised. Penetrations in unincised heart faces of these species may occasionally be as deep as 1/4 inch, but often are not more than 1/16 inch.

Long experience has shown that even slight penetrations have some value, although deeper penetrations are highly desirable to avoid exposing untreated wood when checks occur, particularly for important members of high replacement cost. The heartwood of coast-type Douglas-fir, southern pine, and various hardwoods, while resistant, will frequently show transverse penetrations of 1/4 to 1/2 inch and sometimes considerably more.

Complete penetration of the sapwood should be the ideal in all pressure treatments. It can often be accomplished in small-size timbers of various commercial woods, and with skillful treatment it may often be obtained in piles, ties, and structural timbers. Practically, however, the operator cannot always insure complete penetration of sapwood in every piece when treating large pieces of round material with thick sapwood, for example poles and piles. Specifications therefore permit some tolerance; for instance, AWPA Standard C4 on southern pine poles requires that 2.5 inches, or 85 percent of the sapwood thickness, be penetrated in not less than 18 out of 20 poles sampled in a charge. This applies only to the smaller class of poles. The requirements vary somewhat depending on the species size class and specified retentions.

Preservative retentions, until recently, have been generally specified in terms of the weight of preservative per cubic foot of wood treated, based on total weight of preservative retained and the total volume of wood treated in a charge. Federal specifications for most products, however, stipulate a minimum retention of preservative as determined from chemical analysis of borings from specified zones of the treated wood.

The preservatives and minimum retentions listed in Federal Specification TT–W–571 are shown in table 18–1. Because the figures given in this table are minimums, it may often be desirable to use higher retentions. Higher preservative retentions are justified in products to be installed under severe climatic or exposure conditions. Heavy-duty transmission poles and items such as structural timbers and house foundations, with a high replacement cost, are required to be treated to higher retentions. Correspondingly deeper penetration is also necessary for the same reasons.

It may be necessary to increase retentions to assure satisfactory penetration, particularly when the sapwood is either unusually thick or is somewhat resistant to treatment. To reduce bleeding of the preservative, however, it may be desirable to use preservative-oil retentions lower than the stipulated minimum. Treatment to refusal is usually specified for woods that are resistant to treatment and will not absorb sufficient preservative to meet the minimum retention requirements. However, such a requirement does not assure adequate penetration of preservative and cannot be considered as a substitute for more thorough treatment.

Nonpressure Processes

The numerous nonpressure processes differ widely in the penetrations and retentions of preservative attained and consequently in the degree of protection they provide to the treated wood. When similar retentions and penetrations are achieved, wood treated by a nonpressure method should have a service life comparable to that of wood treated by pressure. Nevertheless, results of nonpressure treatments, particularly those involving superficial applications, are not generally as satisfactory as pressure treatment. The superficial processes do serve a useful purpose when more thorough treatments are either impractical or exposure conditions are such that little preservative protection is required.

Nonpressure methods, in general, consist of: (1) Superficial applications of preservative oils by spraying, brushing, or brief dipping; (2) soaking in preservative oils or steeping in solutions of waterborne preservatives; (3) diffusion processes with waterborne preservatives; (4) various adaptations of the thermal or hot-and-cold bath process; (5) vacuum treatment; and (6) a variety of miscellaneous processes.

Superficial Applications

The simplest treatment is to apply the preservative—creosote or other oils—to the wood with a brush or a spray nozzle. Oils that are throughly liquid when cold should be selected, unless it is possible to heat the preservative. The oil should be flooded over the wood, rather than merely painted upon it. Every check and depression in the wood should be thoroughly filled with the preservative, because any untreated wood left exposed provides ready access for fungi. Rough lumber may require as much as 10 gallons of oil per 1,000 square feet of surface, but surfaced lumber requires considerably less. The transverse penetrations obtained will usually be less than 1/10 inch although, in easily penetrated species, end grain (longitudinal) penetration is considerably greater.

Brush and spray treatments should be used only when more effective treatments cannot be employed. The additional life obtained by such treatments over that of untreated wood will be affected greatly by the conditions of service; for wood in contact with the ground, it may be from 1 to 5 years.

Dipping for a few seconds to several minutes in a preservative oil gives greater assurance (than brushing or spraying) that all surfaces and checks are thoroughly coated with the oil; usually it results in slightly greater penetrations. It is a common practice to treat window sash, frames, and other millwork, either before or after assembly, by dipping for approximately 3 minutes in a water-repellent preservative. Such treatment is covered by Commercial Standard CS–262, which also provides for equivalent treatment by the vacuum process. The amount of preservative used may vary from about 6 to 17 gallons per thousand board feet (0.5 to 1.5 p.c.f.) of millwork treated.

The penetration of preservative into end surfaces of ponderosa pine sapwood is, in some cases, as much as 1 to 3 inches. End penetration in such woods as southern pine and Douglas-fir, however, is much less, particularly in the heartwood. Transverse penetration of the preservative applied by brief dipping is very shallow, usually only a few hundredths of an inch. Since the exposed end surfaces at joints are the most vulnerable to decay in millwork products, good end penetration is especially advantageous. Dip applications provide very limited protection to wood used in contact with the ground or under very moist conditions, and they provide very limited protection against attack by termites. They do have value, however, for exterior woodwork and millwork that is painted, that is not in contact with the ground, and that is exposed to moisture only for brief periods at a time.

Cold Soaking and Steeping

Cold soaking well-seasoned wood for several hours or days in low-viscosity preservative oils or steeping green or seasoned wood for several days in waterborne preservatives have provided varying success on fenceposts, lumber, and timbers.

Pine posts treated by cold soaking for 24 to 48 hours or longer, in a solution containing 5 percent of pentachlorophenol in No. 2 fuel oil, have shown an average life of 16 to 20 years or longer. The sapwood in these posts was well penetrated and preservative solution retentions ranged from 2 to 6 p.c.f. Most species do not treat as satisfactorily as the pines by cold soaking, and test posts of such woods as birch, aspen, and sweetgum treated by this method have failed in much shorter times.

Preservative penetrations and retentions obtained by cold soaking lumber for several hours are considerably better than those obtained by brief dipping of similar species. Preservative retentions, however, seldom equal those obtained in pressure treatment except in cases such as sapwood of pines that has become highly absorptive through mold and stain infection.

Steeping with waterborne preservatives has very limited use in the United States but has been employed for many years in Europe. In treating seasoned wood both the water and the preservative salt in the solution soak into the wood. With green wood, the preservative enters the water-saturated wood by diffusion. Preservative retentions and penetrations vary over a wide range, and the process is not generally recommended when more reliable treatments are practical.

Diffusion Processes

In addition to the steeping process, diffusion processes are used with green or wet wood. These processes employ waterborne preservatives that will diffuse out of the water of the treating solution or paste into the water of the wood.

The double-diffusion process developed by the Forest Products Laboratory has shown very good results in post tests, particularly on full-length immersion treatments. It consists of steeping green or partially seasoned wood first in one chemical and then in another. The two chemicals diffuse into the wood and then react to precipitate an effective preservative with high resistance to leashing. The process has had commercial application in cooling towers where preservative protection is needed to avoid early replacement.

Other diffusion processes involve applying preservatives to the butts or around the groundline of posts or poles. In standing-pole treatments the preservative may be injected into the pole at groundline with a special tool, applied on the pole surface as a paste or bandage, poured into holes bored in the pole at the groundline, or poured on the surface of the pole and into an excavation several inches deep around the groundline of the pole. These treatments have recognized value for application to untreated standing poles and to treated poles where preservative retentions are determined to be inadequate.

Adaptations of Thermal Process

The hot-and cold bath, referred to commercially as thermal treatment, with coal-tar creosote or pentachlorophenol in heavy petroleum oil is also an effective nonpressure process; the thoroughness of treatment obtainable in some cases approaches that of the pressure processes. The wood is heated in the preservative in an open tank for several hours, then quickly submerged in cold preservative and allowed to remain for several hours.

During the hot bath, the air in the wood expands and some is forced out. Heating the wood also improves the penetration of the preservative. In the cooling bath, the air in the wood contracts and a partial vacuum is created, so liquid is forced into the wood by atmospheric pressure. Some preservative is absorbed by the wood during the hot bath, but more is taken up during the cooling bath.

The chief use of the hot-and-cold process is for treating poles of some thin sapwood species, such as incised western redcedar and lodgepole pine, for utility poles (fig. 18–4). The process is also useful for fenceposts and for lumber or timbers for other purposes when circumstances do not permit the more effective pressure treatments. Coal-tar creosote and pentachlorophenol solutions are the preservatives ordinarily chosen for posts and poles. For the preservatives that cannot safely be heated, the process must be modified.

With coal-tar creosote, hot-bath temperatures up to 235° F. may be employed, but usually a temperature of 210° to 220° F. is sufficient. In the commercial treatment of cedar poles, temperatures of from 190° to 235° F., for not less than 6 hours, are specified with creosote and pentachlorophenol solutions. In the cold bath or cooling bath the specified temperature is not less than 90° F. nor more than 150° F. for not less than 2 hours.

The immersion time in both baths must be governed by the ease with which the timber takes treatment. With well-seasoned timber that is moderately easy to treat, a hot bath of 2 or 3 hours and a cold bath of like duration is probably sufficient. Much longer periods are required with resistant woods. With preservative oils, the objective is to obtain as deep penetration as possible, but with a minimum amount of oil.

Preservative retentions are often very high in the hot-and-cold bath treatments of posts of woods such as southern yellow pine, particularly if those posts contain molds, blue stain, and incipient decay. One method of reducing preservative retentions is to employ a final heating or "expansion" bath with the creosote at 200° to 220° F. for an hour or two, and to remove the wood while the oil is hot. This second heating expands the oil and air in the wood, and some of the oil is thus recovered. The expansion bath also leaves the wood cleaner than when it is removed directly from cold oil.

Vacuum Process

The vacuum process has been used to treat millwork with water-repellent preservatives and construction lumber with waterborne and water-repellent preservatives.

In treating millwork, the objective is to use a limited quantity of water-repellent preservative and obtain retentions and penetrations similar to those obtained by dipping for 3 minutes. The treatment is included in Commercial Standard CS–262 for "Water-Repellent Preservative Nonpressure Treatment of Millwork." Here a quick, low initial vacuum is followed by brief immersion in the preservative, and then a high final or recovery vacuum. The treatment is advantageous over the 3-minute-dip treatment because the surface of wood is quickly dried—thus expediting the glazing, priming, and painting operations. The vacuum treatment is also reported to be less likely than dip treatment to leave objectionably high retentions in bacteria-infected wood referred to as "sinker stock."

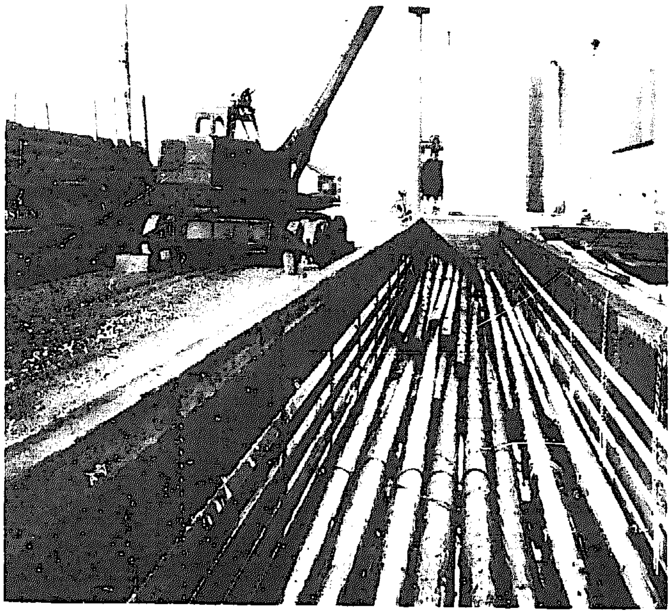

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Figure 18–4.—A commercial plant for the hot-and-cold-bath (thermal) treatment of utility and building poles.

For buildings, lumber has been treated by the vacuum process, either with a waterborne preservative or a water-repellent pentachlorophenol solution, with preservative retentions usually lower than those required for pressure treatment. The process differs from that used in treating millwork in employing a higher initial vacuum and a long immersion or soaking period.

A study of the process by the Forest Products Laboratory employed an initial vacuum of 27.5 inches for 30 minutes, a soaking period of 8 hours, and a final or recovery vacuum of 27.5 inches for 2 hours. The study showed good penetration of preservative in the sapwood of dry lumber of easily penetrated species such as the pines; however, in heartwood and unseasoned sapwood of pine and heartwood of seasoned and unseasoned coast Douglas-fir, penetration was much less than that obtained in pressure treatment. Preservative retention was less controllable in vacuum than in empty-cell pressure treatment. Good control over retentions is possible, in vacuum treatment with a waterborne preservative, by adjusting concentration of the treating solution.

Miscellaneous Nonpressure Processes

A number of other nonpressure methods of various types have been used to a limited extent. Several of these involve the application of waterborne preservatives to living trees. The Boucherie process for the treatment of green, unpeeled poles has been used for many years in Europe. The process involves attaching liquid-tight caps to the butt ends of the poles. Then, through a pipeline or hose leading to the cap, a waterborne preservative is forced into the pole under hydrostatic pressure.

A tire-tube process is a simple adaptation of the Boucherie process used for treating green, unpeeled fenceposts. In this treatment a section of used inner tube is fastened tightly around the butt end of the post to make a bag that holds a solution of waterborne preservative.

Effect of Treatment on Strength

Coal-tar creosote, creosote-coal-tar mixtures, creosote-petroleum oil mixtures, and pentachlorophenol dissolved in petroleum oils are practically inert to wood and have no chemical influence that would affect its strength. Likewise, solutions containing standard waterborne preservatives, in the concentrations commonly used in preservative treatment, have limited or no important effect on the strength of wood.

Although wood preservatives are not harmful in themselves, injecting them into the wood may result in considerable loss in wood strength if the treatment is unusually severe or not properly carried out. Factors that influence the effect of the treating process on strength include (1) species of wood, (2) size and moisture content of the timbers treated, (3) heating medium used and its temperature, (4) length of the heating period in conditioning the wood for treatment and time the wood is in the hot preservative, and (5) amount of pressure used. Most important of these factors are the severity and duration of the heating conditions used. The effect of temperature on the strength of wood is covered in chapter 4.

HANDLING AND SEASONING TIMBER AFTER TREATMENT

Treated timber should be handled with sufficient care to avoid breaking through the treated areas. The use of pikes, cant hooks, picks, tongs, or other pointed tools that dig deeply into the wood should be prohibited. Handling heavy loads of lumber or sawed timber in rope or cable slings may crush the corners or edges of the outside pieces. Breakage or deep abrasions may also result from throwing the lumber or dropping it. If damage results, the exposed places should be retreated as thoroughly as conditions permit. Long storage of treated wood before installation should be avoided because such storage encourages deep and detrimental checking and may also result in significant loss of some preservatives. Treated wood that must be stored before use should be covered for protection from the sun and weather.

Although cutting wood after treatment is highly undesirable, it cannot always be avoided. When cutting is necessary, the damage may be partly overcome in timber for land or fresh-water use by a thorough application of a grease containing 10 percent pentachlorophenol. This provides a protective reservoir of preservative on the surface, some of which may slowly migrate into the end grain of the wood. Thoroughly brushing the cut surfaces with two coats of hot creosote is also helpful, although brush coating cut surfaces gives little protection against marine borers. A special device is available for pressure treating bolt holes bored after treatment. For wood treated with waterborne preservatives, where the use of creosote or pentachlorophenol solution on the cut surfaces is not practicable, a 5 percent solution of the waterborne preservative in use should be substituted.

For treating the end surfaces of piles where they are cut off after driving, at least two generous coats of creosote should be applied. A coat of asphalt or similar material may well applied over the creosote, followed by some protective sheet material, such as metal, roofing felt, or saturated fabric, fitted over the pile head and brought down the sides far enough to protect against damage to the top treatment and against the entrance of storm water. AWPA standard M4 contains instructions for the care of pressure-treated wood after treatment.

Wood treated with preservative oils should generally be installed as soon as practicable after treatment but some times cleanliness of the surface can be improved by exposure to the weather for a limited time before use. Waterborne preservatives or pentachlorophenol in a volatile solvent, however, are best suited to uses where cleanliness or paintability are of great importance.

With waterborne preservatives, seasoning after treatment is important for wood to be used in buildings or other places where shrinkage after placement in the structure would be undesirable. Injecting waterborne preservatives puts large amounts of water into the wood, and considerable shrinkage is to be expected as subsequent seasoning takes place. For best results, the wood should be dried to approximately the moisture content it will ultimately reach in service. During drying, the wood should be carefully piled, and whenever possible, restrained by sufficient weight on the top of the pile to avoid warping.

With some waterborne preservatives, seasoning after treatment is recommended for all treated wood. During this seasoning period, volatile chemicals escape and the chemical reactions are completed within the wood; thus, the resistance of the preservative to leaching by water is increased.

QUALITY ASSURANCE FOR TREATED WOOD

Treating Conditions and Specifications

Specifications on the treatment of various wood products by pressure processes and on the hot-and-cold bath (thermal) treatment of cedar poles have been developed by AWPA. These specifications limit pressures, temperatures, and time during conditioning and treatment to avoid conditions that will cause serious injury to the wood. They also contain minimum requirements as to preservative penetrations and retentions and recommendations for handling wood after treatment, to provide a quality product.

The specifications are rather broad in some respects, allowing the purchaser some latitude in specifying the details of his individual requirements. The purchaser should exercise great care, however, not to limit the operator of the treating plant so he cannot do a good treating job, and not to require treating conditions so severe that they will damage the wood. Federal Specification TT–W–571 lists treatment practices for use on U.S. Government orders for pressure-treated wood products; other purchasers have specifications similar to those of AWPA.

Inspection

Inspection of timber for quality and grade before treatment is desirable. Grademarked lumber, plywood, and timber graded at the producing mill can be obtained in many instances. When inspection prior to treatment is impractical, the purchaser can usually inspect for quality and grade after treatment; if this is to be done, however, it should be made clear in the purchase order.

Currently, the inspection of treatment of complete charges is generally specified at the time of treatment at the treating plant; however, the option is generally available whereby the purchaser could determine the quality of treatment from selected samples of the treated product at destination or within a specified time after treatment. The purchaser should recognize, however, that a sample selected from a charge at the treating plant is likely to be different than a sample taken at destination from a few items from a much larger charge. Furthermore, the nature and quantity of the preservative in the wood change as the period of service increases, so samples of treated wood taken at treatment may not be the same as those taken later. Destination inspection requires consideration of these questions and the details have not yet been worked out for all treated products.

The treating industry, with the assistance of the Federal Housing Administration and the Forest Products Laboratory, has developed a quality-control and grademarking program for treated products, such as lumber, timbers, plywood, and marine piling. This quality control program, administered through the American Wood Preservers' Bureau, promises to assist the user in securing well-treated material; otherwise the purchaser must either accept the statements or certificate of the treating-plant operator or have an inspector at the treating plant to inspect the treated products and insure compliance with the specifications. Railroad companies and other corporations that purchase large quantities of treated timber usually maintain their own inspection services. Commercial inspection and consulting service is available for purchasers willing to pay an inspection fee but not using enough treated timber to justify employing inspectors of their own. Experienced, competent, and reliable inspectors can assure compliance with material and treating standards and thus reduce risk of premature failure of the material.

Penetration measurements should be made at the treating plant if inspection service is provided, but can be made by the purchaser at any time after the timber has been treated. They give about the best single measure of the thoroughness of the treatment.

The depth of penetration of creosote and other dark-colored preservatives can be determined directly by observing a core removed by an increment borer. The core should usually be taken at about midlength of the piece, or at least several feet from the end of the piece, to avoid the unrepresentative end portion that is sometimes completely treated by end penetration. Since preservative oils tend to creep over cut surfaces, the observation should be made promptly after the borer core is taken. Holes made for penetration measurements should be tightly filled with thoroughly treated wood plugs.

The penetration of preservatives that are practically colorless must be determined by chemical dips or sprays that show the penetration by color reactions.

How to Purchase Treated Wood

To receive optimum service from wood when it is exposed to biological deterioration, it should be treated with an effective preservative. The use of treated wood will reduce the maintenance and replacement costs of wood components in structures.

For the purchaser to obtain a treated wood product of high quality, he must avail himself of the appropriate specifications. Specifications and standards of importance here are: Federal Specification TT–W–571, "Wood Preservation—Treating Practices;" F.S. TT–W–572, "Wood Preservation—Water Repellent;" Official Quality Control Standards of the American Wood Preservers' Bureau; and the American Wood-Preservers' Association Book of Standards. The inspection of material for conformity to the minimum requirements listed in the above specifications should be in accordance with the American Wood Preservers' Standard M2, "Standard for Inspection of Treated Timber Products."

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Chapter 19

POLES, PILES, AND TIES

POLES, PILES, AND TIES

Industrial wood products such as railroad ties, poles for transmission and distribution lines and buildings, and piles for bridge, wharf, and building construction continue to be important in the United States. Prime factors in the selection of particular wood species for this type of product are availability in quantity, strength and weight, the natural shape of the tree, and the ability of the wood to receive and retain commercial preservative treatments.

POLES

Principal Species Used for Poles

The principal species used for poles are southern pines, Douglas-fir, western redcedar, and lodgepole pine. Miscellaneous species used for poles are ponderosa pine, red pine, jack pine, northern white-cedar, other cedars, and western larch. Most poles are pressure treated with preservatives although cedar poles are treated principally by the hot-and-cold (thermal) process or are used occasionally without treatment.

Hardwood species can be used for poles when the trees are of suitable size and form; their use is limited, however, by their weight, excessive checking, and by lack of experience in preservative treatment of hardwoods.

Southern Pines

The southern pines (principally loblolly, longleaf, shortleaf, and slash) account for the highest percentage of poles treated in the United States. The thick and easily treated sapwood of these species, their favorable strength properties and form, and their availability in popular pole sizes over a wide area account for their extensive use. In longer lengths, southern pine poles are in limited supply so Douglas-fir, and to some extent western redcedar, are used to meet requirements for 50-foot and longer transmission poles.

Southern pine poles are pressure treated full length generally with preservatives recommended in Federal Specification TT–W–571. Well-treated southern pine poles can be expected to have an average service life of 35 years or longer.

Douglas-Fir

Douglas-fir constitutes approximately 6 percent of total poles treated, for the most part by pressure, with preservatives listed in Federal Specification TT–W–571. This species is widely used in the United States for transmission poles and specifically on the Pacific Coast for distribution and building poles. The sapwood of this species averages about 1.3 inches in thickness in the Interior North Region and from 1.6 to 2.0 inches along the Pacific Coast. Since the heartwood has limited decay and termite resistance, it is important that the sapwood be well treated and poles adequately seasoned or conditioned before treatment to minimize checking after treatment. With these precautions the poles should compare favorably with treated southern pine poles in serviceability.

Western Redcedar

About 3 percent of the poles treated in the United States are of western redcedar, produced mostly in British Columbia. A small number of poles of this species are used without treatment. The poles have comparatively thin sapwood and the heartwood is naturally decay resistant, although without treatment an average pole life somewhat less than 20 years can be expected.

Except when used in dry areas not conductive to “shellrot” in the tops, western redcedar poles are treated full length. Treatment is generally with the oil type preservatives listed in the Federal Specification TT–W–571 by the thermal (hot-and-cold) process, although some poles are pressure treated. The poles are mostly for utility line use, although well-treated western redcedar poles could be used effectively in pole-type buildings. In the northern and western United States, where they are used most, western redcedar poles when well treated full length compare favorably in service life with poles of other species.

Lodgepole Pine

Approximately 2 percent of poles treated are of lodgepole pine. The majority are full length pressure treated or full length thermal (hot-and-cold) treated with approved preservatives. The poles are used both for utility lines and for pole-type buildings. Good service can be expected from well-treated lodgepole pine poles. Special attention is necessary, however, to obtain poles with sufficient sapwood thickness to insure adequate penetration of preservative, because the heartwood is not usually pentrated and is not decay resistant. The poles must also be well seasoned before treatment to avoid checking and exposure of the unpenetrated heartwood to attack by decay fungi.

Other Species

Western larch, ponderosa pine, Atlantic white-cedar, northern white-cedar, jack pine, red pine, eastern redcedar, redwood, spruce, and hemlock are occasionally used for poles.

Western larch poles produced in Montana and Idaho came into use following World War II because of their favorable size, shape, and strength properties. Western larch requires preservative treatment full length for use in most areas, must be selected for adequate sapwood thickness, and must be well seasoned prior to treatment.

Ponderosa pine has been used to some extent because of its availability, favorable shape, and thick sapwood that is easily penetrated with preservatives.

Redwood, Atlantic white-cedar, jack pine, red pine, and eastern redcedar are used to a slight extent, for the most part locally in the areas where they are produced. All of these species generally require preservative treatment.

Other species having local use include tamarack, baldcypress, black locust, ash, elm, and cottonwood. With the exception of black locust, none of these last long without preservative treatment.

Weight and Volume of Poles and Piles

The weight of a pole depends on the species, size, moisture content, and preservative treatment. Weights per cubic foot of the various species of wood may be calculated from the data described in chapters 3 and 4. Poles may be green when first produced, but in service moisture content above ground falls below 30 percent in most areas.

Volumes of poles and piles may be computed by two methods given in American Wood-Preservers' Association Standard F3. Using method 1, the volume can be calculated by the formula

$$V = 3L\left(\frac{C_m}{\pi}\right)^2 0.001818 \qquad (19\text{–}1)$$

where V is volume in cubic feet, L is length in feet, and C_m is midlength circumference in inches. By method 2, the volume can be calculated by the formula

$$\mathrm{V} = 0.001818\mathrm{L}(D^2 + d^2 + Dd) \qquad (19\text{–}2)$$

where D is the top diameter (in inches) and d is the butt diameter. V and L definitions are the same as for formula (19–1). If method 2 is used, a correction factor as indicated below must be used for certain species:

Oak piles	0.82
Southern pine piles	.93
Southern pine and red pine poles	.95

Method 1 is the AWPA official method except for Douglas-fir, for which either method can be used. Volume tables for both methods are given in AWPA Standard F3.

The volume of a pole shows little difference whether green or dry. Drying of poles causes checks to open, but there is little reduction of the gross diameter of the pole.

Engineering Properties of Wood Poles

Round poles used for transmission and distribution lines and buildings are specified by species, class, and length. Specifications for wood poles for transmission and distribution lines, adopted by the National Electric Safety Code, are given in the American National Standards Institute (ANSI) Standard 05.1, "Specifications and Dimensions of Wood Poles." Specifications for wood poles for farm buildings are given in the American Society of Agricultural Engineers Tentative Recommendation R299T, "Construction Poles—Preservative-Treated Wood."

Species of timber commonly used for poles and their fiber stress in bending are given in ANSI Standard 05.1. These values are the near ultimate fiber stress in the outer fibers of the pole at failure in flexure as a cantilever beam. It is customary to reduce the stresses for use in design to provide a factor of safety in accordance with the type of construction in which the poles are used. Recommended reductions are given in the National Electric Safety Code.

Life of Poles

The life of poles can vary within wide limits depending on their growth and use conditions, kind and quality of the preservative, method of treatment, penetration and distribution of preservative, and mechanical damage. Service life, due to line changes and obsolescence, is often somewhat less than the physical life of poles.

It is common to report the "average" life of untreated or treated poles based on observations over a period of years. These average life values are useful as a rough guide to what physical life may be expected from a group of poles. However, it should be kept in mind that, within a given group, 60 percent of the poles will have failed before reaching an age equal to the average life.

Early or premature failure of treated poles can generally be attributed to one or more of three factors: (1) Poor penetration and distribution of preservative; (2) an inadequate retention of preservatives; or (3) a substandard or untried preservative.

Preservative Treatment of Poles

Federal Specification TT–W–571 covers the preservative treatment of utility and building poles and includes the principal requirements of AWPA Standards C1 and C4 for pressure treatment, C8 for full-length thermal (hot-and-cold) treatment of western redcedar, C10 for full-length thermal (hot-and-cold) treatment for lodgepole pine poles, and C23 for pressure treatment in pole building construction.

Seasoning or conditioning requirements are included in these specifications. For western redcedar poles to be treated by the thermal process, incising at the groundline is required to meet the preservative penetration requirement. Penetration and retention requirements for pressure treatment vary for different pole species and service conditions also for group A poles (less than 37.5 in. in circumference 6 ft. from the butt) and group B (larger poles). The zones from which borings are to be taken for retention by assay also differ for different species treated by pressure. Table 18–1 (ch. 18) includes minimum preservative retention figures for poles of different types.

Some treated poles exude preservative sufficiently to make the surface oily in spots. This "bleeding" is not likely to reduce the life of the poles, but it may prove objectionable to men who work on the poles or to anyone who may come in contact with a bleeding pole. Methods of completely preventing bleeding have not been established. The use of lower retentions, low-residue creosotes, or selected oil to act as preservative carriers, and a final heating or expansion bath following treatment, however, will help to produce clean poles. There is an increasing use of the waterborne preservatives as covered in TT–W–571 where cleanliness and paintability of poles are required.

In pole-type structures where siding or other exterior covering is applied, the poles are generally set with the taper to the interior side of the structures to provide a vertical exterior surface. Another common practice is to modify the round poles by slabbing to provide a continuous flat face. The slabbed face permits more secure attachment of sheathing and framing members and facilitates the alinement and setting of intermediate wall and corner poles. The slabbing consists of a minimum cut to provide a single continuous flat face from groundlines to top of intermediate wall poles, and two continuous flat faces at right angles to one another from groundline to top of corner poles.

It should be recognized that preservative penetration is generally limited to the sapwood of most species. Thus slabbing, particularly in the groundline area of poles, with thin sapwood may result in somewhat less protection than that of an unslabbed pole. All cutting and sawing should be confined to that portion of the pole above groundline and should be performed before treatment.

Treatment to Retard Decay in Standing Poles

Preservative applications have been made to the groundline zone of untreated poles to retard decay. A study in Canada on six different preservative applications to untreated cedar showed that from 6 to 13 years of additional service was provided. Studies by the Forest Products Laboratory indicated that groundline treatments had questionable value for well-treated poles with a good reserve supply of preservative in the outer zone or for treated poles with heartwood decay. For treated poles with light surface decay or other evidence of an inadequate supply or quality of preservative in the outer part of the pole, some groundline treatments showed promise of providing additional pole service.

The untreated above-ground sections of butt-treated poles that have started to show sapwood decay or "shellrot" are frequently sprayed with solutions of preservative containing 5 to 10 percent active chemical.

PILES

Choice of Species for Piles

The properties desirable in piles include sufficient strength and straightness to withstand driving and to carry the weight of structures built on them, and in some instances to resist bending stresses. Decay resistance or ease of penetration by preservatives is also important except in piles for temporary use or piles that will be in fresh water and entirely below the permanent water level.

Southern pine, Douglas-fir, and oak are among the principal species used for piles, but western redcedar and numerous other species also are used.

Specifications for timber piles covering kinds of wood, general quality, resistance to decay, dimensions, tolerance, manufacture, inspection, delivery, and shipment have been published in the American Railway Engineering Association (AREA) Manual. Specifications for timber piles have also been prepared by the American Association of State Highway Officials, the American Society for Testing and Materials, and the Federal Supply Service.

Bearing Loads for Piles

Bearing loads on piles are sustained by earth friction along the sides of the pile, by bearing of the tip on a solid stratum, or by a combination of the two. Wood piles, because of their tapered form, are particularly efficient in supporting loads by side friction. Bearing values that depend upon side friction are related to the stability of the soil and generally do not approach the ultimate strength of the pile. Where wood poles sustain foundation loads by bearing of the tip on a solid stratum, loads may be limited by the compressive strength of the wood parallel to the grain. If a large proportion of the length of a pile extends above ground, its bearing value may be limited by its strength as a long column. Side loads may also be applied to piles extending above ground. In such instances, however, bracing is often used to reduce the unsupported column length or to resist the side loads.

There are several ways of determining bearing capacity of piles. Engineering formulas can be used for estimating bearing values from the penetration under blows of known energy from the driving hammer. Some engineers prefer to estimate bearing capacity from experience or observation of the behavior of pile foundations under similar conditions or from the results of static-load tests.

Working stresses for piles are governed by building code requirements by recommendations of the American Society for Testing and Materials.

Eccentric Loading and Crooked Columns

The reduction in strength of a wood column resulting from crooks, eccentric loading, or any other condition that will result in combined bending and compression is not as great as might be expected. Tests have shown that a timber, when subjected to combined bending and compression, develops a higher stress at both the proportional limit and maximum load than when subjected to compression only. This does not imply that crooks and eccentricity should be without restriction, but it should relieve anxiety as to the influence of crooks, such as those found in piles.

Design procedures for eccentrically loaded columns are given in chapter 8.

Seasoning Effect on Pile Driving

Under usual conditions of service, wood piles will be wet, but they may be driven in either the green or the seasoned condition. Because of the increased strength resulting from drying, seasoned piles either treated or untreated are likely to stand driving better than are green or unseasoned ones. This is particularly true of treated piles; tests have demonstrated that, while the strength of green wood may be considerably reduced by pretreatment conditioning, thoroughly seasoned treated wood may be nearly as strong as seasoned untreated wood. Under the same drying conditions, however, untreated wood loses moisture more rapidly than does treated wood.

Decay Resistance and Preservative Treatment of Piles

Species most commonly used for piles generally have rather thick sapwood and consequently low decay resistance. High natural decay resistance will be found only when the piles have thin sapwood and are of species that have decay-resistant heartwood.

Because wood that remains completely submerged in water does not decay, decay resistance is not necessary in piles so used; resistance to decay is necessary in any part of the piles that may extend above the permanent water level. When piles that support the foundations of bridges or buildings are to be cut off above the permanent water level, they should be treated to conform to recognized specifications (such as Federal Specification TT-W-571 and AWPA Standards C1 and C3). The untreated surfaces exposed at the cutoffs should also be protected by thoroughly brushing the cut surface with coal-tar creosote. A coat of pitch, asphalt, or similar material may then be applied over the creosote and a protective sheet material, such as metal, roofing felt, or saturated fabric, fitted over the pile head.

Piles driven into earth that is not constantly wet are subject to about the same service conditions as apply to poles, but are generally expected to last longer and therefore require higher preservative retentions than poles (table 18–1).

Piles used in salt water are, of course, subject to destruction by marine borers even though they do not decay below the waterline. Up to this time the best practical protection against marine borers has been a treatment to refusal with coal-tar creosote or creosote-coal-tar solution. Recent experiments with dual treatments (pressure treatment, first with a waterborne preservative followed after seasoning with a creosote treatment) show promise of providing greater protection. Federal Specification TT-W-571 and AWPA Standard C3 cover the preservative treatment of marine piles (table 18–1).

TIES

Strength and Other Requirements for Ties

Many species of wood are used for ties. The more common are oaks, gums (tupelo and sweetgum), Douglas-fir, mixed hardwoods, hemlock, southern pine, and mixed softwoods. Their relative suitability depends largely upon their strength, wearing qualities, treatability with wood preservatives, and to some extent their natural resistance to decay and tendency to check, although availability and cost must also be considered.

The chief strength properties considered in a wood for crossties are (1) bending strength, (2) end hardness and strength in compression parallel to grain (which indicate resistance to spike pulling and the lateral thrust of spikes), and (3) side hardness and compression perpendicular to the grain (which indicate resistance to wear under the rail or the tieplate).

Sizes of crossties range from 6 by 7 to 7 by 9 inches; lengths are usually 8, 8½, or 9 feet. With heavier traffic and higher speeds of trains, the present tendency is toward increasing use of the larger sizes.

Specifications for crossties covering general quality, resistance to wear, resistance to decay, design, manufacture, inspection, delivery, and shipment have been published in the AREA Manual and in Federal Specification MM-T-371.

Life of Ties

The service conditions under which ties are exposed are severe. The life of ties in service therefore depends on their ability to resist decay and the extent to which they are protected from mechanical destruction by breakage, loosening of spikes, and rail or plate wear. Under sufficiently light traffic, heartwood ties of naturally durable wood, even if of low strength, may give 10 or 15 years average service without preservative treatment; under heavy traffic without adequate mechanical protection, the same ties might fail through mechanical wear in 2 or 3 years. The life of treated ties is affected also by the preservative used and the thoroughness of treatment. As a result, the life of individual groups of ties may vary widely from the general average depending on the local circumstances.

With these limitations, the following rough estimates are given: Ties well treated according to the specifications cited in this chapter should last from 25 to 40 years on an average when protected against mechanical destruction. Untreated white oak ties have lasted 10 to 12 years on an average in the northern United States.

Records on the life of treated and untreated ties are published from time to time in the annual proceedings of AREA and AWPA.

Decay Resistance and Preservative Treatment of Ties

Although the majority of ties used are given preservative treatment before installation, a few are used untreated and, for these, natural decay resistance is important. In ties given preservative treatment, variations in natural decay resistance are less important than ability to accept treatment.

The majority of ties treated are pressure treated with coal-tar creosote, creosote-coal-tar solutions, or creosote-petroleum mixtures. Federal Specification TT-W-571 includes listings for treatment of crossties, switch ties, and bridge ties (table 18-1). AWPA Standards C2 and C6 and specifications of AREA also cover the preservative treatment of crossties and switch ties.

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Chapter 20

THERMAL INSULATION

THERMAL INSULATION

The contribution of thermal insulation to comfort of occupants and economies of heating and cooling have been recognized and the ecological implications are being assessed. In the future the amount of insulation required in buildings may well be governed by factors other than what is economical and will provide a desirable level of comfort for occupants. These other considerations include air pollution from burning fossil fuels, be it in the building proper or at a power station some distance away, thermal pollution from wasted heat, and the need to conserve energy and fuels.

The inflow of heat through outside walls and roofs in hot weather and its outflow during cold weather have important effects upon the comfort of the occupants of a building. During cold weather, heat flow also governs fuel consumption to a great extent. Wood itself is a good insulator but commercial insulating materials are usually incorporated into exposed walls, ceilings, and floors to increase resistance to heat passage. The use of insulation in warmer climates is usually justified with air conditioning not only to reduce cooling costs but also to permit use of smaller capacity units.

Commercial insulating materials are manufactured in a number of forms and types. Each has advantages for specific uses; some are more resistive to heat flow than others, and no one type is best for all applications.

INSULATING MATERIALS

For purposes of description, materials commonly used for insulation may be grouped in five general classes: (1) Rigid insulation, (a) structural or (b) nonstructural; (2) flexible insulation, (a) blanket or (b) batt; (3) loose-fill insulation; (4) reflective insulation; and (5) miscellaneous types.

Rigid Insulation

Structural Insulating Board

Structural insulating board is made by reducing wood, cane, or other lignocellulosic material to a coarse pulp and then felting it into large panels. When these panels are pressed and dried, they have densities ranging from about 10 to 31 pounds per cubic foot (p.c.f.). They provide thermal insulation while also providing some strength or other physical property required for a particular use.

Structural insulating board is fabricated in the following forms, which are described in more detail, as related to the use, in chapter 21:

Building boards; insulating roof deck; roof insulation; wallboard; ceiling tile and lay-in panels; plank; sheathing—regular density, intermediate, nail-base; shingle backer; insulating formboard; and sound-deadening board.

Roof insulation primarily provides thermal resistance to heat flow in roof constructions. It is applied on top of the structural deck and roofing is applied over it. Although products like roof deck, ceiling tile, plank, sheathing, shingle backer, insulating formboard, and sound-deadening board (when used in exterior constructions) are fabricated primarily to serve other functions, they also help to resist heat flow. Building board and wallboard are products for remanufacture and are used in diverse ways.

It is common practice for the insulating board industry to supply sheathing products, where the thermal insulation is of importance, with rated insulating values.

Nonstructural (Block) Insulation

Nonstructural rigid insulation is often called "block insulation." The slabs or blocks are small rigid units, sometimes 1 inch thick but generally thicker, and vary in size usually up to 24 by 28 inches. The types made from wood-base materials are cork blocks, wood fiber blocks, and fiberboard slabs. Cork blocks are made by bonding small pieces of cork together in blocks or slabs 1 to 6 inches thick. They are used for cold-storage insulation and for insulating flat roofs of industrial and commercial buildings.

Wood-fiber blocks are made by bonding wood fibers with some inorganic bonding agent, such as portland cement. They are made in thicknesses of 1 to 3 inches and in various widths and lengths. Principal uses are for roof-deck in industrial buildings, structural floor and ceiling slabs, and nonbearing partitions.

Fiberboard slabs are made by laminating insulating board products to produce rigid blocks. Mineral-wool slabs or blocks are made both of rock wool and glass wool with suitable binders for low-temperature insulation and specialty uses. Other types of blocks and slabs include cellular glass, plastic, cellular-rubber products, and vermiculite or expanded mica with asphalt binder

Flexible Insulation

Flexible insulation is manufactured as blanket and batt. Blanket insulation is furnished in rolls of convenient length and in various widths suited to standard stud and joist spacing. The usual thicknesses are 1½, 2, and 3 inches. Each roll covers from 70 to 140 square feet. The body of the blanket is usually made of loosely felted mats of mineral or vegetable fibers, such as rock, slag, or glass wool, wood fiber, and cotton. Organic fiber mats are chemically treated to make them resistant to fire, decay, insects, and vermin. Most blanket insulation is provided with a covering sheet of paper on one or both sides and with tabs on the edges for fastening the blanket in place. The covering sheet on one side may be of a type which serves as a vapor barrier. In some cases the covering sheet is surfaced with aluminum foil or other reflective material.

Batt insulation also is made of loosely felted fibers, generally of mineral-wool products. It is also made in widths suitable for fitting between standard framing spaces. Thicknesses are usually 4 and 6 inches. Some batts have no covering; others are covered on one side with a vapor barrier similar to that used for blanket insulation. In walls batt insulation is installed in the same manner as blanket insulation. In ceilings it is placed between joists with the vapor barrier facing downward toward the warm side.

Fill Insulation

Loose-fill insulation is usually composed of materials used in bulk form, supplied in bags or bales, and intended to be poured or blown into place or packed by hand. It is used to fill stud spaces or to build up any desired thicknesses on horizontal surfaces. Loose-fill insulation includes rock, glass, and slag wool, wood fibers, granulated cork, ground or macerated woodpulp products, vermiculite, perlite, sawdust, and wood shavings.

Reflective Insulation

Most materials reflect radiant heat, and certain of them have this property to a high degree. Some emit less heat than others. For reflective insulation, high reflectivity and low emissivity are required, as provided by aluminum foil, sheet metal coated with an alloy of lead and tin, and paper products coated with a reflective oxide composition. Aluminum foil is available in sheets mounted on paper, in corrugated form supported on paper, or mounted on the back of gypsum lath or paper-backed wire lath. Reflective insulation is installed with the reflective surface facing or exposed to an air space. It is generally considered to be effective only when the air space is between ¾ and 4 inches deep. Reflective surfaces in contact with other surfaces lose their reflective properties.

Miscellaneous Insulation

Some insulation does not fit in the classifications used here, such as insulation blankets made up of multiple layers of creped or reflective paper. Other types, such as lightweight vermiculite and perlite aggregates, are sometimes used in plaster as a means of reducing heat transmission. Lightweight aggregates made from blast-furnace slag, burned-clay products, and cinders are used in concrete and concrete blocks. The thermal conductivity of concrete products made of such lightweight aggregates is substantially lower than that of concrete products made of gravel and stone aggregates.

Other materials are foamed-in-place insulations, which include sprayed plastic foam types. Other sprayed insulation is usually inorganic fibrous material blown against a clean surface to which a coat of adhesive has been applied. Sprayed insulation is usually applied up to a thickness of 2 inches and the surface lightly tamped to obtain uniformity; density is usually 1 to 3½ p.c.f. It is often left exposed to serve as an acoustical treatment as well as insulation.

Polystyrene and urethane plastic foams may be molded or foamed-in-place. Urethane insulation may also be applied by spraying. These materials can be used in the field and are applied as roof, wall, and floor insulation. Expanded polystyrene is most commonly used in board form in thicknesses of ½ to 2 inches.

The methods of applying these materials are undergoing rapid changes because of improving technology, and manufacturers' recommendations should be consulted before using them as building insulations.

METHODS OF HEAT TRANSFER

Heat seeks to attain a balance with surrounding conditions, just as water will flow from a higher to a lower level. When occupied buildings are heated to maintain inside temperature in the comfort range, there is a difference in temperature between inside and outside. Heat will therefore be transferred through walls, floors, ceilings, windows, and doors at a rate that bears some relation to the temperature difference and to the resistance to heat flow of intervening materials. The transfer of heat takes place by one or more of three methods—conduction, convection, and radiation (fig. 20–1).

Conduction is defined as the transmission of heat through solid materials; for example, the conduction of heat along a metal rod when one end is heated in a fire. Convection involves transfer of heat by air currents; for example, air moving across a hot radiator carries heat to other parts of the room or space. Heat also may be transmitted from a warm body to a cold body by wave motion through space, and this process is called radiation because it represents radiant energy. Heat obtained from the sun is radiant heat.

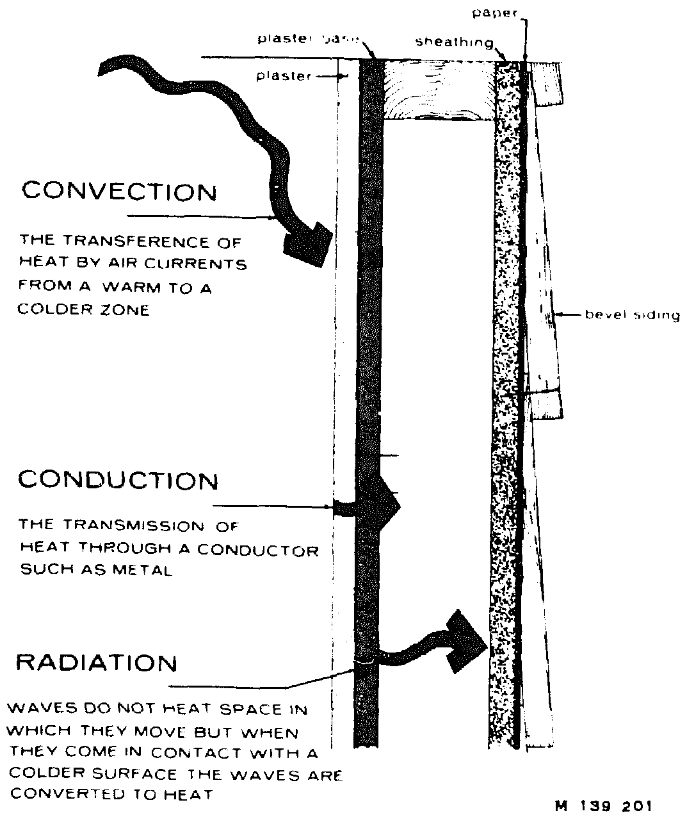

Figure 20–1.—Methods of heat transfer.

Heat transfer through a structural unit composed of a variety of materials may include one or more of the three methods described. Consider a frame house with an exterior wall composed of gypsum lath and plaster, 2- by 4-inch studs, sheathing, sheathing paper, and bevel siding. In such a house, heat is transferred from the room atmosphere to the plaster by radiation, conduction, and convection, and through the lath and plaster by conduction. Heat transfer across the stud space is by radiation and convection. By radiation, it moves from the back of the gypsum lath to the colder sheathing; by convection, the air warmed by the lath moves upward on the warm side of the stud space, and that cooled by the sheathing moves downward on the cold side. Heat transfer through sheathing, sheathing paper, and siding is by conduction. Some small air spaces will be found back of the siding, and the heat transfer across these spaces is principally by radiation. Through the studs from gypsum lath to sheathing, heat is transferred by conduction and from the outer surface of the wall to the atmosphere, it is transferred by convection and radiation.

The thermal conductivity of a material is an inverse measure of the insulating value of that material. The customary measure of heat conductivity is the amount of heat in British thermal units that will flow in 1 hour through 1 square foot of a layer 1 inch thick of a homogeneous material, per 1° F. temperature difference between surfaces of the layer. This is usually expressed by the symbol k.

Where a material is not homogenous in structure, such as one containing air spaces like hollow tile, the term conductance is used instead of conductivity. The conductance, usually designated by the symbol C, is the amount of heat in British thermal units that will flow in 1 hour through 1 square foot of the material or combination of materials per 1° F. temperature difference between surfaces of the material, or the equivalent of a surface layer, or a dead air space with or without a reflective surface.

Resistivity and resistance (direct measures of the insulating value) are the reciprocals of transmission (conductivity or conductance) and are represented by the symbol R. Resistivity, which is unit resistance, is the reciprocal of k and is given the same symbol R as resistance in the technical literature because resistances are added together to calculate the total for any construction. The overall coefficient of heat transmission through a wall or similar unit air to air, including surface resistances, is represented by the symbol U. U defines the movement in British thermal units per hour, per square foot, per 1° F. The total resistance of a construction would be $R = \frac{1}{U}$.

HEAT LOSS

Through Walls

The heat loss through walls and roofs made of different materials can be found by computing the overall coefficients of heat transmission, or U values, of the construction assemblies. To determine the U value by test would be impractical in most cases, but it is a simple matter to calculate this value for most combinations of materials commonly used in building construction whose thermal properties are known.

Table 20–1 gives conductivity and conductance values with corresponding resistivity and resistance values used in calculating the thermal properties of construction units. No values are included for reflective materials because they depend on the reflectivity and permanence of the surface brightness, the direction of heat flow, and to a lesser extent the depth of the adjoining air space. For information on calculating the amount to be credited to reflective insulations consult the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' ASHRAE Handbook of Fundamentals.

To compute the U value: Add the resistance of each material, exposed surface, and air space in the given section, using values given in table 20–1. The sum of these resistances divided into 1 (reciprocal of the sum) gives the coefficient U.

Example: Calculate the U factor for winter (heating) conditions through the stud space of a conventional wood frame wall consisting of ½-inch gypsum board, air space, ½-inch regular density insulating board sheathing, and beveled wood siding, ¾ by 10 inches lapped:

SUMMARY OF RESISTANCE

Interior surface (still air)	0.68
Gypsum board	.45
Air space	1.16
Insulating board sheathing	1.32
Siding	1.05
Outside surface (15 m.p.h. air)	.17
Overall resistance	4.83

$U = \frac{1}{R} = \frac{1}{4.83} = 0.21$ Btu per hour per square foot per °F. difference in temperature (through the stud space).

For the U value through the stud, substitute the resistivity of wood based on the depth of the stud for the resistance value of the air space. For example, a species of wood that has a k value of 0.88 has a resistivity of 1.14. The resistance of a nominal 2- by 4-inch stud is:

$$3\tfrac{1}{2} \times 1.14 = 3.99$$

Substituting the value of 3.99 for the air space value of 1.16 gives an overall resistance value of 7.66 or a U value of 0.13. Assuming the area of the studs, plates, and headers represents 15 percent of the wall area, the corrected transmission value becomes:

$$U = \frac{0.21 \times 85 + 0.13 \times 15}{100} = 0.20$$

If 2-inch mineral wool blanket insulation with one 1½-inch air space is used in the stud space, the resistance contributed by the stud space becomes 8.56 instead of the single air space value of 1.16, and the overall resistance of the wall through the stud space is 12.23, compared with 4.83 without insulation, and the U value becomes 0.08 instead of 0.21.

Through Doors and Windows

In determining heat loss for houses, the loss through doors and windows should be included in the computations. Table 20–2 gives heat transmission values for doors and windows.

WHERE TO INSULATE

Insulation is used to retard the flow of heat through ceilings, walls, and floors if wide temperature differences occur on opposite sides of these structural elements (see fig. 20–2). In dwellings, for example, insulation should be used in the ceiling of those rooms just below an unheated attic. If the attic is heated, the insulation should be placed in the attic ceiling and in the dwarf walls extending from the roof to the floor. All exterior walls should be insulated. Floors over unheated basements, crawl spaces, porches, or garages should also be insulated.

Table 20-1.—*Conductivities (k), conductances (C), and resisitivities or resistances (R) of building and insulating materials (design values)*[1] [2]

Material	Description	Thickness	Density	Conductivity or conductance		Resistivity or resistance (*R*)	
				(*k*)	(*C*)	$\frac{1}{k}$	$\frac{1}{C}$
		In.	*P.c.f.*				
Air spaces[3]	Horizontal position:						
	Heat flow up:						
	Winter	¾ to 4	....	....	1.02	....	0.98
	Summer	¾ to 4	....	....	1.28	....	.78
	Heat flow down:						
	Winter	¾ to 4	....	....	.68	....	1.47
	Summer	¾ to 4	....	....	1.09	....	.92
	Sloping, 45° position						
	Heat flow up, winter	¾ to 4	....	....	.96	....	1.04
	Heat flow down, summer	¾ to 4	....	....	1.15	....	.87
	Vertical position; heat flow horizontal						
	Winter	¾ to 4	....	....	.86	....	1.16
	Summer	¾ to 4	....	....	1.18	....	.85
Air surfaces:[4] Still air	Horizontal position:						
	Heat flow up	....	....	....	1.63	....	.61
	Heat flow down	....	....	....	1.08	....	.92
	Sloping, 45° position:						
	Heat flow up	....	....	....	1.60	....	.62
	Heat flow down	....	....	....	1.32	....	.76
	Vertical position; heat flow horizontal	....	....	....	1.46	....	.68
Moving air	Any position; heat flow any direction:						
15-m.p.h. wind	Winter	....	....	....	6.00	....	.17
7½-m.p.h. wind	Summer	....	....	....	4.00	....	.25
	Asbestos-cement board		120	4.0	....	.25	....
		⅛	....	....	33.00	....	.03
	Gypsum or plaster board	⅜	50	....	3.10	....	.32
		½	50	....	2.25	....	.45
			34	.80	....	1.25	....
	Plywood	¼	34	....	3.20	....	.31
		⅜	34	....	2.13	....	.47
		½	34	....	1.60	....	.62
	Plywood or wood panels	¾	....	....	1.07	....	.93
	Insulating board	....	18	.40	....	2.50	....
	Regular-density sheathing	½	18	....	.76	....	1.32
		25/32	18	....	.49	....	2.06
	Intermediate-density sheathing	½	25	....	.82	....	1.22
	Nail-base sheathing	½	27	....	.88	....	1.14
	Shingle backer	5/16	18	....	1.28	....	.78
		⅜	18	....	1.06	....	.94
	Sound-deadening board	½	15	....	.74	....	1.35

Building boards, panels, sheathing, etc.[5]	Tile, plain or acoustic		18	.40	----	2.50	----
		½	18		.80		1.25
		¾	18		.53		1.89
	Insulating roof deck (nominal)	1½			.24		4.17
		2			.18		5.56
		3			.12		8.33
	Laminated paperboard, homogeneous repulped paperboard		30	.50		2.00	
		⅜	30		1.33		.75
	Medium-density hardboard siding	7/16	40		1.49		.67
	Other medium-density hardboard		50	.73		1.37	
	High-density hardboard:						
	Service, tempered service		55	.82		1.22	
	Standard, tempered		63	1.00		1.00	
	Particleboard:						
	Low-density		37	.54		1.85	
	Medium-density		50	.94		1.06	
	High-density		62.5	1.18		.85	
	Wood:						
	Fir or pine sheathing	¾			1.06		.94
	Fir or pine	1½			.53		1.89
Building paper	Vapor-permeable felt				16.70		.06
	Vapor seal:						
	2 layers of mopped 15-pound felt				8.35		.12
	Plastic film						Negligible
Flooring materials	Carpet and fibrous pad				.48		2.08
	Carpet and rubber pad				.81		1.23
	Cork tile		25	.45		2.22	
		⅛			3.60		.28
	Felt, flooring				16.70		.06
	Floor tile or roll material, average value for asphalt, linoleum, rubber, vinyl	⅛			20.00		.05
	Plywood subfloor	⅝			1.28		.78
	Wood subfloor	¾			1.04		.96
	Wood, hardwood finish	¾			1.47		.68
	Hardboard underlayment	.22	55		3.73		.26
	Particleboard underlayment	⅝	40		1.22		.82
	Terrazzo	1			12.50		.08
Insulating materials Blanket and batt	Cotton fiber[6]		0.8 to 2.0	.26		3.85	
	Mineral wool, fibrous form, processed from rock, slag, or glass[6]		1.5 to 4.0	.27		3.70	
	Wood fiber[6]		2.0 to 3.5	.30		3.33	
			9.5	.25		4.00	
Glass fiber Block and panel	Roof insulation board (wood and mineral fiber)	½	15		.72		1.39
		1			.36		2.78
		1½			.24		4.17
		2			.19		5.26
		2½			.15		6.67
		3			.12		8.33
	Wood wool (excelsior) cement		22	.60		1.67	
	Expanded polyurethane		1.5	.16		6.25	
	Polystyrene:						
	Extruded (R 12 blown)		3.5	.19		5.26	
	Beads, molded		1.0	.28		3.57	

Table 20–1.—*Conductivities (k), conductances (C), and resistivities or resistances (R) of building and insulating materials (design values)*[1] [2]—continued

Material	Description	Thickness	Density	Conductivity or conductance		Resistivity or resistance (*R*)	
				(*k*)	(*C*)	$\frac{1}{k}$	$\frac{1}{C}$
		In.	*P.c.f.*				
Glass fiber Block and panel—continued	Cellular glass		9.0	.40	....	2.50	....
	Cork board (without added binder)		6.5 to 8.0	.27	....	3.70	....
	Hog hair (with asphalt binder)		8.5	.33	....	3.03	....
Loose fill	Macerated paper or pulp products		2.5 to 3.5	.27	....	3.70	....
	Mineral wool (glass, slag, or rock)		2.0 to 5.0	.30	....	3.33	....
	Sawdust or shavings		8.0 to 15.0	.45	....	2.22	....
	Vermiculite (expanded)		7.0 to 8.0	.47	....	2.13	....
	Wood fiber: Redwood, hemlock, or fir		2.0 to 3.5	.30	....	3.33	....
	Perlite (expanded)		5.0 to 8.0	.37	....	2.70	....
Masonry materials	Cement mortar		116	5.0	....	.20	....
	Gypsum-fiber concrete 87½ percent gypsum, 12½ percent wood chips		51	1.66	....	.60	....
	Lightweight aggregates including expanded shale, clay, or slate; expanded slags, cinders, pumice, perlite, vermiculite; also cellular concretes		120	5.2	....	.19	....
			100	3.6	....	.28	....
			80	2.5	....	.40	....
			60	1.7	....	.59	....
			40	1.15	....	.86	....
			30	.90	....	1.11	....
			20	.70	....	1.43	....
	Sand and gravel or stone aggregate:						
	Ovendried		140	9.0	....	.11	....
	Not dried		140	12.0	....	.08	....
	Stucco		116	5.0	....	.20	....
Masonry units	Brick:						
	Common		120	5.0	....	.20	....
	Face		130	9.0	....	.11	....
	Clay tile, hollow:						
	1 cell deep	3		....	1.25	....	.80
		4		....	.90	....	1.11
	2 cells deep	6		....	.66	....	1.52
		8		....	.54	....	1.85
		10		....	.45	....	2.22
	3 cells deep	12		....	.40	....	2.50
	Concrete blocks, three oval core:						
	Sand and gravel aggregate	4		....	1.40	....	.71
		8		....	.90	....	1.11
		12		....	.78	....	1.28
	Cinder aggregate	3		....	1.16	....	.86
		4		....	.90	....	1.11
		8		....	.58	....	1.72
		12		....	.53	....	1.89
	Lightweight aggregate (expanded shale, slag, etc.)	3	75	....	.79	....	1.27
	3-core	4	75	....	.67	....	1.50
	2-core	8		....	.50	....	2.00
	3-core	12		....	.44	....	2.27

	Gypsum partition tile:						
	3 by 12 by 30 inches, solid		----	----	.79	----	1.26
	3 by 12 by 30 inches, 4-cell		--	--	.74	----	1.35
	4 by 12 by 30 inches, 3-cell		----		.60	----	1.67
	Stone masonry, limestone, or sandstone		--	12.50	---	.08	----
Metals	See chapter 30, table 3, of 1972 ASHRAE Handbook of Fundamentals.						
Plastering materials	Cement plaster:						
	Sand aggregate		116	5.0	----	.20	----
		⅜			13.3	----	.08
		¾			6.66	---	.15
	Gypsum plaster:						
	Lightweight aggregate	½	45	----	3.12	----	.32
		⅝	45		2.67	---	.39
	On metal lath	¾			2.13	----	.47
	Perlite aggregate		45	1.5	----	.67	----
	Vermiculite aggregate		45	1.7	----	.59	----
	Sand aggregate		105	5.6	----	.18	----
		⅜	105	14.9	----	---	.07
		½	105		11.10	----	.09
		⅝	105		9.10	----	.11
	On metal lath	¾			7.70	----	.13
	On wood lath		----		2.50	----	.40
Roofing	Asbestos-cement shingles		120		4.76	----	.21
	Asphalt roll roofing		70	--	6.50	----	.15
	Asphalt shingles		70		2.27	----	.44
	Built-up roofing	⅜	70		3.00	----	.33
	Slate	½	----		20.00	----	.05
	Sheet metal		----	400+	----	Negligible	----
	Wood shingles		----		1.06	----	.94
Siding materials (on flat surface)	Shingles:						
	Wood:						
	16-inch, 7½-inch exposure		----		1.15	----	.87
	Double, 16-inch, 12-inch exposure		----	--	.84	----	1.19
	Plus 5/16-inch insulation backer board		----	---	.71	----	1.41
	Siding:						
	Asbestos-cement, ¼-inch, lapped		----	---	4.76	----	.21
	Asphalt roll siding		----	---	6.50	----	.15
	Asphalt insulating siding (½-inch board)		---	---	.69	----	1.45
	Wood:						
	Drop, 1 by 8 inches		----	--	1.27	----	.79
	Bevel: ½ by 8 inches, lapped		----	---	1.23	----	.81
	¾ by 10 inches, lapped		----	--	.95	----	1.05
	Plywood, ⅜ inch, lapped		----	----	1.59	----	.63
	Architectual glass		----	---	10.00	----	.10
	Medium-density hardboard (panel or lapped)	7/16	40	----	1.49	----	.67
Wood[7]	Maple and oak		43	1.11	----	.90	----
	Douglas-fir		32	.88	---	1.14	----

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[1] Table based on values obtained at Forest Products Laboratory for wood and wood-base materials, and from table 3A, chapter 20 of ASHRAE Handbook of Fundamentals for materials of other base.

[2] Representative values for dry materials at 75° F., mean temperature, intended for design and comparison, not for specifications.

[3] Values are dependent on thickness of air space and temperature and temperature differences across air space; ones presented are mean values for typical conditions. For more accurate values consult chapter 20 of ASHRAE Handbook of Fundamentals. Air space resistance values are for spaces faced both sides with ordinary nonreflective building materials.

[4] Surface resistance values are for ordinary nonreflective materials.

[5] See also insulating materials (block and panel) and siding materials.

[6] Includes paper backing and faces, if any, having nonreflective surfaces.

[7] Thermal properties of other woods are discussed in chapter 3.

CONDENSATION AND VAPOR BARRIERS

Two types of condensation create a problem in buildings during cold weather; that which collects on the inner surfaces of windows, ceilings, and walls, and that which collects within walls or roof spaces. Surface condensation is quite common in industrial buildings where relative humidity is high. In a factory or warehouse, water dripping from a ceiling may seriously damage manufactured materials and machinery. "Sweating" walls and windows also are a serious nuisance.

Condensation may collect on the indoor surface of exterior walls of houses, particularly behind furniture, or in outside closets, causing damage to finish, furniture, and flooring. It may also collect on windows, particularly those unprotected by storm sash. Water running off the windows may create conditions favorable to decay in wood sash, cause rust in steel sash, and damage window finish and

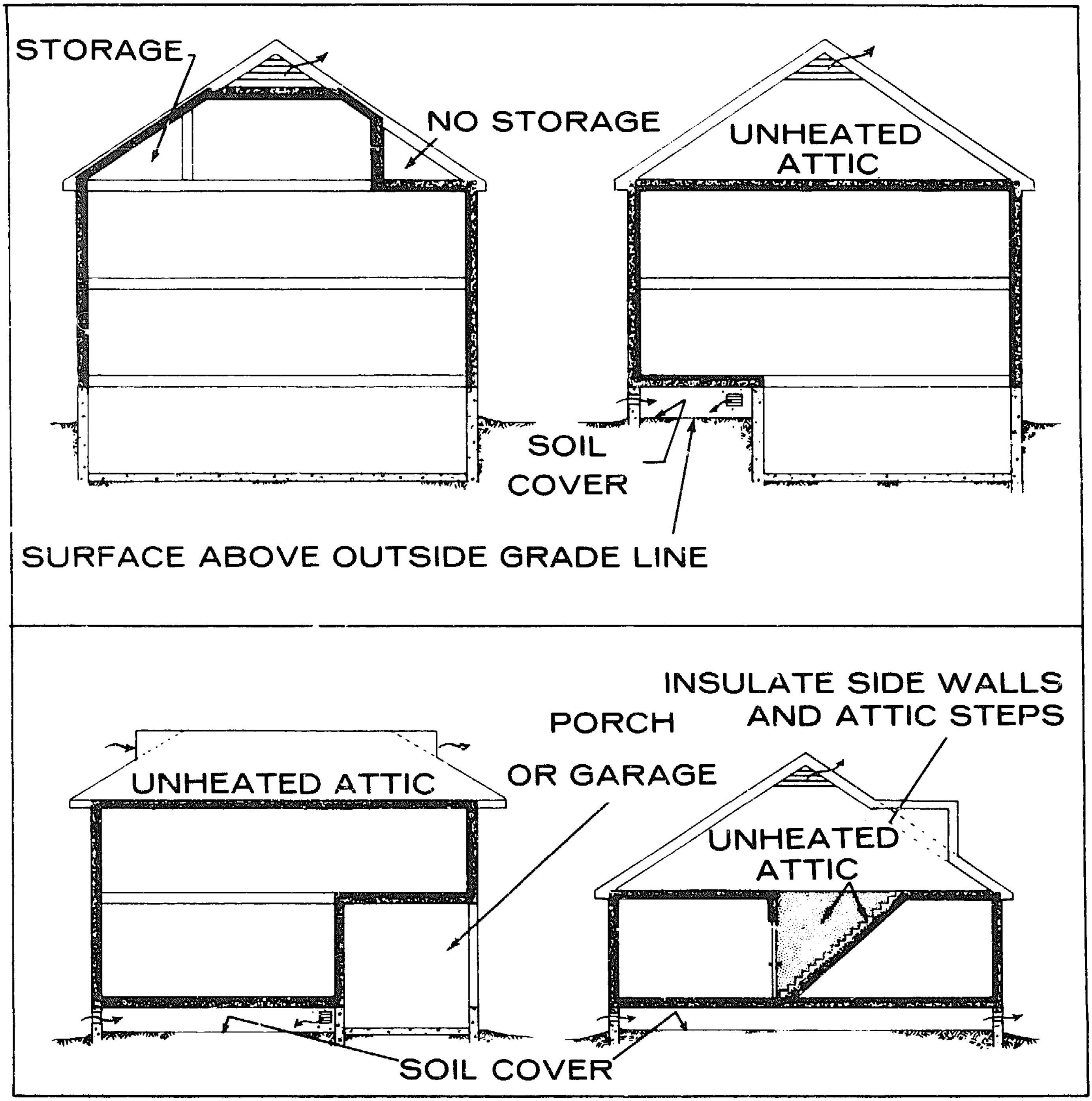

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Figure 20–2.—Insulation should be installed in side walls between heated rooms and outdoors, in walls and floors between unheated garages and porches and heated rooms, in floors in basementless houses, in ceilings below unheated attics, in roofs over heated rooms, and in side walls and below stairs leading to unheated attics.

walls and floors below the windows.

To prevent surface condensation, the relative humidity in the building must be reduced or the surface temperature must be raised above the dew point of the atmosphere. Adding insulation to a wall or roof reduces heat transfer through the unit, and the inside surface temperature is increased accordingly. The amount of insulation required for given conditions can be calculated. Storm sash or double glazing reduces condensation on windows.

Table 20–2.—*Coefficients of transmission (U) commonly used for doors, windows, and glass blocks* [1]

Item	*U* value	
	Exposed unit alone	With glass storm door or storm window
1⅛-inch solid wood, door [2]	0.55	0.34
1⅜-inch solid wood door [2]	.48	.31
1⅝-inch solid wood door [2]	.43	.28
Single glass wood window	1.02	.50
Single glass metal window	1.13	.56
Glass block [3]	.60	
Single glass	1.13	
Double glass (insulated ¼-in. space)	.65	.38

[1] Table based in part on the data from 1972 ASHRAE Handbook of Fundamentals.

[2] For doors containing thin wood panels or glass, use the same *U* value as shown for single windows.

[3] Blocks are 6 by 6 by 4 in.

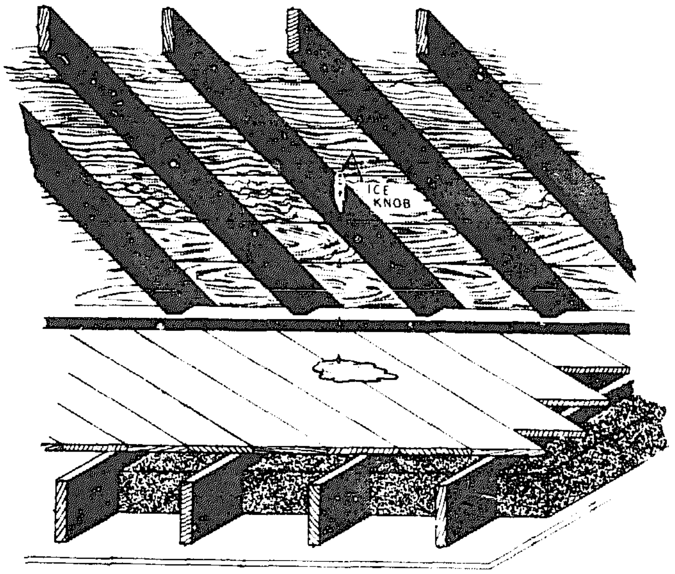

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Figure 20–3.—Condensation collecting on the roof sheathing in an unventilated attic. Ice has collected on the tip of protruding nail (arrow). When outdoor temperatures rise after a cold spell or when the sun strikes the roof the ice melts and drips down to the ceiling below.

Moisture sometimes condenses within the walls or roof spaces of buildings if relative humidity is comparatively high during cold weather (fig. 20–3). In walls, this type of condensation may result in decay of wood, rusting of steel, and damage to exterior paint coatings. In roofs and ceilings it may cause stained finish and loosened plaster and increase the chances of decay in structural members.

When outdoor temperatures are low, water vapor will sometimes pass through permeable inner surface materials and condense within a wall or roof space on some cold surface. Key to this situation is a surface temperature below the dew point of the atmosphere on the warm side. When the condensing surface is considerably below the dew point, differences in vapor pressure between the cold and warm sides cause vapor to move from the high-vapor-pressure zone to the low-pressure zone. The rate of movement is more or less proportional to the resistance of interposed materials. The amount of condensation that collects on the condensing surface depends upon the resistance to permeance of intervening materials, differences in vapor pressure, and time. There will also be some difference in vapor pressure between the condensing surface and the outdoor atmosphere. Some part of the water vapor reaching the condensing surface will therefore escape outside through materials that are permeable. Materials used for side wall coverings preferably should be permeable. Roofing materials are generally highly resistant to vapor transmission. Wood shingles applied over narrow roof boards are not resistant to vapor transmission.

Insulation can cause increased condensation under certain conditions. Heat flow is reduced by insulation, and consequently the temperature of those parts of a wall or roof on the cold side of the insulation is lower during cold weather than if no insulation were used. This in turn means a greater difference in vapor pressure between the warm side and the condensing surface and a greater amount of condensation if vapor is permitted to move through the construction. Insulation is important, however, as a means of conserving heat and creating comfortable living conditions and its influence on condensation can be largely mitigated.

The rate of vapor transmission through inner surfaces may be controlled by the use of materials having high resistance to vapor movement. Such vapor barriers should be located on the warm surface of the wall (fig. 20–4) so that the temperature of the barrier will always be above the dew point of the heated space. Broken barriers of poor installation around outlet boxes in exterior walls will cause escape of water vapor and often condensation problems. The use of a full wall covering with a vapor barrier (enveloping) and calking around the perimeter of the outlet boxes will minimize these problems. Vapor barrier requirements differ with geographic climates, so local conditions determine what is required. More detailed information than is possible to provide in this handbook is presented in references listed in the bibliography.

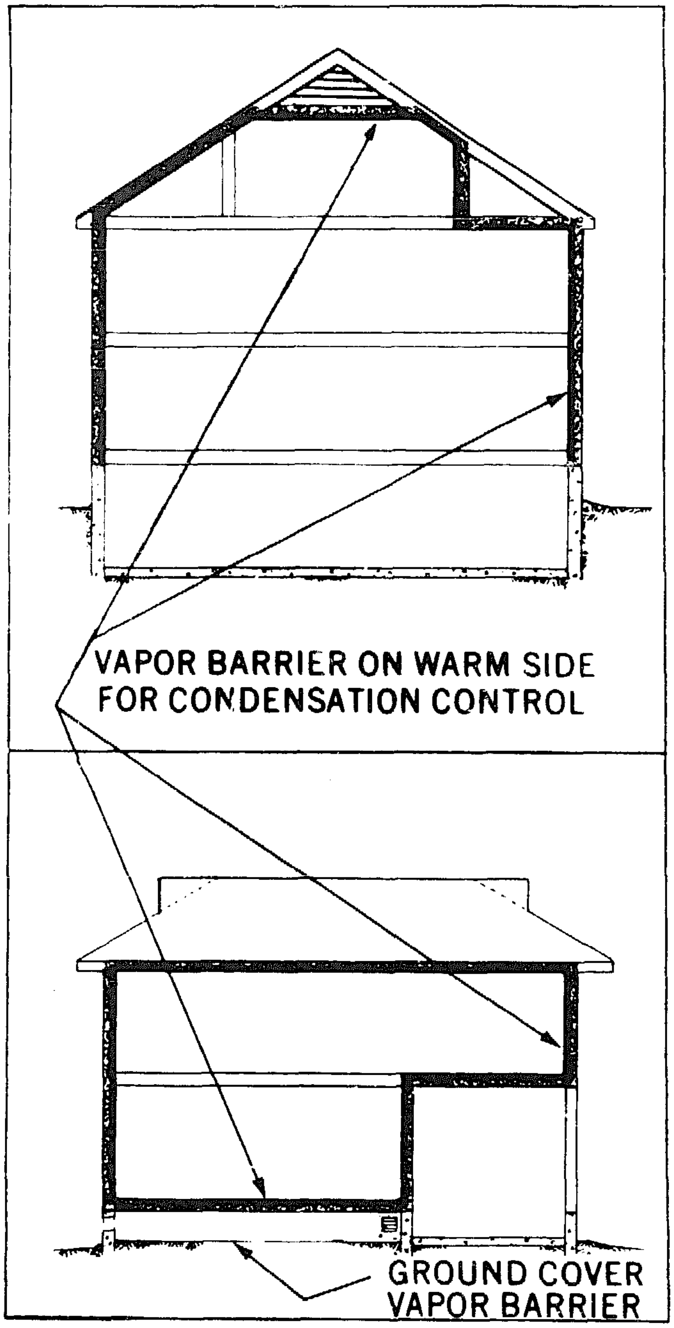

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Figure 20–4.—To control cold weather condensation, a vapor barrier should always be installed on the warm side of the construction.

For new construction, the barrier may be any one of several materials, such as asphalt-impregnated and surface-coated paper applied over the face of the studs, plastic films, gypsum lath with aluminum-foil backing, blanket insulation with vapor-resistive cover, and reflective insulation. For existing construction, certain types of paint coatings add materially to the resistance to vapor transfer. One coat of aluminum primer followed by two decorative coats of flat paint or lead and oil seems to offer satisfactory resistance.

VENTILATION

Attics and roof spaces are generally provided with suitable openings for ventilation, partly for summer cooling and partly to prevent winter condensation (fig. 20–5). For gable roofs, louvered openings are provided in the gable ends, allowing at least 1 square foot of louver opening (minimum net area) for each 300 square feet of projected ceiling area. For hip roofs, inlet openings are usually provided under the over-hanging eaves with a globe or ridge ventilator at or near the peak for an outlet. The inlets should equal 1 square foot to each 900 square feet of projected ceiling area and the outlets 1 square foot (net area) to each 1,600 square feet. Ventilation for flat roofs should be developed to suit the method of construction.

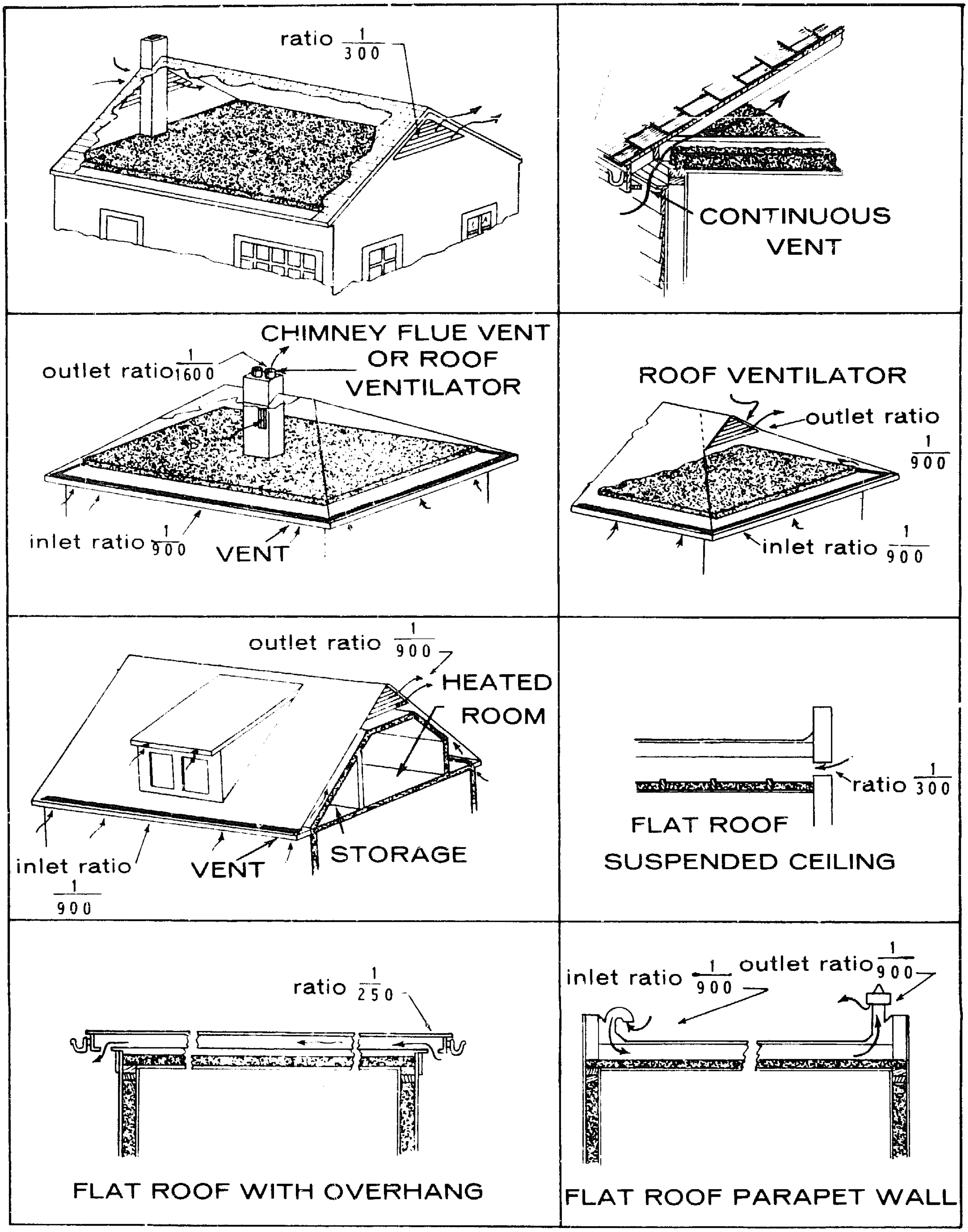

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Figure 20-5.—Methods used to ventilate attics and roof spaces. Air inlet openings under the eaves of pitched roofs in addition to outlet openings near peak provide air movement independent of the effect of wind. For flat roofs where joists are used to support ceiling and roof, continuous vents, open to each joist space, are needed for both inlets and outlets. The dormer has inlets at eave and a roof space opens into attic. All dormers should be carefully framed to assure means of ventilation in the roof space. The sketches show the ratio of free opening in louvers and vents to the area of the ceiling in the rooms below.

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Chapter 21

WOOD-BASE FIBER AND PARTICLE PANEL MATERIALS

WOOD-BASE FIBER AND PARTICLE PANEL MATERIALS

The group of materials generally classified as "wood-base fiber and particle panel materials" includes such familiar products as insulation boards, hardboards, particleboards, and laminated paperboards. In some instances they are known by such proprietary names as "Masonite," "Celotex," "Insulite," and "Beaver board" or, in the instance of particleboards, by the kind of particle used such as flakeboard, chipboard, chipcore, or shavings board.

These panel materials are all reconstituted wood (or some other lignocellulose like bagasse) in that the wood is first reduced to small fractions and then put back together by special forms of manufacture into panels of relatively large size and moderate thickness. These board or panel materials in final form retain some of the properties of the original wood but, because of the manufacturing methods, gain new and different properties from those of the wood. Because they are manufactured, they can be and are "tailored" to satisfy a use-need, or a group of needs.

Generally speaking, the wood-base panel materials are manufactured either (1) by converting wood substance essentially to fibers and then interfelting them together again into the panel material classed as building fiberboard, or (2) by strictly mechanical means of cutting or breaking wood into small discrete particles and then, with a synthetic resin adhesive or other suitable binder, bonding them together again in the presence of heat and pressure. These latter products are appropriately called particleboards.

Building fiberboards, then, are made essentially of fiberlike components of wood that are interfelted together in the reconstitution and are characterized by a bond produced by that interfelting. They are frequently classified as fibrous-felted board products. At certain densities under controlled conditions of hot-pressing, rebonding of the lignin effects a further bond in the panel product produced. Binding agents and other materials may be added during manufacture to increase strength, resistance to fire, moisture, or decay, or to improve some other property. Among the materials added are rosin, alum, asphalt, paraffin, synthetic and natural resins, preservative and fire-resistant chemicals, and drying oils. References for greater detail on methods of manufacture of building fiberboards are included in the bibliography at the end of this chapter. Evaluation procedures for basic properties are reasonably well standardized.

Particleboards are manufactured from small components of wood that are glued together with a thermosetting synthetic resin or equivalent binder. Wax sizing is added to all commercially produced particleboard to improve water resistance. Other additives may be introduced during manufacture to improve some property or provide added resistance to fire, insects such as termites, or decay. Particleboard is among the newest of the wood-base panel materials. It has become a successful and economical panel product because of the availability and economy of thermosetting synthetic resins, which permit blends of wood particles and the synthetic resin to be consolidated and the resin set (cured) in a press that is heated.

Thermosetting resins used are primarily urea formaldehyde and phenol-formaldehyde. Urea-formaldehyde is lowest in cost and is the binder used in greatest quantity for particleboard intended for interior or other nonsevere exposures. Where moderate water or heat resistance is required, melamine-urea-formaldehyde resin blends are being used. For severe exposures like exteriors or where some heat resistance is required, phenolics are generally used.

The kinds of wood particles used in the manufacture of particleboard range from specially cut flakes an inch or more in length (parallel to the grain of the wood) and only a few hundredths of an inch thick to fine particles approaching fibers or flour in size. The synthetic resin solids are usually between 5 and 10 percent by weight of the dry wood furnish. These resins are set by heat as the wood particle-resin blend is compressed either in flat-platen presses, similar to those used for hot-pressing hardboard and plywood, or in extrusion presses where the wood-resin mixture is squeezed through a long, wide, and thin die that is heated to provide the energy to set the resin.

Particleboards produced by flat-platen presses are called "mat-formed" or "platen-pressed." Those produced in an extrusion press are called "extruded" particleboards.

Building fiberboards and particleboards are produced from small components of wood, hence the raw material need not be in log form. Many processes for manufacture of board materials start with wood in the form of pulp chips. Coarse residues from other primary forest products manufacture therefore are an important source of raw materials for both kinds of wood-based panel products. Particleboards, and to a lesser extent building fiberboards, use fine residues as raw material. For instance, planer shavings are significant in manufacture of particleboard. Overall, about 70 percent of the raw material requirements for wood-base fiber and particle panel materials are satisfied by residues. Bagasse, the fiber residue from sugar cane, and wastepaper are used also as raw material for board products.

In total, the wood-base fiber and particle panel materials form an important part of the forest products industry in the United States. Not only are they valuable from the standpoint of integrated utilization, but the total production of more than 7 billion square feet is important in terms of forest products consumed. Along with softwood plywood they are among the fastest growing components of the industry and production has been doubling about each 10 years.

FIBER PANEL MATERIALS

Broadly, the wood-base fiber panel materials (building fiberboards) are divided into two groups—insulation board (the lower density products) and hardboard, which requires consolidation under heat and pressure as a separate step in manufacture. The dividing point between an insulation board and a hardboard, on a density basis, is a specific gravity of 0.5 (about 31 p.c.f.). Practically, because of the range of uses and specially developed products within the broad classification, further breakdowns are necessary to classify the various products adequately. The following breakdown by density places the building fiberboards in their various groups:

	DENSITY	
	G. per cc.	*P.c.f.*
Insulation board	0.02 to 0.50	1.2 to 31
Semirigid insulation board	.02 to .16	1.2 to 10
Rigid insulation board	.16 to .5	10 to 31
Hardboard	.5 to 1.45	31 to 90
Medium-density hardboard	.5 to .8	31 to 50
High-density hardboard	.8 to 1.20	50 to 75
Special densified hardboard	1.35 to 1.45	84 to 90
Laminated paperboard	.50 to .59	31 to 37

Laminated paperboards require a special classification because the density of these products is slightly greater than the maximum for non-hot-pressed, fibrous-felted, wood-base panel materials. Also, because these products are made by laminating together plies of paper about 1/16 inch thick, they have different properties along the direction of the plies than across the machine direction. The other fibrous-felted products have nearly equal properties along and across the panel.

PARTICLE PANEL MATERIALS

Mat-formed particleboards, because of differences in properties and uses, are generally classified by density into low, medium, and high categories:

	DENSITY	
	G. per cc.	*P.c.f.*
Low density	Less than 0.59	Less than 37
Medium density	0.59 to 0.80	37 to 50
High density	More than 0.80	More than 50

All mat-formed particleboards are hot-pressed to cure the resins used as binders.

These mat-formed particleboards are further described as being homogeneous (the same kind, size, and quality of particle throughout the thickness), graduated (a gradation of particle size from coarsest in the center of the thickness to finest at each surface), or "three layer" (the material on and near each surface is different than that in the core). These boards may be also described by the predominant kind of particle, as shavings, flakes, slivers, or the combination in the instance of layered construction as "flake-faced" or "fines-surfaced" boards.

Extruded boards account for less than 5 percent of total production of particleboard, and standards have not been developed for them to any appreciable extent. Most extruded particleboard can be classed as being of medium density because the compression applied to the wood particles during extruding does not increase the density beyond 50 p.c.f. Particleboards thicker than about 5/8 inch can be extruded with hollow core sections similar to those molded in concrete blocks. Because of these hollow core sections the equivalent density may fall below that of medium-density, mat-formed particleboard. Extruded particleboards of that type, usually called "fluted" particleboards, are commonly classified on the basis of weight per square foot for a specified thickness.

PROPERTIES AND USES

Properties of the various wood-base panel materials to a considerable extent either suggest or limit the uses. In the following sections the fiber- and particle-based panel materials are divided into the various categories suggested by kind of manufacture, properties, and use.

Semirigid Insulation Board

Semirigid insulation board is the term applied to fiberboard products manufactured primarily for use as insulation and cushioning. These very low-density fiberboards have about the same heat-flow characteristics as conventional blanket or batt insulation but have sufficient stiffness and strength to maintain their position and form without being attached to the structure. They may be bent around curves or corners and, when cemented, mechanically fastened, or placed between framing members, will hold their shape and position even though subjected to considerable vibration.

The semirigid insulation boards are manufactured in sheets from ½ to 1½ inches thick. When greater thicknesses are required, two or more sheets are cemented together. Sheet sizes vary from 1 by 2 feet to 4 by 4 feet. The thermal conductivity factors (*k*) range from 0.24 to 0.27 Btu · in./h · ft^2 · deg F (British thermal units per inch of thickness per hour per square foot of surface per degree Fahrenheit) difference in temperature.

Semirigid insulation boards are used for heat insulation in truck and bus bodies, automobiles, refrigerators, railway cars, on the outside of ductwork, and wherever vibrations are so severe that loosefill or batt insulation may pack or shift. They are also used as sound insulation for the walls of telephone booths and around speakers in radios, public address systems, and phonographs, and as cushioning in furniture, mattresses, and special packaging applications.

Rigid Insulation Board

Rigid insulation board is the oldest of the wood-base fiber and particle panel materials. It has been produced in the United States for more than a half century and, when produced to the various standards developed by the insulation board industry, is classed as structural insulating board. Structural insulating board is manufactured mainly for specific uses in construction although some is fabricated for special padding and blocking in packaging and a wide variety of other industrial uses. Insulation board is produced in two general types, interior and sheathing. Interior-quality boards are for uses where high water resistance is not required, but a light-colored product is desired. Sheathing-quality boards are used where water resistance is required and are manufactured with added water-resistant materials (usually asphalt). Density is somewhat greater for sheathing-quality boards than for interior boards. Some sheathing-quality boards are coated with asphalt as well as impregnated.

Important strength and related properties for insulating board are included in table 21–1 with those for other building fiberboards. The two basic insulating board products, with only minor modification in manufacture as relates to composition, are fabricated into a group of products designed to satisfy specific use requirements in construction. These requirements may call for structural strength and either high thermal insulation or good acoustical properties, or both. Since individual structural insulating board products are use-oriented, the name of the product describes the use. Principal ones are described as follows:

General Purpose Board

There are two general purpose structural insulating boards—"Building Board" and "Wallboard" (sometimes called "Thin Board" in the trade because it is either 5/16 or 3/8 inch thick while most other insulating board is ½ inch or thicker). Both of these general purpose boards may be converted for a multiplicity of uses not specifically covered in the other products. Some material could be classed as industrial board because it is used by others in some other article of commerce. The general use boards are usually furnished with a factory-applied, flame-resistant finish. "Building Board" is ½ inch thick and may be obtained in panels 4 feet by 8, 9, 10, or 12 feet with square edges. "Wallboard" is furnished regularly 4 feet wide in either 8- or 10-foot lengths. Quality limits are set for these and other regular products in the standards.

Table 21-1.—*Strength and mechanical properties of wood-base building fiberboards*[1]

Property	Value for structural insulating board	Value for medium-density hardboard	Value for high-density hardboard	Value for tempered hardboard	Value for special densified hardboard	Unit
Density	10–30	33–50	50–80	60–80	85–90	P.c.f.
Specific gravity	0.16–0.42	0.53–0.80	0.80–1.28	0.93–1.28	1.36–1.44	....
Modulus of elasticity (bending)	25–125	325–700	400–800	650–1,100	1,250	1,000 p.s.i.
Modulus of rupture	200–800	1,900–6,000	3,000–7,000	5,600–10,000	10,000–12,500	P.s.i.
Tensile strength parallel to surface	200–500	1,000–4,000	3,000–6,000	3,600–7,800	7,800	Do.
Tensile strength perpendicular to surface	10–25	40–200	75–400	160–450	500	Do.
Compressive strength parallel to surface	....	1,000–5,500	1,800–6,000	3,700–6,000	26,500	Do.
Shear strength (in plane of board)	....	100–475	300–600	430–850	....	Do.
Shear strength (across plane of board)	....	600–2,500	2,000–3,000	2,800–3,400	....	Do.
24-hour water absorption	1–10	....	....	....	....	Pct. by volume
24-hour water absorption	....	5–20	3–30	3–20	0.3–1.2	Pct. by weight
Thickness swelling, 24-hour soaking	....	2–10	10–25	8–15	....	Pct.
Linear expansion from 50 to 90 percent relative humidity[2]	0.2–0.5	0.2–0.4	0.15–0.45	0.15–0.45	....	Do.
Thermal conductivity at mean temperature of 75° F.	0.27–0.45	0.54–0.75	0.75–1.40	0.75–1.50	1.85	Btu · in./h · ft^2 · deg F

[1] The data presented are general round-figure values, accumulated from numerous sources; for more exact figures on a specific product, individual manufacturers should be consulted or actual tests made. Values are for general laboratory conditions of temperature and humidity.

[2] Measurements made on material at equilibrium at each condition at room temperature.

Insulating Roof Deck

Insulating roof deck is a laminated structural insulating board product maufactured of several layers of sheathing-grade board and one layer of factory-finished interior board (either perforated or plain). It is used in exposed-beam ceiling constructions where the factory-finished interior board is applied face down. Insulating roof deck is regularly made in 1½-, 2-, and 3-inch nominal thickness in 2- by 8-foot panels. The 1½-inch-thick panel is made to span 24 inches, the 2-inch-thick panel to span 32 inches, and the 3-inch-thick material to span 48 inches. Panel ends are square and sides are tongued and grooved.

In climates where condensation due to winter cold can be a problem, insulating roof deck is furnished with a vapor-barrier membrane installed in the glueline between the layer of ½-inch-thick interior-finish board and the first sheathing-quality layer. In this construction the roof decking furnishes the structural rigidity to support snow and water or wind loads, besides providing the interior ceiling finish and thermal insulation. Thermal conductance factors for the various thicknesses are specified at 0.24, 0.18, and 0.12 Btu per hour per square foot of area per °F. difference in temperature for the thickness, respectively, of 1½, 2, and 3 inches. For flat roofs a builtup roof is applied directly to the top surface of the deck. When pitch of the roof is sufficient, asphalt shingles may be attached to 2- and 3-inch-thick decking with special annular grooved nails.

Roof Insulation

Above-deck thermal insulation made of structural insulating board has been a major product for many years. It competes well from the cost and service standpoint with other products made for that use and is included with them in the specifications for such materials. Roof insulation is manufactured in blocks 23 by 47 or 24 by 48 inches in ½-inch multiples of thickness between ½ and 3 inches. The blocks are usually multiple ½-inch thicknesses of insulation board and may be laminated or stapled together in the greater thicknesses. Thicknesses are nominal and may be less than or greater than nominal by any amount necessary to give certified conductance values for the thicknesses:

Nominal thickness *In.*	"C" value *Btu/h · ft² · deg F*
½	0.72
1	.36
1½	.24
2	.19
2½	.15
3	.12

Insulation board roof insulation is applied above decks, where the final roofing is of the builtup variety. It is secured in place by hot asphalt or roofing pitch or by mechanical fasteners, and has enough internal bond strength to resist uplift forces on the roof structure.

Ceiling Tile and Lay-In Panels

Ceiling tile, either plain or perforated, is an important use for structural insulating board. Such board has a paint finish applied in the factory to provide resistance to flame spread. Interior-finish insulating board, when perforated or provided with special fissures or other sound traps, will also provide a substantial reduction in noise reflectance. The fissures and special sound traps are designed to provide improved appearance over that of the conventional perforations while satisfying the requirements for sound absorption. The manufacturers of insulation board long have recognized the appeal of esthetically pleasing ceiling finishes. Each of them offers finishes in designs that blend with either traditional or contemporary architecture and furnishings.

Generally ceiling tiles are 12 by 12 and 12 by 24 inches in size, ½ inch thick, and have tongue and groove or butt and chamfered edges. They are applied to nailing strips with nails, staples, or special mechanical fastenings, or directly to a surface with adhesives.

A panel product similar to tile, but nominally 24 by 24 or 24 by 48 inches, is gaining popularity. These panels, commonly called "lay-in ceiling panels," are installed in metal tees and angles in suspended ceiling systems. These lay-in panels are usually ½ inch thick and are supported in place along all four edges. They are frequently used in combination with translucent plastic panels that conceal light fixtures. Finishes and perforation treatments for sound absorption are the same as for regular ceiling tile. Producers of insulating board are extending their manufacture to specially embossed ceiling panels that can be applied with butt joint edges and ends that present an essentially unbroken surface. Plastic films are being used increasingly for surfacing ceiling tile for applications like kitchens and bathrooms where repeated washability and resistance to moisture is desired. These products are especially adaptable for remodeling.

Plank

Structural insulating board plank is installed on side walls, often in remodeling, where it is used in conjunction with ceiling tile installations. Plank is manufactured 12 inches wide with matching long edges and is finished with a flame-resistant paint applied at the factory. Because of its low density, it is subject to abrasion when used for the lower part of walls where chairs or other furniture can bump it. Frequently it is used in conjunction with wainscoting of wood paneling or one of the other wood-base panel materials like hardboard or particleboard.

Sheathing

Insulation board is used more than any other material for sheathing houses in the United States (fig. 21–1). Sheathing is regularly manufactured in three grades: Regular-density, intermediate, and nail-base. Regular-density sheathing is manufactured in both ½- and 25/32-in thicknesses. Intermediate and nail base are made only ½ inch thick. Regular-density sheathing is furnished in two sizes, 2 by 8 feet with long edges matched, or 4 by 8, 9, 10, or 12 feet with edges square; the other two grades are furnished only in 4-foot widths and 8- or 9-foot lengths with square edges.

Regular-density sheathing is usually about 18 p.c.f. in density and is sold with a thermal resistance (R) rating of 2.06 (deg F · h · ft² · Btu) for 25/32-inch material and 1.32 for the ½-inch thickness. When the 2- by 8-foot material is used as sheathing, it is applied with long edges horizontal. The 4-foot-wide material is recommended for application with long edges vertical. When 25/32-inch-thick regular-density sheathing is applied with the long edges vertical and adequate fastening (either nails or staples) around the perimeter and along intermediate framing, requirements for racking resistance of the wall construction are usually satisfied. Horizontal applications with the 25/32-inch material require additional bracing in the wall system to meet code requirements for rigidity, as do some applications of the ½-inch-thick regular-density sheathing applied with long edges vertical. Regular-density sheathing,

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Figure 21-1.—Proper nailing provides racking resistance with insulation board sheathing.

because of its resistance to heat flow and air infiltration, provides sufficient resistance so that added thermal insulation is not required to meet minimum standards in many parts of the country.

Costs of heating and requirements for air-conditioning from summer heat may justify added thermal insulation over that required by minimum standards. When such added thermal insulation is used in construction of walls, intermediate and nail-base sheathing (with lower thermal resistance) are used. They are applied with long edges vertical. With recommended fastening, such sheathing provides the racking rigidity and strength for the wall without added bracing.

Intermediate sheathing is usually about 22 p.c.f. in density; nail-base is about 25. The insulation board industry provides intermediate density and nail-base sheathing with rated thermal resistance (*R*) values also. The *R* values for those materials are 1.22 and 1.14, respectively. Nail-base sheathing has adequate nail-holding strength so that asbestos and wood shingles for weather course (siding) can be attached directly to the nail-base sheathing with special annular grooved nails. With the other grades of sheathing, siding materials must be nailed directly to framing members or to nailing strips attached through the sheathing to framing. Because the method and amount of fastening is critical to racking resistance, local building codes should be consulted for requirements in different areas.

Shingle Backer

Shingle backer is a specially manufactured sheathing-grade structural insulating board 5/16 or 3/8 inch thick, 11¾, 13½, or 15 inches wide, and 4 feet long. It is used with coursed wood shingles on sidewalls. The shingle backer is installed beneath each course of shingles to provide the deep shadow line so desirable for that type of sidewall finish; by nailing through the added thickness of insulation board, as well as sheathing, adequate nail holding is provided to keep the shingles in position. Special long deformed nails (usually annularly grooved) are used for the fastening.

Insulating Formboard

Insulating formboard is a special insulating board for permanent in-place forms; lightweight aggregate cement or gypsum roof decks are poured on it. The formboard has sufficient stiffness, when installed as recommended, to support the wet deck material until it sets. After cure it remains in place to provide thermal insulation; it also shares in carrying roof loads because the poured deck and the formboard act as a composite beam. Standard thicknesses of insulating formboard are 1 and 1½ inches; widths are 24, 32, and 48 inches; and lengths are between 4 and 12 feet, as required. When formboard is to be exposed in the final construction, the exposed surface may be furnished with a factory-applied paint finish.

Sound-Deadening Board

Sound-deadening board is specially manufactured to provide a meaningful reduction in sound transmission through walls. Standard sizes are ½ inch thick, 4 feet wide, and 8 or 9 feet long. In light-frame construction, sound-deadening board is usually applied to the wall framing; the final wall finish, such as gypsum board, is then applied to the outside faces of the sound-deadening board. Acoustic efficiency of walls constructed with sound-deadening board depends on tight construction with no air leaks around the edges of panels, and close adherence to prescribed methods of installation.

Medium-Density Hardboard

Medium-density hardboard, formerly classified as medium-density building fiberboard, is the newest of the wood-based panel products. Nearly all of the material being manufactured by the conventional methods used for other hardboard is being tailored for use as house siding (fig. 21-2). Medium-density hardboard for house siding use is mostly ⅜ and $^7/_{16}$ inch thick and is fabricated for application as either panel or lap siding.

Medium-density hardboard is also manufactured by a newer process that involves radio-frequency energy for curing thicker panels (usually about ¾ in. although it is possible to make panels as thick as 3 in.) for use mainly in furniture and cabinets as corestock or panel stock. Properties of medium-density hardboard are summarized in table 21-1.

Panel siding is 4 feet wide and commonly furnished in 8-, 9-, or 10-foot lengths. Surfaces may be grooved 2 inches or more on center parallel to the long dimension to simulate reversed board and batten or may be pressed with ridges simulating a raised batten.

Lap siding is frequently 12 inches wide with lengths to 16 feet and is applied in the same way as conventional wood lap siding. Some manufacturers offer their lap siding products with special attachment systems that provide either concealed fastening or a wider shadow line at the bottom of the lap.

Most siding is furnished with some kind of a factory-applied finish. At least the surface and edges are given a prime coat of paint. Finishing is completed later by application of at least one coat of paint. Two coats of additional paint, one of a second primer and one of topcoat, provide for a longer interval before

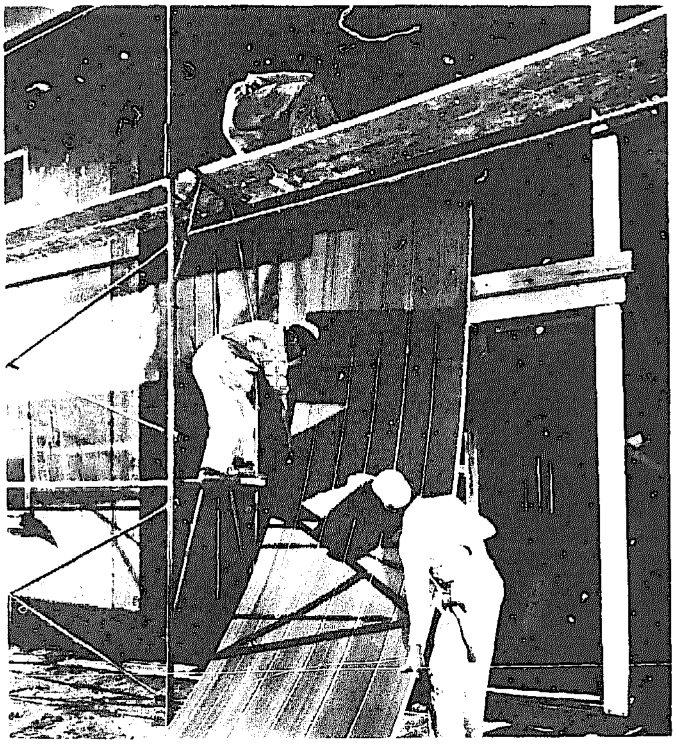

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Figure 21-2.—A 16-foot hardboard panel is applied quickly to a sidewall of a two-story building.

repainting. There is a trend for complete prefinishing of medium-density hardboard siding. The complete prefinishing ranges from several coats of liquid finishes to cementing various films to the surfaces and edges of boards. Surfaces of medium-density hardboard for house siding range from very smooth to textured; one of the newest ones simulates weathered wood with the latewood grain raised as though earlywood has been eroded away.

Small amounts of medium-density hardboard are being prefinished for interior paneling along with the high-density hardboards. Siding is the most important use and others will not become extensive until that market is fully developed and exploited. The experience with medium-density hardboard has been good. Dimensional movement with moisture change has not produced major problems in service. When hardboard is properly painted with high-quality paints, it has required little paint maintenance. Medium-density hardboard siding has been accepted largely on an individual manufacturer basis. Code authorities and others have recognized the evidence submitted by manufacturers on the performance of medium-density hardboard siding.

The properties of medium-density hardboard make it a desirable material for industrial use. Since possible uses are many, the American hardboard industry offers this product for industrial use under the name of "Industrialite." A summary of the range in properties for this material is included in table 21–1.

High-Density Hardboard

Manufacture of high-density hardboard has grown rapidly since World War II. Numerous older uses are well established and new ones are being developed continually. Properties are summarized in table 21–1, but in the trade the various qualities are subdivided in smaller groups beyond those shown in the table. There is an overlapping of properties as shown by the limiting values in the various standards for hardboard.

Originally there were two basic qualities, standard and tempered, for high-density hardboard. These are still the two qualities used in greatest quantity. Standard hardboard is a panel product with a density of about 60 to 65 p.c.f., usually unaltered except for humidification as it is produced by hot pressing. Tempered hardboard is a standard-quality hardboard that is treated with a blend of siccative resins (drying oil blends or synthetics) after hot-pressing. The resins are stabilized by baking after the board has been impregnated. Usually about 5 percent solids are required to produce a hardboard of tempered quality. Tempering improves water resistance, hardness, and strength appreciably, but embrittles the board and makes it less shock resistant.

A third hardboard, service quality, has become important. This is a product of lower density than standard, usually 50 to 55 p.c.f., made to satisfy needs where the higher strength of standard quality is not required. Because of its lower density, service-quality hardboard has better dimensional stability than the denser products.

When service hardboard is given the tempering treatment it is classed as tempered service, and property limits have been set for specifications. It is used where water resistance is required but the higher strength of regular treatment is not. Underlayment is service-quality hardboard, nominally $\frac{1}{4}$ inch thick, that is sanded or planed on the back surface to provide a thickness of 0.215 ± 0.005 inch.

These are the regular qualities of high-density hardboard; because a substantial amount of this hardboard is manufactured for industrial use, special qualities are made with different properties dictated by the specific use. For example, hardboard manufactured for concrete forms is frequently given a double tempering treatment. For some uses where high impact resistance is required, like backs of television cabinets, boards are formulated from specially prepared fiber and additives. Where special machining properties like die punching or post-forming requirements must be satisfied, the methods of manufacturing and additives used are modified to produce the desired properties.

High-density and medium-density conventional hardboard are manufactured in several ways and the result is reflected in the appearance of the final product. Hardboard is described as being screen-backed or S-2-S (smooth two sides). When the mat from which the board is made is formed from a water slurry (wet-felted) and the wet mat is hot-pressed, a screen is required to permit steam to escape. In the final board the reverse impression of the screen is apparent on the back of the board, hence the screen-back designation. A screen is similarly required with mats formed from an air suspension (air-felted) when moisture contents are sufficiently high going into the hot press so that venting is required.

In some variations of hardboard manufacture, a wet-felted mat is dried before being hot-pressed. With this variation it is possible to hot-press without using the screen, and an S–2–S board is produced. In air-felting hardboard manufacture, it is possible also to press without the screen, if moisture content of mats entering the hot press is low. In a new adaptation of pressing hardboard mats, a caul with slots or small circular holes is used to vent steam; the board produced has a series of small ridges or circular nubbins which, when planed or sanded off, yield an S–2–S board.

Medium-density hardboard produced by the newer process using radio-frequency curing is produced from relatively dry fiber-resin blends. The mats are pressed between heated platens where the high-frequency heat provides additional heat energy to cure the resin binder (usually urea-formaldehyde as compared to phenolics when used with the more conventional hardboards). This kind of hardboard is S–2–S.

Commercial thicknesses of high-density hardboard generally range from ½ to ⅜ inch. Not all thicknesses are produced in all grades. The thicknesses of $1/10$ and $1/12$ inch are regularly produced only in the standard grade. Tempered hardboards are produced regularly in thicknesses between ⅛ and $5/16$ inch. Service and tempered service are regularly produced in fewer thicknesses, none less than ⅛ inch and not by all manufacturers or in screen-back and S–2–S types. The appropriate standard specification or source of material should be consulted for specific thicknesses of each kind.

High-density hardboards are produced in 4- and 5-foot widths with the more common width being 4 feet. Standard commercial lengths are 4, 6, 8, 12, and 16 feet with an 18-foot length being available in the 4-foot width. Most manufacturers maintain cut-to-size departments for special orders. Retail lumberyards and warehouses commonly stock 8-foot lengths, except for underlayment, which is usually 4 feet square.

About 15 percent of the hardboard used in the United States is imported. Foreign-made board may or may not be manufactured to the same standards as domestically produced products. Before substituting a foreign-made product in a use where specific properties are required, it should be determined that it has properties required for the use. Canadian products are usually produced to the same standards as United States products.

In addition to the standard smooth-surface hardboards, special products are made using patterned cauls so the surface is striated or produced with a relief to simulate ceramic tile, leather, basket weave, etched wood, or other texture. Hardboards are punched to provide holes for anchoring fittings for shelves and fixtures (perforated board) or with holes comprising 15 percent or more of the area for installation in ceilings with sound-absorbent material behind it for acoustical treatments or as air diffusers above plenums. Cutout designs are fabricated in hardboard to produce "filigree" effects when the hardboard is used in screens.

More and more effort is being put forth by industry to modify and finish hardboard so it can be used in more ways with less "on-the-job" cost of installation and finishing and to permit industrial users a saving in final product. Most important is prefinishing, particularly wood graining, where the surface of the board is finished with lithographic patterns of popular cabinet woods printed in two or more colors.

The uses for hardboard are diverse. It has been claimed that "hardboard is the grainless wood of 1,000 uses, and can be used wherever a dense, hard panel material in the thicknesses as manufactured will satisfy a need better or more economically than any other material." Because of its density it is harder than most natural wood, and because of its grainless character it has nearly equal properties in all directions in the plane of the board. It is not so stiff nor as strong as natural wood along the grain, but is substantially stronger and stiffer than wood across the grain. Specific properties in table 21–1 can be compared with similar properties for wood, wood-base, and other materials. Hardboard retains some of the properties of wood; it is hygroscopic and shrinks and swells with changes in moisture content.

Changes in moisture content due to service exposures may be a limiting factor in satisfactory performance. Correct application and attachment as well as prior conditioning to a proper moisture content may permit satisfactory service when improper application or conditioning precludes it. Proper moisture conditioning prior to assembly is of particular importance in glued assemblies.

Product development in hardboard has held generally to the line of class and type of board product, in contrast with structural insulating board which deals with specific items for particular uses. During the past few years much of the success of hardboard resulted because the industry developed certain products for a specific use and had treatments, fabrication, and finishes required by the use. Typical are prefinished paneling, house siding, underlayment, and concrete form hardboard.

Many uses for hardboard have been listed but generally they can be subdivided according to uses developed for construction, furniture and furnishings, cabinet and store fixture work, appliances, and automotive and rolling stock.

In construction, hardboard is used as floor underlayment to provide a smooth undercourse under plastic or linoleum flooring, as a facing for concrete forms for architectural concrete, facings for flush doors, as insert panels and facings for garage doors, and material punched with holes for wall linings in storage walls and in built-ins where ventilation is desired. Prefinished hardboard, either with baked finishes or the regular ones like those used generally in wood-grain printing, is used for wall lining in kitchens, bathrooms, family rooms, and recreation rooms.

In furniture, furnishings, and cabinetwork, conventional hardboard is used extensively for drawer bottoms, dust dividers, case goods and mirror backs, insert panels, television, radio, and stereo cabinet sides, backs (die-cut openings for ventilation), and as crossbands and balancing sheets in laminated or overlay panels. Hardboard also has use as a core material for relatively thin panels overlaid with films and thin veneers, and as backup material for metal panels. In appliances other than television, radio, and stereo cabinets, it is used wherever the properties of the dense, hard sheet satisfy a need economically. Because it can be post-formed to single curvature (and in some instances to mild double curvature) by the application of heat and moisture, it is used in components of appliances requiring that kind of forming.

In automobiles, trucks, buses, and railway cars, hardboard is commonly used in interior linings. Door and interior sidewall panels of automobiles are frequently hardboard, post-formed, and covered with cloth or plastic. The base for sun visors is often hardboard, as are the platforms between seats and rear windows. Molded hardboard also has been used for three-dimensional-shaped components like door panels and armrests. Ceilings of station wagons and truck cabs are often enameled or vinyl-covered thin hardboard.

Medium-density hardboard corestock about 3/4 inch thick is used with veneer or other overlays in the same way as particleboard, but it may not be necessary to edge band because of the smooth edge. Places in furniture and cabinets where it finds most use are in tops, doors, drawer fronts, and shelves.

Special Densified Hardboard

This special building fiberboard product is manufactured mainly as diestock and electrical panel material. It has a density of 85 to 90 p.c.f. and is produced in thicknesses between 1/8 and 2 inches in panel sizes of 3 by 4, 4 by 6, and 4 by 12 feet.

Special densified hardboard is machined easily with machine tools and its low weight as compared with metals (aluminum alloys about 170 p.c.f.) makes it a useful material for templates and jigs for manufacturing. It is relatively stable dimensionally from moisture change because of low rates of moisture absorption. It is more stable for changes in temperature than the metals generally used for those purposes. The 1/8-inch-thick board is specially manufactured for use as lofting board.

As diestock, it finds use for stretch- and press-forming and spinning of metal parts, particularly when few of the manufactured items are required and where the cost of making the die itself is important in the choice of material.

The electrical properties of the special densified hardboard meet many of the requirements set forth by the National Electrical Manufacturers Association for insulation resistance and dielectric capacity in electrical components so it is used extensively in electronic and communication equipment.

Other uses where its combination of hardness, abrasion resistance, machinability, stability, and other properties are important include cams, gears, wear plates, laboratory work surfaces, and welding fixtures.

Laminated Paperboards

Laminated paperboards are made in two general qualities, an interior and a weather-resistant quality. The main differences be-

Table 21–2.—*Strength and mechanical properties of laminated paperboard* [1]

Property	Value	Unit
Density	32–33	P.c.f.
Specific gravity	0.52–0.53	----
Modulus of elasticity (compression):		
Along the length of the panel [2]	300–390	1,000 p.s.i.
Across the length of the panel [2]	100–140	Do.
Modulus of rupture:		
Span parallel to length of panel [2]	1,400–1,900	P.s.i.
Span perpendicular to length of panel [2]	900–1,100	Do.
Tensile strength parallel to surface:		
Along the length of the panel [2]	1,700–2,100	Do.
Across the length of the panel [2]	600–800	Do.
Compressive strength parallel to surface:		
Along the length of the panel [2]	700–900	Do.
Across the length of the panel [2]	500–800	Do.
24-hour water absorption	10–170	Pct. by weight
Linear expansion from 50 to 90 percent relative humidity: [3]		
Along the length of the panel [2]	0.2–0.3	Pct.
Across the length of the panel [2]	1.1–1.3	Do.
Thermal conductivity at mean temperature of 75° F.	0.51	Btu in./h · ft^2 · deg F

[1] The data presented are general round-figure values, accumulated from numerous sources; for more exact figures on a specific product, individual manufacturers should be consulted or actual tests made. Values are for general laboratory conditions of temperature and humidity.

[2] Because of directional properties, values are presented for two principal directions, along the usual length of the panel (machine direction) and across it.

[3] Measurements made on material at equilibrium at each condition at room temperature.

tween the two qualities are in the kind of bond used to laminate the layers together and in the amount of sizing used in the pulp stock from which the individual layers are made. For interior-quality boards, the laminating adhesives are commonly of starch origin while for the weather-resistant board synthetic resin adhesives are used. Laminated paperboard is regularly manufactured in thicknesses of 3/16, 1/4, and 3/8 inch for construction uses although for such industrial uses as dust dividers in case goods, furniture, and automotives liners, 1/8-inch thickness is common. Important properties are presented in table 21–2.

For building use, considerable amounts go into the prefabricated housing and mobile home construction industry as interior wall and ceiling finish. In the more conventional building construction market, interior-quality boards are also used for wall and ceiling finish, often in remodeling to cover cracked plaster.

Water-resistant grades are manufactured for use as sheathing, soffit linings, and other "exterior protected" applications like porch and carport ceilings. Soffit linings and lap siding are specially fabricated in widths commonly used and are prime coated with paint at the factory.

The common width of laminated paperboard is 4 feet, although 8-foot widths are available in 12-, 14-, 16-foot, and longer lengths for such building applications as sheathing entire walls. Laminated paperboards for use where a surface is exposed have the surface ply coated with a high-quality pulp to improve surface appearance and performance. Surface finish may be smooth or textured.

Particleboard

Important properties for mat-formed particleboards are presented in table 21–3. Similar values are not presented for extruded particleboards since they are never used without facings of some kind glued to them, and the facings influence the physical and strength properties. Extruded particleboards have a distinct zone of weakness across the length of the panel as extruded. They also have a strong tendency to swell in the lengthwise (extruded) direction because of the compression and orientation of particles from the extrusion pressures (ram or screw that forces the particle mass through the extruder). Consequently, extruded particleboards are always used as corestock; mat-formed boards are used both as corestock and as panel stock where the only thing added to the surface is finish.

From the selling standpoint, mat-formed particleboards are classified as to class and type, as are hardboards. For certain uses where special requirements must be satisfied, additional specifications outline the requirements for the particleboard. Particleboard is manufactured in both 4- and 5-foot widths and wider, although for industrial sales much is cut to size for the purchaser. In construction, the common size panel is 4 by 8 feet, as for other panel materials.

The uses for particleboard are still developing, but the main ones parallel those for lumber core in veneered or overlaid construction and plywood. The two properties of particleboard that have the greatest positive influence on its selection for a use are (1) uniform surface and (2) that the panel stays flat as manufactured, particularly in applications where edges are not fastened to a rigid framework.

For the majority of uses where exposures are interior or equivalent (furniture, cabinetwork, interior doors, and most floor underlayment), urea-formaldehyde resins are used. Boards with that kind of bond are classed as type 1 in specifications. Where greater resistance to heat, moisture, or a combination of heat and moisture is required, type 2 boards generally bonded with phenolic resin are required.

In general, particleboards are manufactured in about the same thicknesses as softwood plywood; most manufacture is in thicknesses between ½ and 1 inch, although there are notable use developments for particleboard thinner than ½ inch and thicker than 1 inch. Much extruded particleboard is of the "fluted" kind in thicknesses that satisfy the need for cores for flush doors. Similarly low-density, mat-formed particleboard is manufactured for solid core doors in thicknesses so that, when facings are applied, final door thicknesses are the standard 1⅜ and 1¾ inches.

While particleboard manufacturers formerly concentrated production in thick boards, there has been a decided trend toward thinner products. Thicknesses of ¼ and ⅜ inch are becoming more common, both for special and general use in the United States. In other countries where alternate thin materials are not available, thicknesses of less than ⅛ inch are produced.

The two uses for particleboard that are major in terms of volume are furniture and cabinet core and floor underlayment (fig. 21–3). As corestock, particleboard has moved into a market formerly held by lumber core and, to a limited extent, plywood. For example, certain grades of hardwood plywood now permit the use of particleboard as the core ply where formerly lumber core was specified.

Table 21–3.—*Strength and mechanical properties of mat-formed (platen-pressed) wood particleboard* [1]

Property	Value for low-density particleboard	Value for medium-density particleboard	Value for high-density particleboard	Unit
Density	[2] 25–37	37–50	50–70	P.c.f.
Specific gravity	[2] 0.40–0.59	0.59–0.80	0.80–1.12	
Modulus of elasticity (bending)	[3] 150–250	250–700	350–1,000	1,000 p.s.i.
Modulus of rupture	[3] 800–1,400	1,600–5,000	2,400–7,500	P.s.i.
Tensile strength parallel to surface		500–4,000	1,000–5,000	Do.
Tensile strength perpendicular to surface	[3] 20–30	40–200	125–450	Do.
Compression strength parallel to surface		1,400–3,000	3,500–5,200	Do.
Shear strength (in the plane of board)		100–450	200–800	Do.
Shear strength (across the plane of the board)		200–1,800		Do.
24-hour water absorption		10–50	15–40	Pct. by weight
Thickness swelling from 24-hour soaking		5–50	15–40	Pct.
Linear expansion [4] from 50 to 90 percent relative humidity	[5] 0.30	0.2–0.6	0.2–0.85	Do.
Thermal conductivity at a mean temperature of 75° F.	0.55–0.75	0.75–1.00	1.00–1.25	Btu · in./h · ft² · deg F

[1] The data presented are general round-figure values; accumulated from numerous sources; for more exact figures on a specific product, individual manufacturers should be consulted or actual tests made. Values are for general laboratory conditions of temperature and humidity.

[2] Lower limit is for boards as generally manufactured; lower density products with lower properties may be made.

[3] Only limited production of low-density particleboard so values presented are specification limits.

[4] Measurements made on material at equilibrium at each condition at room temperature.

[5] Maximum permitted by specification.

In built-up constructions where particleboard is used as the core, both three and five plies are employed. Extruded particleboard nearly always requires five-ply construction because of the board's instability and low strength in the one direction. A relatively thick crossband with the grain direction parallel to the extruded direction stiffens, strengthens, and stabilizes the core. Thinner face plies are laid with the grain at right angles to the crossband to provide the final finish.

With mat-formed particleboard corestock, the use of three- or five-ply construction depends on the class and type of particleboard core (stiffness and strength), kind of facings being applied (plastic or veneer), and the requirements of the final construction. Balanced construction in lay-ups using particleboard is important; otherwise facings or crossbands with different properties can cause objectionable warping, cupping, or twisting in service. Edge bonding of wood or the facing material is frequently employed in panelized units using particleboard as corestock.

As floor underlayment, particleboard provides (1) the leveling, (2) the thickness of construction required to bring the final floor to elevation, and (3) the indentation-resistant smooth surface necessary as the base for resilient finish floors of linoleum, rubber, vinyl, and vinyl asbestos tile and sheet material. Particleboard for this use is produced in 4- by 8-foot panels commonly $\frac{1}{4}$, $\frac{3}{8}$, or $\frac{5}{8}$ inch thick. Separate use specifications cover particleboard floor underlayment. In addition, all manufacturers of particleboard floor underlayment provide individual application instructions and guarantees because of the importance of proper application and the interaction effects of joists, subfloor, underlayment, adhesives, and finish flooring. Particleboard underlayment is sold under a certified quality program where established grade marks clearly identify the use, quality, grade, and originating mill.

Other uses for particleboard have special requirements, as for phenol-formaldehyde, a more durable adhesive, in the board. Particleboard for siding, combined siding-sheathing, and use as soffit linings and ceilings for carports, porches, and the like requires this more durable adhesive. For these uses, type 2 medium-density board is required. In addition, such agencies as Federal Housing Administration have established requirements for particleboard for such use. The satisfactory performance of particleboard in exterior exposure depends not only on the manufacture and kind of adhesive used, but on the protection afforded by finish. Manufacturers recognize the importance by providing both paint-primed panels and those completely finished with liquid paint systems or factory-applied plastic films.

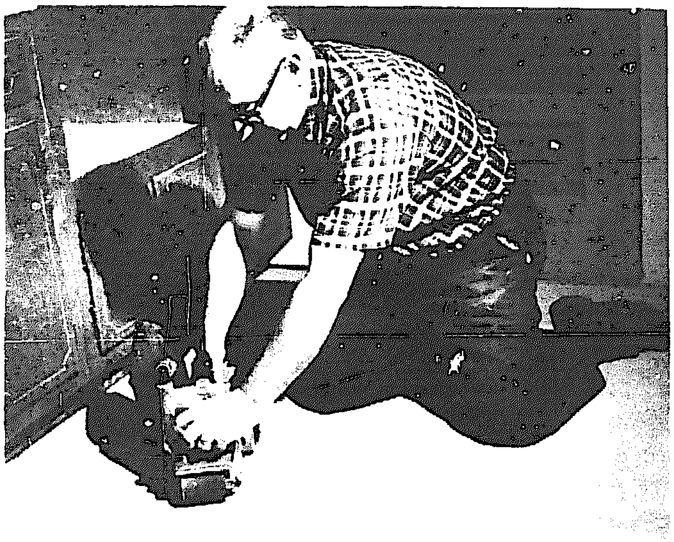

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Figure 21–3.—Joints in particleboard floor underlayment are filled and sanded smooth before application of resilient finish floor.

Mobile home manufacture and factory-building of conventional housing are increasing. These industries are important and increasing users of forest products. Since particleboard is actually manufactured in hot presses as large as 8 by 40 feet, larger sized panels are available than those generally used for conventional construction. With mechanical handling available in factories, large-sized panels can be attached effectively and economically. Two particleboard products have been developed to satisfy these uses. Mobile home decking is used for combined subfloor and underlayment. It is a board with a type 1 bond, but is protected from moisture in use by a "bottom board," so is generally regarded as giving satisfactory service for the limited life of a mobile home. Particleboard decking for factory-built housing is similar to mobile home decking but it has a type 2 bond because of the greater durability requirements for regular housing. The United States industry has established separate standards for these products. They are marketed under a certified product quality program with each product adequately identified.

Another use that commonly requires the more durable bond of a type 2 quality is a special corestock where laminated plastic sheets are formed on the face and back of a particleboard at the same time as they are bonded to it. Usually a high-density particleboard is used for that purpose. The temperatures used in curing the resin-impregnated plastic sheets may reduce the strength of the bonds in boards made with the urea-formaldehyde resins.

A special particleboard is fabricated for finish flooring. Here a board with a void-free, tight surface is required to prevent dirt buildup in service. To simulate service conditions of such flooring, special test procedures have been developed. Specifications with limiting values based on those procedures have been established for finish flooring of particleboard.

The properties of particleboard depend on the shape and quality of particle used, as well as the kinds and amount of resin binder. While most particleboard is produced using particles that yield a board of intermediate strength and stiffness, a substantial production uses flakes or other "engineered" particles for a board of higher strength and stiffness. In the specifications, the boards of intermediate stiffness and bending strength are called the class 1 and those of the higher stiffness and bending strength are called class 2. Class 2 particleboards are naturally more expensive than those in class 1, but they are usually justified for uses where the greater stiffness and strength are required. The same applies to those applications where a special surface like "fines surfaced" will provide either a better base for finishing or less "showthrough" of an overlaid construction.

Particleboard in molded, three-dimensional shapes is being found in commerce. At present, relatively high die costs and limited flow of the particle-resin blend during molding restrict the kinds of items that can be molded profitably. Such items as bowls, trays, and counter sections with limited relief are presently being molded from conventional size particles. Toilet seats, croquet balls, hamper tops, and similar high-density items are being compression-molded from small particles approaching wood flour in size and synthetic resin.

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Chapter 22

MODIFIED WOODS AND PAPER-BASE LAMINATES

MODIFIED WOODS AND PAPER-BASE PLASTIC LAMINATES

Materials with properties substantially different than the base material are obtained by chemically treating a wood or wood-base material, compressing it under specially controlled conditions, or by combining the processes of chemical treatment and compression. Sheets of paper treated with chemicals (plastics) are laminated and hot-pressed into thicker panels that have the appearance of plastic rather than paper, and they are used in special applications because of their structural properties and on items requiring hard, impervious, and decorative surfaces.

Modified woods, modified wood-base materials, and paper-base laminates are normally more expensive than wood because of the cost of the chemicals and the special processing required to produce them. Thus, their use is generally limited to special applications where the increased cost is justified by the special properties needed. Volume manufacture of the paper-base plastic laminates has made them the most commonly used surfacing for kitchen and bathroom countertops and similar applications.

MODIFIED WOODS

Wood is treated with chemicals to increase its decay, fire, and moisture resistance. Application of water-resistant chemicals to the surface of wood, or impregnation of the wood with such chemicals dissolved in volatile solvents, reduces the rate of swelling and shrinking of the wood when in contact with water. Such treatments may also reduce the rate at which wood changes dimension because of humidity changes, even though they do not affect the final dimension changes caused by long-duration exposures. Paints, varnishes, lacquers, wood-penetrating water repellents, and plastic and metallic films retard the rate of moisture absorption, but have little effect on total dimension change if exposures are long enough.

Resin-Treated Wood (Impreg)

Permanent stabilization of the dimensions of wood is needed for certain specialty uses. This can be accomplished by depositing a bulking agent within the swollen structure of the wood fibers. The most successful bulking agents that have been commercially applied are highly water-soluble, thermosetting, phenol-formaldehyde resin-forming systems, with initially low molecular weights. No thermoplastic resins have been found that effectively stabilize the dimensions of wood.

Wood treated with a thermosetting fiber-penetrating resin and cured without compressing is known as impreg. The wood (preferably green veneer to facilitate resin pickup) is soaked in the aqeuous resin solution or, if air-dry, is impregnated with the solution under pressure until the resin content equals 25 to 35 percent of the weight of dry wood. The treated wood is allowed to stand under nondrying conditions for a day or two to permit uniform distribution of the solution throughout the wood. The resin-containing wood is dried at moderate temperatures to remove the water and then heated to higher temperatures to set the resin.

Uniform distribution of the resin has been effectively accomplished with solid wood[1] only in sapwood of readily penetrated species in lengths up to 6 feet. Drying resin-treated solid wood may result in checking and honeycombing. For these reasons, treatments should be confined to veneer and the treated and cured veneer be used to build up the desired products. Any species can be used for the veneer except the resinous pines. The stronger the original wood, the stronger will be the product.

Impreg has a number of properties differing from those of normal wood and ordinary plywood. These are given in table 22–1, together with similar generalized findings for other modified woods. Table 22–2 gives data for the strength properties of birch impreg. Table 22–3 presents information on thermal expansion properties of "bone-dry" impreg.

Dimensional stability as a basic property of impreg has been the basis of one use where its cost was no deterrent to its acceptability. Wood dies of all parts of automobile bodies serve as the master from which the metal forming dies for actual manufacture of parts are made. Small changes in moisture content, even with the most dimensionally stable wood, produce

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[1] Veneers with thickness up to ⅓ inch have been successfully treated, although treating times increases rapidly with increases in thickness. Boards of greater thickness and lengths of more than a few inches are classified here as "solid" wood.

changes in dimension and curvature of an unmodified wood die; such changes create major problems in making the metal forming dies where close final tolerances are required. The substitution of impreg, with its high antishrink efficiency, almost entirely eliminated the problem of dimensional change during the entire period that the wood master dies were needed. Despite the tendency of the resins to dull cutting tools, patternmakers accepted the impreg readily because it machined more easily than the unmodified wood.

Patterns made from impreg also were superior to unmodified wood in resisting heat when used with shell molding techniques where temperatures as high as 400° F. were required to cure the resin in the molding sand.

Resin-Treated Compressed Wood (Compreg)

Compreg is similar to impreg except that it is compressed before the resin is cured within the wood. The resin-forming chemicals (usually phenol-formaldehyde) act as plasticizers for the wood so that it can be compressed under modest pressures (1,000 p.s.i.) to a specific gravity of 1.35. Some of its properties are similar to those of impreg, and others vary considerably (tables 22–1 and 22–2). Its advantages over impreg are its natural lustrous finish that can be developed on any cut surface by sanding with fine-grit paper and buffing, its greater strength properties, and the fact that it can be molded (tables 22–1 and 22–2). Thermal expansion coefficients of bone-dry compreg are increased also (table 22–3).

Compreg can be molded by: (1) Gluing blocks of resin-treated (but still uncured) wood with a phenolic glue so that the gluelines and resin within the plies are only partially set; (2) cutting to the desired length and width but two to three times the desired thickness; and (3) compressing in a split mold at about 300° F. Only a small flash squeezeout at the parting line between the two halves of the mold need be machined off. This technique was used for molding motor-test "club" propellers and airplane antenna masts during World War II.

A more generally satisfactory molding technique, known as expansion molding, has been developed. The method consists of rapidly precompressing dry but uncured single sheets of resin-treated veneer in a cold press after preheating them to 200° to 240° F. The heat-plasticized wood responds to compression before cooling. The heat is insufficient to cure the resin, but the subsequent cooling sets the resin temporarily. These compressed sheets are cut to the desired size, and the assembly of plies is placed in a split mold of the final desired dimensions. Because the wood was precompressed, the filled mold can be closed and locked. When the mold is heated, the wood is again plasticized and tends to recover its uncompressed dimensions. This exerts an internal pressure in all directions against the mold equal to about half of the original compressing pressure. On continued heating, the resin is set. After cooling, the object may be removed from the mold in finished form. Metal inserts or metal surfaces can be molded to compreg or compreg handles molded onto tools by this means. Compreg bands have been molded to the outside of turned wood cylinders without compressing the core. Compreg tubes and small airplane propellers have been molded in this way.

Past uses for compreg once related largely to aircraft—such items as adjustable pitch propellers for training airplanes, antenna masts, and spar and connector plates. Compreg is a suitable material where bolt-bearing strength is required, as in connector plates, because of its good specific strength (strength per unit of weight). Layers of veneer making up the compreg for such uses are often cross-laminated (alternate plies at right angles to each other, as in plywood) to give nearly equal properties in all directions.

Compreg is useful also as supporting blocks for refrigerators, where the combination of load-bearing strength and relatively low thermal conductivity is advantageous. Compreg is extremely useful for aluminum drawing and forming dies, drilling jigs, and jigs for holding parts in place while welding, because of its excellent strength properties, dimensional stability, low thermal conductivity, and ease of fabrication.

Compreg also can be used in silent gears, pulleys, water-lubricated bearings, fan blades, shuttles, bobbins and picker sticks for looms, instrument bases and cases, clarinets, electrical insulators, tool handles, and various novelties. Compreg at present finds considerable use in handles for knives and other cutlery. Both the expansion molding techniques of forming and curing the compreg around the metal parts of the handle and attaching previously made compreg with rivets are used.

Experimental designs with compreg for bowling alley approaches have proved satisfactory. In this instance, the surface sliding

Table 22–1.—*Properties of modified woods*

Property	Impreg	Compreg	Staypak
Specific gravity	15 to 20 percent greater than normal wood.	Usually 1.0 to 1.4	1.25 to 1.40.
Equilibrium swelling and shrinking.	¼ to ⅓ that of normal wood	¼ to ⅓ that of normal wood at right angles to direction of compression, greater in direction of compression but very slow to attain.	Same as normal wood at right angles to compression, greater in direction of compression but very slow to attain.
Springback	None	Very small when properly made	Moderate when properly made.
Face checking	Practically eliminated	Practically eliminated for specific gravities below 1.3.	About the same as in normal wood.
Grain raising	Greatly reduced	Greatly reduced for uniform-texture woods, considerable for contrasting-grain woods.	About the same as in normal wood.
Surface finish	Similar to normal wood	Varnished-like appearance for specific gravities above about 1.0. Cut surfaces can be given this surface by sanding and buffing.	Varnished-like appearance. Cut surfaces can be given this surface by sanding and buffing.
Permeability to water vapor.	About 1/10 that of normal wood	No data, but much lower than impreg	No data but presumably lower than impreg.
Decay and termite resisttance.	Considerably better than normal wood	Considerably better than normal wood	Normal, but decay occurs somewhat more slowly.
Acid resistance	Considerably better than normal wood	Better than impreg because of impermeability.	Better than normal wood because of impermeability but not as good as compreg.
Alkali resistance	Same as normal wood	Somewhat better than normal wood because of impermeability.	Somewhat better than normal wood because of impermeability.
Fire resistance	Same as normal wood	Same as normal wood for long exposure, somewhat better for short exposure.	Same as normal wood for long exposures, somewhat better for short exposures.
Heat resistance	Greatly increased	Greatly increased	No data.
Electrical conductivity	1/10 that of normal wood at 30 percent relative humidity; 1/1000 that of normal wood at 90 percent relative humidity.	Slightly more than impreg at low relative humidity values due to entrapped water.	No data.

Table 22-1.—*Properties of modified woods*—Continued

Property	Impreg	Compreg	Staypak
Heat conductivity	Slightly increased	Increased about in proportion to specific gravity increase.	No data, but should increase about in proportion to specific gravity increase.
Compressive strength	Increased more than proportional to specific gravity increase.	Increased considerably more than proportional to specific gravity increase.	Increased about in proportion to specific gravity increase parallel to grain, increased more perpendicular to grain.
Tensile strength	Decreased significantly	Increased less than proportional to specific gravity increase.	Increased about in proportion to specific gravity increase.
Flexural strength	Increased less than proportional to specific gravity increase.	Increased less than proportional to specific gravity increase parallel to grain, increased more perpendicular to grain.	Increased proportional to specific gravity increase parallel to grain, increased more perpendicular to grain.
Hardness	Increased considerably more than proportional to specific gravity increase.	10 to 20 times that of normal wood	10 to 18 times that of normal wood.
Impact strength:			
Toughness	About ½ of value for normal wood but very susceptible to the variables of manufacture.	½ to ¾ of value for normal wood but very susceptible to the variables of manufacture.	Same to somewhat greater than normal wood.
Izod	About ⅕ of value for normal wood	⅓ to ¾ of value for normal wood	Same to somewhat greater than normal wood.
Abrasion resistance (tangential).	About ½ of value for normal wood	Increased about in proportion to specific gravity increase.	Increased about in proportion to specific gravity increase.
Machinability	Cuts cleaner than normal wood, but dulls tools more.	Requires metalworking tools and metalworking-tool speeds.	Requires metalworking tools and metalworking-tool speeds.
Moldability	Cannot be molded, but can be formed to single curvatures at time of assembly.	Can be molded by compression and expansion molding methods.	Cannot be molded.
Gluability	Same as normal wood	Same as normal wood after light sanding, or, in the case of thick stock, machining surfaces plane.	Same as normal wood after light sanding, or, in the case of thick stock, machining surfaces plane.

Table 22-2.—*Strength properties of normal and modified laminates*[1] *of yellow birch and a laminated paper plastic*

Property	Normal[2] laminated wood	Impreg[3] (impregnated, uncompressed)	Compreg[3] (impregnated, highly compressed)	Staypak[2] (unimpregnated, highly compressed)	Papreg[4] (impregnated, highly compressed)
Thickness (t) of laminate ... in.	0.94	1.03	0.63	0.48	0.126 0.512
Moisture content at time of test ... pct.	9.2	5.0	5.0	4.0	----
Specific gravity (based on weight and volume at test)	0.7	0.8	1.3	1.4	1.4
PARALLEL LAMINATES					
Flexure—grain parallel to span (flatwise):[5]					
Proportional limit stress ... p.s.i.	11,500	15,900	26,700	20,100	15,900
Modulus of rupture ... p.s.i.	20,400	18,800	36,300	39,400	36,600
Modulus of elasticity ... 1,000 p.s.i.	2,320	2,380	3,690	4,450	3,010
Flexure—grain perpendicular to span (flatwise):[5]					
Proportional limit stress ... p.s.i.	1,000	1,300	4,200	3,200	10,500
Modulus of rupture ... p.s.i.	1,900	1,700	4,600	5,000	24,300
Modulus of elasticity ... 1,000 p.s.i.	153	220	626	602	1,480
Compression parallel to grain (edgewise):[6]					
Proportional limit stress ... p.s.i.	6,400	10,200	16,400	9,700	7,200
Ultimate strength ... p.s.i.	9,500	15,400	26,100	19,100	20,900
Modulus of elasticity ... 1,000 p.s.i.	2,300	2,470	3,790	4,670	3,120
Compression perpendicular to grain (edgewise):[6]					
Proportional limit stress ... p.s.i.	670	1,000	4,800	2,600	4,200
Ultimate strength ... p.s.i.	2,100	3,600	14,000	9,400	18,200
Modulus of elasticity ... 1,000 p.si.	162	243	571	583	1,600
Compression perpendicular to grain (flatwise)[5] maximum crushing strength ... p.s.i.	----	4,280	16,700	13,200	42,200
Tension parallel to grain (lengthwise):					
Ultimate strength ... p.s.i.	22,200	15,800	37,000	45,000	35,600
Modulus of elasticity ... 1,000 p.s.i.	2,300	2,510	3,950	4,610	3,640
Tension perpendicular to grain (crosswise):					
Ultimate strength ... p.s.i.	1,400	1,400	3,200	3,300	20,000
Modulus of elasticity ... 1,000 p.s.i.	166	227	622	575	1,710
Shear strength parallel to grain (edgewise):[6]					
Johnson, double shear across laminations ... p.s.i.	2,980	3,460	7,370	6,370	17,800
Cylindrical, double shear parallel to laminates ... p.s.i.	3,030	3,560	5,690	3,080	3,000
Shear modulus:					
Torsion method ... 1,000 p.s.i.	182	255	454	----	----
Plate shear method (FPL test) ... 1,000 p.s.i.	----	----	----	385	909
Toughness (FPL test, edgewise)[6] ... in.-lb.	235	125	145	250	----
Do ... in.-lb. per in. of width	250	120	230	515	----
Impact strength (Izod)—grain lengthwise:					
Flatwise (notch in face) ... ft.-lb. per in. of notch	14.0	2.3	4.3	12.7	4.7
Edgewise (notch in face) ... ft.-lb. per in. of notch	11.3	1.9	[7] 3.2	...	0.67
Hardness (Rockwell, flatwise)[5] ... M-numbers	----	—22	84	...	110
Load to imbed 0.444-inch steel ball to ½ its diameter ... lb.	1,600	2,400	----	----	----
Hardness modulus (H_M)[8] ... p.s.i.	5,400	9,200	41,300	48,800	35,600
Abrasion-Navy wear-test machine (flatwise),[5] wear per 1,000 revolutions ... in.	0.030	0.057	0.018	0.015	0.018
Water absorption (24-hr. immersion), increase in weight ... pct.	43.6	13.7	2.7	4.3	2.2
Dimensional stability in thickness direction:					
Equilibrium swelling ... pct.	9.9	2.8	8.0	29	----
Recovery from compression ... pct.	----	0	0	4	----

Table 22-2.—*Strength properties of normal and modified laminates*[1] *of yellow birch and a laminated paper plastic*—(cont.)

Property	Normal[2] laminated wood	Impreg[3] (impregnated, uncompressed)	Compreg[3] (impregnated, highly compressed)	Staypak[2] (unimpregnated, highly compressed)	Papreg[4] (impregnated, highly compressed)
CROSSBAND LAMINATES					
Flexure—face grain parallel to span (flatwise):[5]					
Proportional limit stress ..... p.s.i.	6,900	8,100	14,400	11,400	12,600
Modulus of rupture ..... p.s.i.	13,100	11,400	22,800	25,100	31,300
Modulus of elasticity ..... 1,000 p.s.i.	1,310	1,670	2,480	2,900	2,240
Compression parallel to face grain (edgewise):[6]					
Proportional limit stress ..... p.s.i.	3,300	5,200	8,700	5,200	5,000
Ultimate strength ..... p.s.i.	5,800	11,400	23,900	14,000	18,900
Modulus of elasticity ..... 1,000 p.s.i	1,360	1,500	2,300	2,700	2,370
Tension parallel to face grain (lengthwise):					
Ultimate strength ..... p.s.i.	12,300	7,900	16,500	24,500	27,200
Modulus of elasticity ..... 1,000 p.s.i.	1,290	1,460	2,190	2,570	2,700
Toughness (FPL test edgewise)[6] ..... in.-lb. per in. of width	105	40	115	320	-----

[1] Laminates made from 17 plies of 1/16-in. rotary-cut yellow birch veneer.

[2] Veneer conditioned at 80° F. and 65 pct. relative humidity before assembly with phenol resin film glue.

[3] Impregnation, 25 to 30 pct. of water-soluble phenol-formaldehyde resin based on the dry weight of untreated veneer.

[4] High-strength paper (0.003-in. thickness) made from commercial unbleached black spruce pulp (Mitscherlich sulfite), phenol resin content 36.3 pct., based on weight of treated paper. Izod impact, abrasion, flatwise compression, and shear specimens, all on ½-in.-thick papreg.

[5] Load applied to the surface of the original material (parallel to laminating pressure direction).

[6] Load applied to the edge of the laminations (perpendicular to laminating pressure direction).

[7] Values as high as 10.0 ft.-lb per in. of notch have been reported for compreg made with alcohol-soluble resins and 7.0 ft.-lb. with water-soluble resins.

[8] Values based on the average slope of load-penetration plots, where H_M is an expression for load per unit of spherical area of penetration of the 0.444-in. steel ball expressed in pounds per square inch:

$$H_M = \frac{P}{2\pi rh} \text{ or } 0.717\frac{P}{h}.$$

Table 22–3.—*Coefficients of linear thermal expansion per degree Celsius of wood, hydrolyzed wood, and paper products* [1]

Material [2]	Specific gravity of product	Glue plus resin content [3]	Linear expansion per °C. by 10^6			Cubical expansion per °C. by 10^6
			Fiber or machine direction	Perpendicular to fiber or machine direction in plane of laminations	Pressing direction	
		Pct.				
Yellow birch laminate	0.72	3.1	3.254	40.29	36.64	80.18
Yellow birch staypak laminate	1.30	4.7	3.406	37.88	65.34	106.63
Yellow birch impreg laminate	.86	33.2	4.648	35.11	37.05	76.81
Yellow birch compreg laminate	1.30	24.8	4.251	39.47	59.14	102.86
Do	1.31	34.3	4.931	39.32	54.83	99.08
Sitka spruce laminate	.53	[4] 6.0	3.837	37.14	27.67	68.65
Parallel-laminated papreg	1.40	36.5	5.73	15.14	65.10	85.97
Crossbanded papreg	1.40	36.5	10.89	[5] 11.00	62.20	84.09
Molded hydrolyzed-wood plastic	1.33	25	42.69	42.69	42.69	128.07
Hydrolyzed-wood sheet laminate	1.39	18	13.49	24.68	77.41	115.58

[1] These coefficients refer to bone-dry material. Generally, air-dry material has a negative thermal coefficient of expansion, because the shrinkage resulting from the loss in moisture is greater than the normal thermal expansion.

[2] All wood laminates made from rotary-cut veneer, annual rings in plane of sheet.

[3] On basis of dry weight of product.

[4] Approximate.

[5] Calculated value.

coefficient so necessary for proper delivery of a bowling ball remained more consistent than for conventional approaches, with practically no maintenance. It was found that surfaces could be maintained with only occasional renewing by light sanding. No top-dressing was required, and the surface was not sensitive to humidity changes. It was never "sticky." Other flooring uses show promise where low maintenance can offset higher initial cost as compared with more conventional flooring materials. Compreg can replace fabric-reinforced plastics in a number of uses because of its better strength properties and lower cost. It should be significantly less expensive because veneer costs less than fabric on a weight basis and about 50 percent less resin is used per unit weight of compreg than for fabric laminates.

Veneer of any nonresinous species can be used for making compreg. Most properties depend upon the specific gravity to which the wood is compressed rather than the species used. Up to the present, however, compreg has been made almost exclusively from yellow birch or sugar maple.

Untreated Compressed Wood (Staypak)

Resin-treated wood in both the uncompressed (impreg) and compressed (compreg) forms is more brittle than the original wood. To meet the demand for a tougher compressed product than compreg, a compressed wood containing no resin (staypak) was developed. It will not lose its compression under swelling conditions as will ordinary compressed untreated wood. In making staypak, the compressing conditions are modified so the lignin cementing material between the cellulose fibers flows sufficiently to eliminate internal stresses.

Staypak is not as water resistant as compreg, but it is about twice as tough and has higher tensile and flexural strength properties, as shown in tables 22–1 and 22–2. The natural finish of staypak is almost equal to that of compreg. Under weathering conditions, however, it is definitely inferior to compreg. For outdoor use a good synthetic resin varnish or paint finish should be applied to staypak.

Staypak can be used in the same way as compreg where extremely high water resistance is not needed. It shows promise for use in tool handles, forming dies, connector plates, propellors, and picker sticks and shuttles for weaving, where high impact strength is needed. As staypak is not impregnated, it can be made from solid wood as well as from veneer. It should cost less than compreg.

Staypak is not being manufactured at the present time. Several companies, however, are prepared to make it if the demand becomes appreciable. Two commercial applications (both patented) of the staypak principle are densification of the corners of desk legs (places subject to wear and slivering) and of ball-line areas of bowling pins where major impacts reduce service life.

Polyethylene-Glycol (PEG) Treated Wood

The dimensional stabilization of wood with polyethylene glycol-1000 (PEG) is accomplished by bulking the fibers to keep the wood in a partially swollen condition. PEG acts in the same manner as does the previously described phenolic resin. It cannot be further cured. The only reason for heating the wood after treatment is to drive off water. PEG remains water soluble. Above 60 percent relative humidity it is a strong humectant; and unless used with care and properly protected, PEG-treated wood can become sticky at these high relative humidities.

Treatment with PEG is facilitated by using green wood. Here pressure is without effect. Treating times are such that uniform uptakes of 25 to 30 percent of chemical are achieved (based on dry weight). The time necessary for this uptake depends on the thickness of the wood and may require weeks. This treatment is being effectively used for walnut gunstocks for high-quality rifles. The dimensional stability of such gunstocks greatly enhances the continued accuracy of the guns. Tabletops of high-quality furniture stay remarkably flat and dimensionally stable when made from PEG-treated wood.

Another application of this chemical is to reduce the checking of green wood during drying. For this application a high degree of polyethylene glycol penetration is not required. This method of treatment has been used to reduce checking during drying of small wood blanks or turnings.

Cracking and distortion that old, waterlogged wood undergoes when it is dried can be substantially reduced by treating the wood with polyethylene glycol. The process was used to dry 200-year-old waterlogged wood boats raised from Lake George, N.Y. The "Vasa," a Swedish ship that sunk on its initial trial voyage in 1628, has also been treated after it was raised.

Wood-Plastic Combination (WPC)

In the modified wood products previously discussed, most of the chemical resides in cell walls; the lumens are essentially empty. If wood is vacuum impregnated with certain liquid vinyl monomers that do not swell wood, and which are later polymerized by gamma radiation or catalyst heat systems, the resulting polymer resides almost exclusively in the lumens. Methyl methacrylate is a common monomer used for a wood-plastic combination. It is converted to polymethyl methacrylate. Such wood-plastic combinations (WPC) with resin contents of 75 to 100 percent (based on the dry weight of wood) resist moisture movement through them. Moisture movement is extremely slow so that normal equilibrium swelling is reached very slowly.

The main commercial use of this modified wood at present is as parquet flooring where it is produced in squares about 5½ inches on a side from strips about ⅞ inch wide and 5/16 inch thick. It has a specific gravity of 1.0. Comparative tests with conventional wood flooring indicate WPC material resisted indentation from rolling, concentrated, and impact loads better than white oak. This is largely attributed to improved hardness, which was increased 40 percent in regular wood-plastic combination and 20 percent in the same material treated with a fire retardant. Abrasion resistance was no better than white oak; but because the finish was built-in (buffing is all that is required for finishing), finish is easily maintained even under severe traffic conditions.

Wood-plastic combinations are also being used in sporting goods. One producer of archery equipment is using WPC in bows.

PAPER-BASE PLASTIC LAMINATES

Papreg

Commercially, papreg has become the most important of the resin-impregnated wood-base materials. In thicknesses of about 1/16 inch, quantities of papreg approaching ½ billion square feet are used as facings for doors, walls, and tops for counters, tables, desks, and other furniture. In other instances, thinner laminates are formed directly on a core material. Here resin-impregnated sheets of paper are hot-pressed, cured, and bonded to the core, which is usually of hardboard or particleboard. Because balanced construction is required if panels are to remain flat in service, a backing is formed at the same time.

Papreg is more generally known as decorative laminate or, technically, as laminated thermosetting decorative sheets. In the trade, it is often referred to by the brand name of the manufacturer. Such names as Consoweld, Formica, Micarta, Textolite, and Panelyte are typical. These decorative laminates are usually composed of a combination of phenolic- and melamine-impregnated sheets of paper. The phenolic-impregnated sheets are brown because of the impregnating resins and comprise most of the built-up thickness of the laminate. The phenolic sheets are overlaid with ones impregnated with melamine resin, which is water-white and transparent. One sheet of the overlay is usually a relatively thick one of high opacity and has the color or design printed on it. Then one or more tissue-thin sheets which become transparent after the resin is cured, are overlaid on the printed sheet to protect it in service.

Paper-base plastic laminates inherit their final properties from the paper from which they are made. High-strength papers yield higher strength plastics than do low-strength papers. Papers with definite directional properties result in plastics with definite directional properties unless they are cross-laminate (alternate sheets oriented with the machine direction at 90° to each other).

Strength and some other properties of commerical laminates show directional effects introduced from the paper. Tables 22–2 and 22–3 show the properties of parallel- and cross-laminated papreg manufactured for the structural aspect alone (not decorative) or for such purposes as electrical insulation, the oldest use.

Improving the paper used has helped develop paper-base laminates suitable for structural use. Pulping under milder conditions and operating the paper machines to give optimum orientation of the fibers in one direction, together with the desired absorbency, contribute markedly to improvements in strength.

Phenolic resins are the most suitable resins for impregnating the paper from the standpoint of high water resistance, low swelling and shrinking, and high-strength properties (except for impact). Phenolics are also lower in cost than other resins that give comparable properties. Water-soluble resins of the type used for impreg impart the highest water resistance and compressive strength properties to the product, but they unfortunately make the product brittle (low impact strength). Advanced phenolic resins produce a considerably tougher product, but the resins fail to penetrate the fibers as well as water-soluble resins and thus impart less water resistance and dimensional stability to the product. In practice, compromise alcohol-soluble phenolic resins are generally used.

Table 22–2 gives the strength properties of high-strength paper-base laminates. The strength properties of paper-base laminates compare favorably with those for the wood laminates, compreg and staypak, and are superior to those for fabric laminates, except in the edgewise Izod impact test. Fabric laminates have one advantage—they can be molded to greater double curvatures. As paper is considerably less expensive than fabric and can be molded at considerably lower pressures, the paper-base laminates should have an appreciable price advantage over fabric laminates.

Physical properties of the paper are imparted to the paper plastic. Of course, paper will absorb or give off moisture, depending upon conditions of exposure. This moisture change causes paper to shrink and swell, usually more across the machine direction than along it. Likewise, the laminated paper plastics shrink and swell, although at a much slower rate. Cross-laminating minimizes the amount of this shrinking and swelling. In many uses in furniture where laminates are bonded to cores, these changes in dimension due to moisture changes in service with the change of seasons are different than those of the core material. To balance the construction, a paper plastic with similar properties may be glued to the opposite face of the core to prevent bowing or cupping from the moisture changes. Plastics made from different papers will have different shrinking and swelling properties, as shown in table 22–4 for six typical commercial products.

Papreg was used during World War II for molding nonstructural and semistructural airplane parts, such as gunner's seats and turrets, ammunition boxes, wing tabs, and the surfaces of cargo aircraft flooring and "catwalks." It was tried to a limited extent for the skin surface of airplane structural parts, such as wing tips. One major objection to its use for such parts is that it is more brittle than aluminum and requires special fittings.

Papreg has been used to some extent for heavy-duty truck floors and industrial processing trays for nonedible materials, and with melamine-treated papers for decorative table-

Table 22-4.—*Rate of length change of papreg specimens exposed at 80° F., 90 percent relative humidity*[1]

Type of material	Position of specimen with respect to length of sheet	Time (days)						
		1	2	4	7	14	29	56
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Decorative laminate	Parallel	0.055	0.075	0.105	0.115	0.100	0.085	0.075
Do	Perpendicular	.110	.170	.260	.325	.345	.365	.350
Do	Parallel	.030	.035	.035	.045	.025	.015	-.005
Do	Perpendicular	.080	.110	.155	.230	.255	.270	.245
Do	Parallel	.080	.115	.140	.145	.135	.135	.130
Do	Perpendicular	.170	.265	.360	.410	.410	.435	.420
Do	Parallel	.065	.10[illegible]	.145	.175	.180	.190	.180
Do	Perpendicular	.135	.210	.310	.400	.420	.515	.500
Average parallel		.058	.081	.106	.120	.110	.106	.095
Average perpendicular		.124	.189	.271	.341	.358	.496	.379
Backing sheet	Parallel	.130	.115	.105	.105	.090	.085	.075
Do	Perpendicular	.370	.425	.430	.445	.430	.425	.405
Do	Parallel	.110	.090	.080	.075	.065	.045	.030
Do	Perpendicular	.435	.420	.430	.440	.445	.420	.385
Average parallel		.120	.103	.093	.090	.078	.065	.053
Average perpendicular		.403	.423	.430	.443	.438	.423	.395

[1] Material at equilibrium at 80° F., 30 pct. relative humidity before exposure began.

tops. Papreg also appears suitable for pulleys, gears, bobbins, and many other objects for which fabric laminates are used. Because it can be molded at low pressures and is made from thin papers, it is advantageous for use where very large single sheets or accurate control of panel thickness are required.

Lignin-Filled Laminates

The cost of phenolic resins resulted in considerable effort to find impregnating and bonding agents that were more inexpensive and yet readily available. Lignin-filled laminates made with lignin recovered from the spent liquor of the soda pulping process have been produced as a result of this search. Lignin is precipitated from solution within the pulp or added in a pre-precipitated form before the paper is made. The lignin-filled sheets of paper can be laminated without the addition of other resins, but their water resistance is considerably enhanced when some phenolic resin is used. The water resistance can also be improved by merely impregnating the surface sheet with phenolic resin. It is also possible to introduce lignin, together with phenolic resin, into untreated paper sheets with an impregnating machine.

The lignin-filled laminates are always dark brown or black. Their strength properties except for toughness are, in general, lower than those of papreg. The Izod impact values are usually twice those for papreg. In spite of the fact that lignin is somewhat thermoplastic, the loss in strength on heating to 200° F. is proportionately no more than for papreg.

Reduction in costs of phenolic resins has virtually eliminated the lignin-filled laminates from American commerce. They have a number of potential applications, however, where a cheaper laminate with less critical properties than papreg can be used.

Paper-Face Overlays

Paper has found considerable use as an overlay material for veneer or plywood. Overlays can be classified into three different types according to their use—masking, decorative, and structural. Masking overlays are used to cover minor defects in plywood, such as face checks and patches, minimize grain raising, and provide a more uniform paintable surface, thus making possible the use of lower grade veneer. Paper for this purpose need not be of high strength, as the overlays need not add strength to the product. For adequate masking a single surface sheet with a thickness of 0.015 to 0.030 inch is desirable. Paper impregnated with phenolic resins to about 25 percent of the weight of the paper gives the best all-around product. Higher resin contents make the product too costly and tend to make the overlay more transparent. Appreciably lower resin contents give a product with low scratch and abrasion resistance, especially when the panels are wet or exposed to high relative humidities.

The paper faces can be applied at the same time that the veneer is assembled into plywood in a hot press. Undue thermal stresses that might result in checking are not set up if the machine direction of the paper overlays is at right angles to the grain direction of the face plies of the plywood.

Commercially, most of the paper-face overlays are applied to softwood plywood; however, for masking purposes overlays of paper impregnated with resin but only partially cured are available to apply to lumber or other wood-base material like particleboard or hardboard. The curing of the resin is completed at the same time the paper is bonded to the wood or wood-base material in a hot press.

Specific plywood grades with paper-face overlays are available commercially. These are of three types—high density, medium density, and special overlay. Although they are designed for either exterior or interior service, all commercial overlaid plywood conforming to the Product Standards is made in the exterior type.

By specification, the high-density type is one in which the surface on the finished product is hard, smooth, and of such character that further finishing by paint or varnish is not required. It consists of a cellulose fiber sheet or sheets, in which not less than 45 percent of the weight of the laminate is a thermosetting resin of the phenolic or melamine type. The resin-impregnated material cannot be less than 0.012 inch thick before pressing and must weigh not less than 60 pounds per 1,000 square feet of single face before hot-pressing (including both resin and fiber).

By specification also, the medium-density type must present a smooth, uniform surface suitable for high-quality paint finishes. It consists of a cellulose-fiber sheet in which not less than 17 percent resin solids by weight of the laminate for a beater-loaded sheet (or 22 pct. by weight if impregnated) is a thermosetting resin of either the phenolic or melamine type. The resin-impregnated material is at least 0.012 inch thick after application and weighs not less than 58 pounds per 1,000 square feet of single face before hot-pressing (including both resin and fiber). An integral phenolic resin is applied to one surface of the facing material to bond it to the plywood.

The main difference between the two kinds of paper-face overlays for plywood is that the medium-density overlay face is opaque (of solid color) and not translucent like the high-density one. Some evidence of the underlying grain may appear, but compared to the high-density surface, there is no consistent show-through.

Special overlays are those surfacing materials with special characteristics that do not fit the exact description of high- or medium-density overlay types but otherwise meet the test requirements for overlaid plywood.

Thin, transparent (when cured) papers impregnated with melamine resins are used for covering and providing permanent finishes for decorative veneers in furniture and similar articles of wood. In this use the impregnated sheet is bonded to the wood surface in hot presses at the same time the resin is cured. The heat and stain resistance and the strength of this kind of film make it a superior finish.

Masking paper-base overlays unimpregnated with resin are used for such applications as wood house siding that is painted. Vulcanized fiber is the most important commercially. These overlays mask defects in the wood, prevent bleedthrough of resins and extractives in the wood, provide a better substrate for paint, and improve the across-the-board stability from changes in dimension due to changes in moisture content.

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GLOSSARY

ADHESIVE. A substance capable of holding materials together by surface attachment. It is a general term and includes cements, mucilage, and paste, as well as glue.

AIR-DRIED. (*See* **SEASONING.**)

ALLOWABLE PROPERTY.—The value of a property normally published for design use. Allowable properties are identified with grade descriptions and standards, reflect the orthotropic structure of wood, and anticipate certain end uses.

ALLOWABLE STRESS. (*See* **ALLOWABLE PROPERTY.**)

AMERICAN LUMBER STANDARDS. American lumber standards embody provisions for softwood lumber dealing with recognized classifications, nomenclature, basic grades, sizes, description, measurements, tally, shipping provisions, grademarking, and inspection of lumber. The primary purpose of these standards is to serve as a guide in the preparation or revision of the grading rules of the various lumber manufacturers' associations. A purchaser must, however, make use of association rules as the basic standards are not in themselves commercial rules.

ANISOTROPIC. Not isotropic; that is, not having the same properties in all directions. In general, fibrous materials such as wood are anisotropic.

ANNUAL GROWTH RING. The layer of wood growth put on a tree during a single growing season. In the temperature zone the annual growth rings of many species (e.g., oaks and pines) are readily distinguished because of differences in the cells formed during the early and late parts of the season. In some temperate zone species (black gum and sweetgum) and many tropical species, annual growth rings are not easily recognized.

BALANCED CONSTRUCTION. A construction such that the forces induced by uniformly distributed changes in moisture content will not cause warping. Symmetrical construction of plywood in which the grain direction of each ply is perpendicular to that of adjacent plies is balanced construction.

BARK POCKET. An opening between annual growth rings that contains bark. Bark pockets appear as dark streaks on radial surfaces and as rounded areas on tangential surfaces.

BASTARD SAWN. Lumber (primarily hardwoods) in which the annual rings make angles of 30° to 60° with the surface of the piece.

BEAM. A structural member supporting a load applied transversely to it.

BENDING, STEAM. The process of forming curved wood members by steaming or boiling the wood and bending it to a form.

BENT WOOD. (*See* **BENDING, STEAM.**)

BIRD PECK. A small hole or patch of distorted grain resulting from birds pecking through the growing cells in the tree. In shape, bird peck usually resembles a carpet tack with the point towards the bark; bird peck is usually accompanied by discoloration extending for considerable distance along the grain and to a much lesser extent across the grain.

BIRDSEYE. Small localized areas in wood with the fibers indented and otherwise contorted to form few to many small circular or elliptical figures remotely resembling birds' eyes on the tangential surface. Sometimes found in sugar maple and used for decorative purposes; rare in other hardwood species.

BLOOM. Crystals formed on the surface of treated wood by exudation and evaporation of the solvent in preservative solutions.

BLUE STAIN. (*See* **STAIN.**)

BOARD. (*See* **LUMBER.**)

BOARD FOOT. A unit of measurement of lumber represented by a board 1 foot long, 12 inches wide, and 1 inch thick or its cubic equivalent. In practice, the board foot calculation for lumber 1 inch or more in thickness is based on its nominal thickness and width and the length. Lumber with a nominal thickness of less than 1 inch is calculated as 1 inch.

BOLE The main stem of a tree of substantial diameter—roughly, capable of yielding sawtimber, veneer logs, or large poles. Seedlings, saplings, and small-diameter trees have stems, not boles.

BOLT. (1) A short section of a tree trunk; (2) in veneer production, a short log of a length suitable for peeling in a lathe.

BOW. The distortion of lumber in which there is a deviation, in a direction perpendicular to the flat face, from a straight line from end-to-end of the piece.

BOX BEAM. A built-up beam with solid wood flanges and plywood or wood-base panel product webs.

BOXED HEART. The term used when the pith falls entirely within the four faces of a piece of wood anywhere in its length. Also called boxed pith.

BRASHNESS. A condition that causes some pieces of wood to be relatively low in shock resistance for the species and, when broken in bending, to fail abruptly without splintering at comparatively small deflections.

BREAKING RADIUS. The limiting radius of curvature to which wood or plywood can be bent without breaking.

BRIGHT. Free from discoloration.

BROAD-LEAVED TREES. (*See* **HARDWOODS.**)

BROWN ROT. In wood, any decay in which the attack concentrates on the cellulose and associated carbohydrates rather than on the lignin, producing a light to dark brown friable residue—hence loosely termed "dry rot." An advanced stage where the wood splits along rectangular planes, in shrinking, is termed "cubical rot."

BROWN STAIN. (*See* **STAIN.**)

BUILT-UP TIMBERS. An assembly made by joining layers of lumber together with mechanical fastenings so that the grain of all laminations is essentially parallel.

BURL. (1) A hard, woody outgrowth on a tree, more or less rounded in form, usually resulting from the entwined growth of a cluster of adventitious buds. Such burls are the source of the highly figured burl veneers used for purely ornamental purposes. (2) In lumber or veneer, a localized severe distortion of the grain generally rounded in outline, usually resulting from overgrowth of dead branch stubs. varying from ½ inch to several inches in diameter; frequently includes one or more clusters of several small contiguous conical protuberances, each usually having a core or pith but no appreciable amount of end grain (in tangential view) surrounding it.

BUTT JOINT. (*See* **JOINT.**)

BUTTRESS. A ridge of wood developed in the angle between a lateral root and the butt of a tree, which may extend up the stem to a considerable height.

CAMBIUM. A thin layer of tissue between the bark and wood that repeatedly subdivides to form new wood and bark cells.

CANT. A log that has been slabbed on one or more sides. Ordinarily, cants are intended for resawing at right angles to their widest sawn face. The term is loosely used. (*See* **FLITCH.**)

CASEHARDENING. A condition of stress and set in dry lumber characterized by compressive stress in the outer layers and tensile stress in the center or core.

CELL. A general term for the structural units of plant tissue, including wood fibers, vessel members, and other elements of diverse structure and function.

CELLULOSE. The carbohydrate that is the principal constituent of wood and forms the framework of the wood cells.

CHECK. A lengthwise separation of the wood that usually extends across the rings of annual growth and commonly results from stresses set up in wood during seasoning.

CHEMICAL BROWN STAIN. (*See* **STAIN.**)

CHIPBOARD. A paperboard used for many purposes that may or may not have specifications for strength, color, or other characteristics. It is normally made from paper stock with a relatively low density in the thickness of 0.006 inch and up.

CLOSE GRAINED. (*See* **GRAIN.**)

COARSE GRAIN. (*See* **GRAIN.**)

COLD-PRESS PLYWOOD. (*See* **PLYWOOD.**)

COLLAPSE. The flattening of single cells or rows of cells in heartwood during the drying or pressure treatment of wood. Often characterized by a caved-in or corrugated appearance of the wood surface.

COMPARTMENT KILN. (*See* **KILN.**)

COMPOUND CURVATURE. Wood bent to a compound curvature has curved surfaces, no element of which is a straight line.

COMPREG. Wood in which the cell walls have been impregnated with synthetic resin and compressed to give it reduced swelling and shrinking characteristics and increased density and strength properties.

COMPRESSION FAILURE. Deformation of the wood fibers resulting from excessive compression along the grain either in direct end compression or in bending. It may develop in standing trees due to bending by wind or snow or to internal longitudinal stresses developed in growth, or it may result from stresses imposed after the tree is cut. In surfaced lumber compression failures may appear as fine wrinkles across the face of the piece.

COMPRESSION WOOD. Wood formed on the lower side of branches and inclined trunks of softwood trees. Compression wood is identified by its relatively wide annual rings, usually eccentric, relatively large amount of summerwood, sometimes more than 50 percent of the width of the annual rings in which it occurs, and its lack of demarcation between springwood and summerwood in the same annual rings. Compression wood shrinks excessively lengthwise, as compared with normal wood.

CONIFER. (*See* **SOFTWOODS.**)

CONNECTOR, TIMBER. Metal rings, plates, or grids which are embedded in the wood of adjacent members, as at the bolted points of a truss, to increase the strength of the joint.

COOPERAGE. Containers consisting of two round heads and a body composed of staves held together with hoops, such as barrels and kegs.

Slack cooperage. Cooperage used as containers for dry, semidry or solid products. The staves are usually not closely fitted and are held together with beaded steel, wire, or wood hoops.

Tight cooperage. Cooperage used as containers for liquids, semi-solids, and heavy solids. Staves are well fitted and held tightly with cooperage grade steel hoops.

CORBEL. A projection from the face of a wall or column supporting a weight.

CORE STOCK. A solid or discontinuous center ply used in panel-type glued structures (such as furniture panels and solid or hollowcore doors).

CROOK. The distortion of lumber in which there is a deviation, in a direction perpendicular to the edge, from a straight line from end-to-end of the piece.

CROSSBAND. To place the grain of layers of wood at right angles in order to minimize shrinking and swelling; also, in plywood of three or more plies, a layer of veneer whose grain direction is at right angles to that of the face plies.

CROSS BREAK. A separation of the wood cells across the grain. Such breaks may be due to internal stress resulting from unequal longitudinal shrinkage or to external forces.

CROSS GRAIN. (*See* **GRAIN.**)

CUP. A distortion of a board in which there is a deviation flatwise from a straight line across the width of the board.

CURE. To change the properties of an adhesive by chemical reaction (which may be condensation, polymerization, or vulcanization) and thereby develop maximum strength. Generally accomplished by the action of heat or a catalyst, with or without pressure.

CURLY GRAIN. (*See* **GRAIN.**)

CUT STOCK. A term for softwood stock comparable to dimension stock in hardwoods. (*See* **DIMENSION STOCK.**)

CUTTINGS. In hardwoods, a portion of a board or plank having the quality required by a specific grade or for a particular use. Obtained from a board by crosscutting or ripping.

DECAY. The decomposition of wood substance by fungi.

Advanced (or typical) decay. The older stage of decay in which the destruction is readily recognized because the wood has become punky, soft and spongy, stringy, ringshaked, pitted, or crumbly. Decided discoloration or bleaching of the rotted wood is often apparent.

Incipient decay. The early stage of decay that has not proceeded far enough to soften or otherwise perceptibly impair the hardness of the wood. It is usually accompanied by a slight discoloration or bleaching of the wood.

DELAMINATION. The separation of layers in a laminate through failure within the adhesive or at the bond between the adhesive and the laminae.

DELIGNIFICATION. Removal of part or all of the lignin from wood by chemical treatment.

DENSITY. As usually applied to wood of normal cellular form, density is the mass of wood substance enclosed within the boundary surfaces of a wood-plus-voids complex having unit volume. It is variously expressed as pounds per cubic foot, kilograms per cubic meter, or grams per cubic centimeter at a specified moisture content.

DENSITY RULES. A procedure for segregating wood according to density, based on percentage of latewood and number of growth rings per inch of radius.

DEW POINT. The temperature at which a vapor begins to deposit as a liquid. Applies especially to water in the atmosphere.

DIAGONAL GRAIN. (*See* **GRAIN.**)

DIFFUSE-POROUS WOOD. Certain hardwoods in which the pores tend to be uniform in size and distribution throughout each annual ring or to decrease in size slightly and gradually toward the outer border of the ring.

DIMENSION. (*See* **LUMBER.**)

DIMENSION STOCK. A term largely superseded by the term "hardwood dimension lumber." It is hardwood stock processed to a point where the maximum waste is left at the mill, and the maximum utility is delivered to the user. It is stock of specified thickness, width, and length, or multiples thereof. According to specification it may be solid or glued up, rough or surfaced, semifabricated or completely fabricated.

DIMENSIONAL STABILIZATION. Special treatment of wood to reduce the swelling and shrinking that is caused by changes in its moisture content with changes in relative humidity.

DOTE. "Dote," "doze," and "rot" are synonymous with "decay" and are any form of decay that may be evident as either a discoloration or a softening of the wood.

DRESSED LUMBER. (*See* **LUMBER.**)

DRY-BULB TEMPERATURE. The temperature of air as indicated by a standard thermometer. (*See* **PSYCHROMETER.**)

DRY KILN. (*See* **KILN.**)

DRY ROT. A term loosely applied to any dry, crumbly rot but especially to that which, when in an advanced stage, permits the wood to be crushed easily to a dry powder. The term is actually a misnomer for any decay, since all fungi require considerable moisture for growth.

DRY WALL. Interior covering material, such as gypsum board, hardboard, or plywood, which is applied in large sheets or panels.

DURABILITY. A general term for permanence or resistance to deterioration. Frequently used to refer to the degree of resistance of a species of wood to attack by wood-destroying fungi under conditions that favor such attack. In this connection the term "decay resistance" is more specific.

EARLYWOOD. The portion of the annual growth ring that is formed during the early part of the growing season. It is usually less dense and weaker mechanically than latewood.

EDGE GRAIN. (*See* **GRAIN.**)

EDGE JOINT. (*See* **JOINT.**)

EMPTY-CELL PROCESS. Any process for impregnating wood with preservatives or chemicals in which air, imprisoned in the wood under pressure, expands when pressure is released to drive out part of the injected preservative or chemical. The distinguishing characteristic of the empty-cell process is that no vacuum is drawn before applying the preservative. The aim is to obtain good preservative distribution in the wood and leave the cell cavities only partially filled.

ENCASED KNOT. (*See* **KNOT.**)

END GRAIN. (*See* **GRAIN.**)

END JOINT. (*See* **JOINT.**)

EQUILIBRIUM MOISTURE CONTENT. The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

EXTERIOR PLYWOOD. (*See* **PLYWOOD.**)

EXTRACTIVE. Substances in wood, not an integral part of the cellular structure, that can be removed by solution in hot or cold water, ether, benzene, or other solvents that do not react chemically with wood components.

FACTORY AND SHOP LUMBER. (*See* **LUMBER.**)

FEED RATE. The distance that the stock being processed moves during a given interval of time or operational cycle.

FIBER, WOOD. A wood cell comparatively long ($\frac{1}{25}$ or less to $\frac{1}{3}$ in.), narrow, tapering, and closed at both ends.

FIBERBOARD. A broad generic term inclusive of sheet materials of widely varying densities manufactured of refined or partially refined wood (or other vegetable) fibers. Bonding agents and other materials may be added to increase strength, resistance to moisture, fire, or decay, or to improve some other property.

FIBER SATURATION POINT. The stage in the drying or wetting of wood at which the cell walls are saturated and the cell cavities free from water. It applies to an individual cell or group of cells, not to whole boards. It is usually taken as approximately 30 percent moisture content, based on ovendry weight.

FIBRIL. A threadlike component of cell walls, visible under a light microscope.

FIDDLEBACK. (*See* **GRAIN.**)

FIGURE. The pattern produced in a wood surface by annual growth rings, rays, knots, deviations from regular grain such as interlocked and wavy grain, and irregular coloration.

FILLER. In woodworking, any substance used to fill the holes and irregularities in planed or sanded surfaces to decrease the porosity of the surface before applying finish coatings.

FINE GRAIN. (*See* **GRAIN.**)

FINGER JOINT. (*See* **JOINT.**)

FINISH (FINISHING). Wood products such as doors, stairs, and other fine work required to complete a building, especially the interior. Also, coatings of paint, varnish, lacquer, wax, etc., applied to wood surfaces to protect and enhance their durability or appearance.

FIRE ENDURANCE. A measure of the time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance.

FIRE RESISTANCE. The property of a material or assembly to withstand fire or to give protection from it.

FIRE RETARDANT. A chemical or preparation of chemicals used to reduce flammability or to retard spread of a fire over the surface.

FLAKE. A small flat wood particle of predetermined dimensions, uniform thickness, with fiber direction essentially in the plane of the flake; in overall character resembling a small piece of veneer. Produced by special equipment for use in the manufacture of flakeboard.

FLAKEBOARD. A particleboard composed of flakes.

FLAT GRAIN. (*See* **GRAIN.**)

FLAT-SAWN. (*See* **GRAIN, FLAT.**)

FLECKS. (*See* **RAYS, WOOD.**)

FLITCH. A portion of a log sawn on two or more faces—commonly on opposite faces, leaving two waney edges. When intended for resawing into lumber, it is resawn parallel to its original wide faces. Or, it may be sliced or sawn into veneer, in which case the resulting sheets of veneer laid together in the sequence of cutting are called a flitch. The term is loosely used. (See also Cant.)

FRAMING. Lumber used for the structural member of a building, such as studs and joists.

FULL-CELL PROCESS. Any process for impregnating wood with preservatives or chemicals in which a vacuum is drawn to remove air from the wood before admitting the preservative. This favors heavy adsorption and retention of preservative in the treated portions.

GELATINOUS FIBERS. Modified fibers that are associated with tension wood in hardwoods.

GIRDER. A large or principal beam of wood or steel used to support concentrated loads at isolated points along its length.

GRADE. The designation of the quality of a manufactured piece of wood or of logs.

GRAIN. The direction, size, arrangement, appearance, or quality of the fibers in wood or lumber. To have a specific meaning the term must be qualified.

Close-grained wood. Wood with narrow, inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine textured" is more often used.

Coarse-grained wood. Wood with wide conspicuous annual rings in which there is considerable difference between springwood and summerwood. The term is sometimes used to designate wood with large pores, such as oak, ash, chestnut, and walnut, but in this sense the term "coarse textured" is more often used.

Cross-grained wood. Wood in which the fibers deviate from a line parallel to the sides of the piece. Cross grain may be either diagonal or spiral grain or a combination of the two.

Grain (con't.)

Curly-grained wood. Wood in which the fibers are distorted so that they have a curled appearance, as in "birdseye" wood. The areas showing curly grain may vary up to several inches in diameter.

Diagonal-grained wood. Wood in which the annual rings are at an angle with the axis of a piece as a result of sawing at an angle with the bark of the tree or log. A form of cross-grain.

Edge-grained lumber. Lumber that has been sawed so that the wide surfaces extend approximately at right angles to the annual growth rings. Lumber is considered edge grained when the rings form an angle of 45° to 90° with the wide surface of the piece.

End-grained wood. The grain as seen on a cut made at a right angle to the direction of the fibers (e.g., on a cross section of a tree).

Fiddleback-grained wood. Figure produced by a type of fine wavy grain found, for example, in species of maple, such wood being traditionally used for the backs of violins.

Fine-grained wood. (*See* **Close-grained wood.**)

Flat-grained wood. Lumber that has been sawed parallel to the pith and approximately tangent to the growth rings. Lumber is considered flat grained when the annual growth rings make an angle of less than 45° with the surface of the piece.

Interlocked-grained wood. Grain in which the fibers put on for several years may slope in a right-handed direction, and then for a number of years the slope reverses to a left-handed direction, and later changes back to a right-handed pitch, and so on. Such wood is exceedingly difficult to split radially, though tangentially it may split fairly easily.

Open-grained wood. Common classification for woods with large pores, such as oak, ash, chestnut, and walnut. Also known as "coarse textured."

Plainsawed lumber. Another term for flat-grained lumber.

Quartersawed lumber. Another term for edge-grained lumber.

Side-grained wood. Another term for flat-grained lumber.

Slash-grained wood. Another term for flat-grained lumber.

Spiral-grained wood. Wood in which the fibers take a spiral course about the trunk of a tree instead of the normal vertical course. The spiral may extend in a right-handed or left-handed direction around the tree trunk. Spiral grain is a form of cross grain.

Straight-grained wood. Wood in which the fibers run parallel to the axis of a piece.

Vertical-grained lumber. Another term for edge-grained lumber.

Wavy-grained wood. Wood in which the fibers collectively take the form of waves or undulations.

GREEN. Freshly sawed or undried wood. Wood that has become completely wet after immersion in water would not be considered green, but may be said to be in the "green condition."

GROWTH RING. (*See* **ANNUAL GROWTH RING.**)

LAMINATE. A product made by bonding together two or more layers (laminations) of material or materials.

LAMINATE, PAPER-BASE. A multilayered panel made by compressing sheets of resin-impregnated paper together into a coherent solid mass.

LAMINATED WOOD. An assembly made by bonding layers of veneer or lumber with an adhesive so that the grain of all laminations is essentially parallel. (*See* **Built-up timbers.**)

- **Horizontally laminated wood.** Laminated wood in which the laminations are so arranged that the wider dimension of each lamination is approximately perpendicular to the direction of load.
- **Vertically laminated wood.** Laminated wood in which the laminations are so arranged that the wider dimension of each lamination is approximately parallel to the direction of load.

LAP JOINT. (*See* **JOINT.**)

LATEWOOD. The portion of the annual growth ring that is formed after the earlywood formation has ceased. It is usually denser and stronger mechanically than earlywood.

LIGNIN. The second most abundant constituent of wood, located principally in the secondary wall and the middle lamella, which is the thin cementing layer between wood cells. Chemically it is an irregular polymer of substituted propylphenol groups, and thus no simple chemical formula can be written for it.

LONGITUDINAL. Generally, parallel to the direction of the wood fibers.

LOOSE KNOT. (*See* **KNOT.**)

LUMBER. The product of the saw and planing mill not further manufactured than by sawing, resawing, passing lengthwise through a standard planing machine, crosscutting to length, and matching.

- **Boards.** Lumber that is nominally less than 2 inches thick and 2 or more inches wide. Boards less than 6 inches wide are sometimes called strips.
- **Dimension.** Lumber with a nominal thickness of from 2 up to but not including 5 inches and a nominal width of 2 inches or more.
- **Dressed size.** The dimensions of lumber after being surfaced with a planing machine. The dressed size is usually ½ to ¾ inch less than the nominal or rough size. A 2- by 4-inch stud, for example, actually measures about 1½ by 3½ inches.
- **Factory and shop lumber.** Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area that will produce a limited number of cuttings of a specified minimum size and quality.
- **Matched lumber.** Lumber that is edge dressed and shaped to make a close tongued-and-grooved joint at the edges or ends when laid edge to edge or end to end.
- **Nominal size.** As applied to timber or lumber, the size by which it is known and sold in the market; often differs from the actual size. (See also, Dressed size.)
- **Patterned lumber.** Lumber that is shaped to a pattern or to a molded form in addition to being dressed, matched, or shiplapped, or any combination of these workings.
- **Rough lumber.** Lumber which has not been dressed (surfaced) but which has been sawed, edged, and trimmed.

Lumber (con't.)

- **Shiplapped lumber.** Lumber that is edge dressed to make a lapped joint.
- **Shipping-dry lumber.** Lumber that is partially dried to prevent stain and mold in transit.
- **Side lumber.** A board from the outer portion of the log—ordinarily one produced when squaring off a log for a tie or timber.
- **Structural lumber.** Lumber that is intended for use where allowable properties are required. The grading of structural lumber is based on the strength of the piece as related to anticipated uses.
- **Surface lumber.** Lumber that is dressed by running it through a planer.
- **Timbers.** Lumber that is nominally 5 or more inches in least dimension. Timbers may be used as beams, stringers, posts, caps, sills, griders, purlins, etc.
- **Yard lumber.** A little-used term for lumber of all sizes and patterns that is intended for general building purposes having no design property requirements.

LUMEN. In wood anatomy, the cell cavity.

MANUFACTURING DEFECTS. Includes all defects or blemishes that are produced in manufacturing, such as chipped grain, loosened grain, raised grain, torn grain, skips in dressing, hit and miss (series of surfaced areas with skips between them), variation in sawing, miscut lumber, machine burn, machine gouge, mismatching, and insufficient tongue or groove.

MATCHED LUMBER. (*See* **LUMBER.**)

MILLWORK. Planed and patterned lumber for finish work in buildings, including items such as sash, doors, cornices, panelwork, and other items of interior or exterior trim. Does not include flooring, ceiling, or siding.

MINERAL STREAK. An olive to greenish-black or brown discoloration of undermined cause in hardwoods.

MODIFIED WOOD. Wood processed by chemical treatment, compression, or other means (with or without heat) to impart properties quite different from those of the original wood.

MOISTURE CONTENT. The amount of water contained in the wood, usually expressed as a percentage of the weight of the ovendry wood.

MOLDED PLYWOOD. (*See* **PLYWOOD.**)

MOLDING. A wood strip having a curved or projecting surface, used for decorative purposes.

MORTISE. A slot cut into a board, plank, or timber, usually edgewise, to receive the tenon of another board, plank, or timber to form a joint.

NAVAL STORES. A term applied to the oils, resins, tars, and pitches derived from oleoresin contained in, exuded by, or extracted from trees; chiefly species of pines (genus *Pinus*). Historically, these were important items in the stores of wood sailing vessels.

NOMINAL-SIZE LUMBER. (*See* **LUMBER.**)

OLD GROWTH. Timber in or from a mature, naturally established forest. When the trees have grown during most if not all of their individual lives in active competition with their companions for sunlight and moisture, this timber is usually straight and relatively free of knots.

OLEORESIN. A solution of resin in an essential oil that occurs in or exudes from many plants, especially softwoods. The oleoresin from pine is a solution of pine resin (rosin) in turpentine.

OPEN GRAIN. (*See* **GRAIN.**)

ORTHOTROPIC. Having unique and independent properties in three mutually orthogonal (perpendicular) planes of symmetry. A special case of anisotropy.

OVENDRY WOOD. Wood dried to a relatively constant weight in a ventilated oven at 101° to 105°C.

OVERLAY. A thin layer of paper, plastic, film, metal foil, or other material bonded to one or both faces of panel products or to lumber to provide a protective or decorative face or a base for painting.

PALLET. A low wood or metal platform on which material can be stacked to facilitate mechanical handling. moving, and storage.

PAPERBOARD. The distinction between paper and paperboard is not sharp, but broadly speaking, the thicker (over 0.012 in.), heavier, and more rigid grades of paper are called paperboard.

PAPREG. Any of various paper products made by impregnating sheets of specially manufactured high-strength paper with synthetic resin and laminating the sheets to form a dense, moisture-resistant product.

PARENCHYMA. Short cells having simple pits and functioning primarily in the metabolism and storage of plant food materials. They remain alive longer than the tracheids, fibers, and vessel segments, sometimes for many years. Two kinds of parenchyma cells are recognized—those in vertical strands, known more specifically as axial parenchyma, and those in horizontal series in the rays, known as ray parenchyma.

PARTICLEBOARD. A generic term for a panel manufactured from lignocellulosic materials—commonly wood—essentially in the form of particles (as distinct from fibers). These materials are bonded together with synthetic resin or other suitable binder, under heat and pressure, by a process wherein the interparticle bonds are created wholly by the added binder.

PATTERNED LUMBER. (*See* **LUMBER.**)

PECK. Pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. It is usually associated with cypress and incense-cedar. There is no further development of peck once the lumber is seasoned.

PEEL. To convert a log into veneer by rotary cutting.

PHLOEM. The tissues of the inner bark, characterized by the presence of sieve tubes and serving for the transport of elaborate foodstuffs.

PILE. A long, heavy timber, round or square cut, that is driven deep into the ground to provide a secure foundation for structures built on soft, wet, or submerged sites; e.g., landing stages, bridge abutments.

PIN-KNOT. (*See* **KNOT.**)

PITCH POCKET. An opening extending parallel to the annual growth rings and containing, or that has contained, pitch, either solid or liquid.

PITCH STREAKS. A well-defined accumulation of pitch in a more or less regular streak in the wood of certain conifers.

PITH. The small, soft core occurring near the center of a tree trunk, branch, twig, or log.

PITH FLECK. A narrow streak, resembling pith on the surface of a piece; usually brownish, up to several inches in length; resulting from burrowing of larvae in the growing tissues of the tree.

PLAINSAWED. (*See* **GRAIN.**)

PLANING MILL PRODUCTS. Products worked to pattern, such as flooring, ceiling, and siding.

PLANK. A broad board, usually more than 1 inch thick, laid with its wide dimension horizontal and used as a bearing surface.

PLASTICIZING WOOD. Softening wood by hot water, steam, or chemical treatment to increase its moldability.

PLYWOOD. A composite panel or board made up of cross-banded layers of veneer only or veneer in combination with a core of lumber or of particleboard bonded with an adhesive. Generally the grain of one or more plies is roughly at right angles to the other plies, and almost always an odd number of plies are used.

Cold-pressed plywood. Refers to interior-type plywood manufactured in a press without external applications of heat.

Exterior plywood. A general term for plywood bonded with a type of adhesive that by systematic tests and service records has proved highly resistant to weather; micro-organisms; cold, hot, and boiling water; steam; and dry heat.

Molded plywood. Plywood that is glued to the desired shape either between curved forms or more commonly by fluid pressure applied with flexible bags or blankets (bag molding) or other means.

Postformed plywood. The product formed when flat plywood is reshaped into a curve configuration by steaming or plasticizing agents.

POCKET ROT. Advanced decay that appears in the form of a hole or pocket, usually surrounded by apparently sound wood.

PORE. (*See* **VESSELS.**)

POROUS WOODS. Hardwoods having vessels or pores large enough to be seen readily without magnification.

POSTFORMED PLYWOOD. (*See* **PLYWOOD.**)

PRESERVATIVE. Any substance that, for a reasonable length of time, is effective in preventing the development and action of wood-rotting fungi, borers of various kinds, and harmful insects that deteriorate wood.

PRESSURE PROCESS. Any process of treating wood in a closed container whereby the preservative or fire retardant is forced into the wood under pressures greater than 1 atmosphere. Pressure is generally preceded or followed by vacuum, as in the vacuum-pressure and empty cell processes respectively, or they may alternate, as in the full cell and alternating-pressure processes.

PROGRESSIVE KILN. (*See* **KILN.**)

PSYCHROMETER. An instrument for measuring the amount of water vapor in the atmosphere. It has both a dry-bulb and wet-bulb thermometer. The bulb of the wet-bulb thermometer is kept moistened and is, therefore, cooled by evaporation to a temperature lower than that shown by the dry-bulb thermometer. Because evaporation is greater in dry air, the difference between the two thermometer readings will be greater when the air is dry than when it is moist.

QUARTERSAWED. (*See* **GRAIN.**)

RADIAL. Coincident with a radius from the axis of the tree or log to the circumference. A radial section is a lengthwise section in a plane that passes through the centerline of the tree trunk.

RAFTER. One of a series of structural members of a roof designed to support roof loads. The rafters of a flat roof are sometimes called roof joists.

RAISED GRAIN. A roughened condition of the surface of dressed lumber in which the hard summerwood is raised above the softer springwood but not torn loose from it.

RAYS, WOOD. Strips of cells extending radially within a tree and varying in height from a few cells in some species to 4 or more inches in oak. The rays serve primarily to store food and transport it horizontally in the tree. On quartersawed oak, the rays form a conspicuous figure, sometimes referred to as flecks.

REACTION WOOD. Wood with more or less distinctive anatomical characters, formed typically in parts of leaning or crooked stems and in branches. In hardwoods this consists of tension wood and in softwoods of compression wood.

RELATIVE HUMIDITY. Ratio of the amount of water vapor present in the air to that which the air would hold at saturation at the same temperature. It is usually considered on the basis of the weight of the vapor but, for accuracy, should be considered on the basis of vapor pressures.

RESILIENCE. The property whereby a strained body gives up its stored energy on the removal of the deforming force.

RESIN. Inflammable, water-soluble, vegetable substances secreted by certain plants or trees, and characterizing the wood of many coniferous species. The term is also applied to synthetic organic products related to the natural resins.

RESIN DUCTS. Intercellular passages that contain and transmit resinous materials. On a cut surface, they are usually inconspicuous. They may extend vertically parallel to the axis of the tree or at right angles to the axis and parallel to the rays.

RETENTION BY ASSAY. The determination of preservative retention in a specific zone of treated wood by extraction or analysis of specified samples.

RING FAILURE. A separation of the wood during seasoning, occurring along the grain and parallel to the growth rings. (See also, Shake.)

RING-POROUS WOODS. A group of hardwoods in which the pores are comparatively large at the beginning of each annual ring and decrease in size more or less abruptly toward the outer portion of the ring, thus forming a distinct inner zone of pores, known as the earlywood, and an outer zone with smaller pores, known as the latewood.

RING SHAKE. (*See* **SHAKE.**)

RIP. To cut lengthwise, parallel to the grain.

ROT. (*See* **DECAY.**)

ROTARY-CUT VENEER. (*See* **VENEER.**)

ROUGH LUMBER. (*See* **LUMBER.**)

SANDWICH CONSTRUCTION. (*See* **STRUCTURAL SANDWICH CONSTRUCTION.**)

SAP STAIN. (*See* **STAIN.**)

SAPWOOD. The wood of pale color near the outside of the log. Under most conditions the sapwood is more susceptible to decay than heartwood.

SASH. A frame structure, normally glazed (e.g., a window), that is hung or fixed in a frame set in an opening.

SAWED VENEER. (*See* **VENEER.**)

SAW KERF. (1) Grooves or notches made in cutting with a saw; (2) that portion of a log, timber, or other piece of wood removed by the saw in parting the material into two pieces.

SCARF JOINT. (*See* **JOINT.**)

SCHEDULE, KILN DRYING. A prescribed series of dry- and wet-bulb temperatures and air velocities used in drying a kiln charge of lumber or other wood products.

SEASONING. Removing moisture from green wood to improve its serviceability.

Air-dried. Dried by exposure to air in a yard or shed, without artificial heat.

Kiln-dried. Dried in a kiln with the use of artificial heat.

SECOND GROWTH. Timber that has grown after the removal, whether by cutting, fire, wind, or other agency, of all or a large part of the previous stand.

SET. A permanent or semipermanent deformation.

SHAKE. A separation along the grain, the greater part of which occurs between the rings of annual growth. Usually considered to have occurred in the standing tree or during felling.

SHAKES. In construction, shakes are a type of shingle usually hand cleft from a bolt and used for roofing or weatherboarding.

SHAVING. A small wood particle of indefinite dimensions developed incidental to certain woodworking operations involving rotary cutterheads usually turning in the direction of the grain. This cutting action produces a thin chip of varying thickness, usually feathered along at least one edge and thick at another and generally curled.

SHEAR. A condition of stress or strain where parallel planes slide relative to one another.

SHEATHING. The structural covering, usually of boards, building fiberboards, or plywood, placed over exterior studding or rafters of a structure.

SHIPLAPPED LUMBER. (*See* **LUMBER.**)

SHIPPING-DRY LUMBER. (*See* **LUMBER.**)

SHOP LUMBER. (*See* **LUMBER.**)

SIDE-GRAIN. (*See* **GRAIN.**)

SIDE LUMBER. (*See* **LUMBER.**)

SIDING. The finish covering of the outside wall of a frame building, whether made of horizontal weatherboards, vertical boards with battens, shingles, or other material.

SLASH GRAINED. (*See* **GRAIN.**)

SLICED VENEER. (*See* **VENEER.**)

SOFT ROT. A special type of decay developing under very wet conditions (as in cooling towers and boat timbers) in the outer wood layers, caused by cellulose-destroying microfungi that attack the secondary cell walls and not the intercellular layer.

SOFTWOODS. Generally, one of the botanical groups of trees that in most cases have needlelike or scalelike leaves; the conifers, also the wood produced by such trees. The term has no reference to the actual hardness of the wood.

SOUND KNOT. (*See* **KNOT.**)

SPECIFIC GRAVITY. As applied to wood, the ratio of the ovendry weight of a sample to the weight of a volume of water equal to the volume of the sample at a specified moisture content (green, air-dry, or ovendry).

SPIKE KNOT. (*See* **KNOT.**)

SPIRAL GRAIN. (*See* **GRAIN.**)

SPRINGWOOD. (*See* **EARLYWOOD.**)

STAIN. A discoloration in wood that may be caused by such diverse agencies as micro-organisms, metal, or chemicals. The term also applies to materials used to impart color to wood.

Blue stain. A bluish or grayish discoloration of the sapwood caused by the growth of certain dark-colored fungi on the surface and in the interior of the wood; made possible by the same conditions that favor the growth of other fungi.

Stain (con't.)

Brown stain. A rich brown to deep chocolate-brown discoloration of the sapwood of some pines caused by a fungus that acts much like the blue-stain fungi.

Chemical brown stain. A chemical discoloration of wood, which sometimes occurs during the air-drying or kiln-drying of several species, apparently caused by the concentration and modification of extractives.

Sap stain. (*See* **Blue stain.**)

Sticker stain. A brown or blue stain that develops in seasoning lumber where it has been in contact with the stickers.

STARVED JOINT. (*See* **JOINT.**)

STATIC BENDING. Bending under a constant or slowly applied load; flexure.

STAYPAK. Wood that is compressed in its natural state (that is, without resin or other chemical treatment) under controlled conditions of moisture, temperature, and pressure that practically eliminate springback or recovery from compression. The product has increased density and strength characteristics.

STICKERS. Strips or boards used to separate the layers of lumber in a pile and thus improve air circulation.

STICKER STAIN. (*See* **STAIN.**)

STRAIGHT GRAINED. (*See* **GRAIN.**)

STRENGTH. (1) The ability of a member to sustain stress without failure. (2) In a specific mode of test, the maximum stress sustained by a member loaded to failure.

STRENGTH RATIO. The hypothetical ratio of the strength of a structural member to that which it would have if it contained no strength-reducing characteristics (knots, cross-grain, shake, etc.).

STRESSED-SKIN CONSTRUCTION. A construction in which panels are separated from one another by a central partition of spaced strips with the whole assembly bonded so that it acts as a unit when loaded.

STRINGER. A timber or other support for cross members in floors or ceilings. In stairs, the support on which the stair treads rests.

STRUCTURAL LUMBER. (*See* **LUMBER.**)

STRUCTURAL SANDWICH CONSTRUCTION. A layered construction comprising a combination of relatively high-strength facing materials intimately bonded to and acting integrally with a low-density core material.

STRUCTURAL TIMBERS. Pieces of wood of relatively large size, the strength of which is the controlling element in their selection and use. Trestle timbers (stringers, caps, posts, sills, bracing, bridge ties, guardrails); car timbers (car framing, including upper framing, car sills); framing for building (posts, sills, girders); ship timber (ship timbers, ship decking); and cross-arms for poles are examples of structural timbers.

STUD. One of a series of slender wood structural members used as supporting elements in walls and partitions.

SUMMERWOOD. (*See* **LATEWOOD.**)

SURFACED LUMBER. (*See* **LUMBER.**)

SYMMETRICAL CONSTRUCTION. Plywood panels in which the plies on one side of a center ply or core are essentially equal in thickness, grain direction, properties, and arrangement to those on the other side of the core.

TANGENTIAL. Strictly, coincident with a tangent at the circumference of a tree or log, or parallel to such a tangent. In practice, however, it often means roughly coincident with a growth ring. A tangential section is a longitudinal section through a tree or limb perpendicular to a radius. Flat-grained lumber is sawed tangentially.

TENON. A projecting member left by cutting away the wood around it for insertion into a mortise to make a joint.

TENSION WOOD. A form of wood found in leaning trees of some hardwood species and characterized by the presence of gelatinous fibers and excessive longitudinal shrinkage. Tension wood fibers hold together tenaciously, so that sawed surfaces usually have projecting fibers, and planed surfaces often are torn or have raised grain. Tension wood may cause warping.

TEXTURE. A term often used interchangeably with grain. Sometimes used to combine the concepts of density and degree of contrast between springwood and summerwood. In this handbook texture refers to the finer structure of the wood (*see* Grain) rather than the annual rings.

THERMOPLASTIC GLUES AND RESINS. Glues and resins that are capable of being repeatedly softened by heat and hardened by cooling.

THERMOSETTING GLUES AND RESINS. Glues and resins that are cured with heat but do not soften when subsequently subjected to high temperatures.

TIMBERS, ROUND. Timbers used in the original round form, such as poles, piling, posts, and mine timbers.

TIMBER, STANDING. Timber still on the stump.

TIMBERS. (*See* **LUMBER.**)

TOUGHNESS. A quality of wood which permits the material to absorb a relatively large amount of energy, to withstand repeated shocks, and to undergo considerable deformation before breaking.

TRACHEID. The elongated cells that constitute the greater part of the structure of the softwoods (frequently referred to as fibers). Also present in some hardwoods.

TRANSVERSE. Directions in wood at right angles to the wood fibers. Includes radial and tangential directions. A transverse section is a section through a tree or timber at right angles to the pith.

TREENAIL. A wooden pin, peg, or spike used chiefly for fastening planking and ceiling to a framework.

TRIM. The finish materials in a building, such as moldings, applied around openings (window trim, door trim) or at the floor and ceiling of rooms (baseboard, cornice, and other moldings).

TRUSS. An assembly of members, such as beams, bars, rods, and the like, so combined as to form a rigid framework. All members are interconnected to form triangles.

TWIST. A distortion caused by the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane.

TYLOSES. Masses of parenchyma cells appearing somewhat like froth in the pores of some hardwoods, notably the white oaks and black locust. Tyloses are formed by the extension of the cell wall of the living cells surrounding vessels of hardwood.

VAPOR BARRIER. A material with a high resistance to vapor movement, such as foil, plastic film, or specially coated paper, that is used in combination with insulation to control condensation.

VENEER. A thin layer or sheet of wood.

Rotary-cut veneer. Veneer cut in a lathe which rotates a log or bolt, chucked in the center, against a knife.

Sawed veneer. Veneer produced by sawing.

Sliced veneer. Veneer that is sliced off a log, bolt, or flitch with a knife.

VERTICAL GRAIN. (*See* **Grain.**)

VERTICALLY LAMINATED WOOD. (*See* **Laminated wood.**)

VESSELS. Wood cells of comparatively large diameter that have open ends and are set one above the other to form continuous tubes. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

VIRGIN GROWTH. The original growth of mature trees.

WANE. Bark or lack of wood from any cause on edge or corner of a piece.

WARP. Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, or any combination thereof.

WAVY-GRAIN. (*See* **Grain.**)

WEATHERING. The mechanical or chemical disintegration and discoloration of the surface of wood caused by exposure to light, the action of dust and sand carried by winds, and the alternate shrinking and swelling of the surface fibers with the continual variation in moisture content brought by changes in the weather. Weathering does not include decay.

WET-BULB TEMPERATURE. The temperature indicated by the wet-bulb thermometer of a psychrometer.

WHITE-ROT. In wood, any decay or rot attacking both the cellulose and the lignin, producing a generally whitish residue that may be spongy or stringy rot, or occur as pocket rot.

WOOD FLOUR. Wood reduced to finely divided particles approximately those of cereal flours in size, appearance, and texture, and passing a 40–100 mesh screen.

WOOD SUBSTANCE. The solid material of which wood is composed. It usually refers to the extractive-free solid substance of which the cell walls are composed, but this is not always true. There is no wide variation in chemical composition or specific gravity between the wood substance of various species, the characteristic differences of species being largely due to differences in extractives and variations in relative amounts of cell walls and cell cavities.

WORKABILITY. The degree of ease and smoothness of cut obtainable with hand or machine tools.

XYLEM. The portion of the tree trunk, branches, and roots that lies between the pith and the cambium.

YARD LUMBER. (*See* **LUMBER.**)

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