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Forest Products Laboratory

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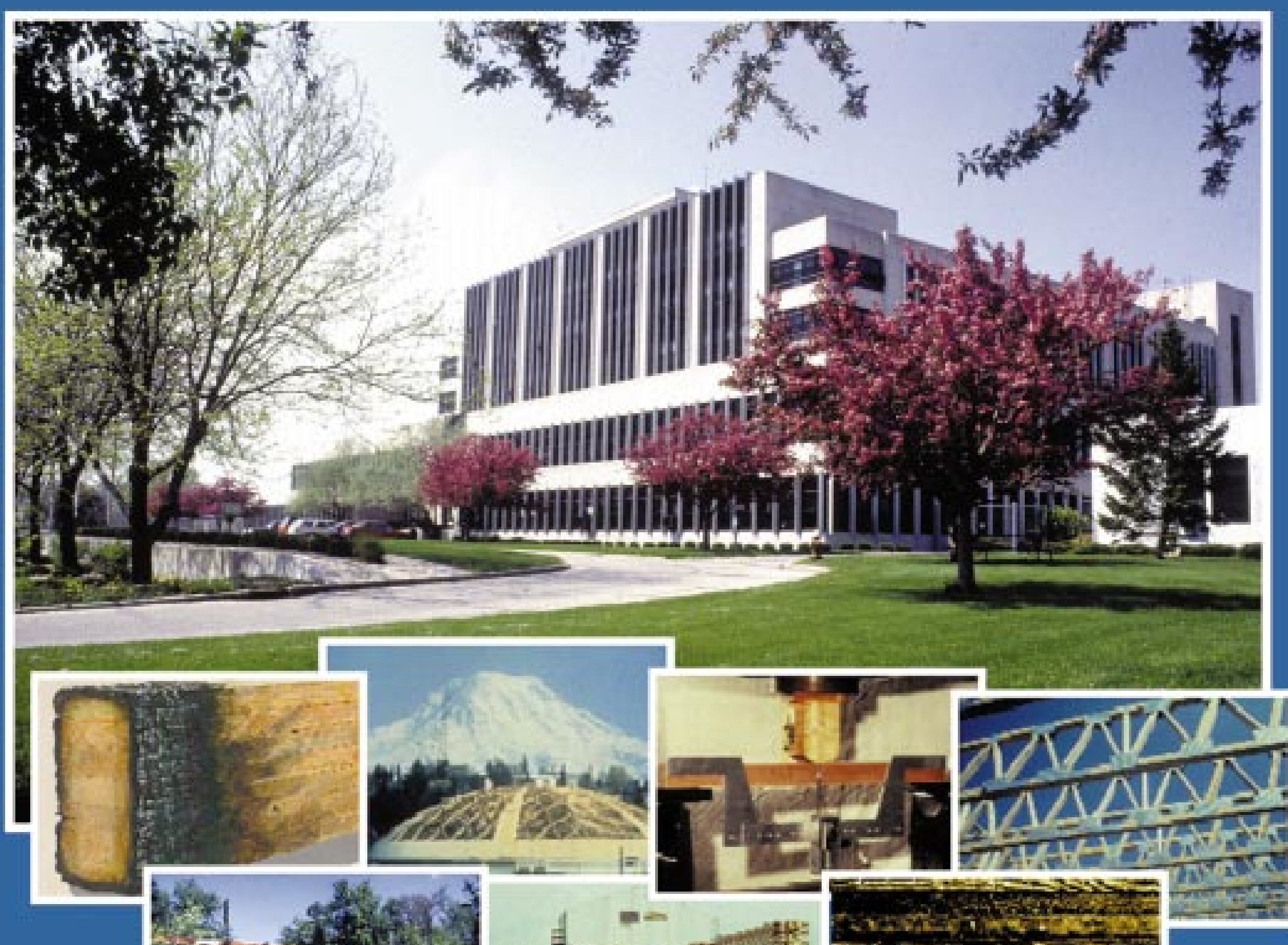
Wood Handbook

Wood as an Engineering Material



Abstract

Summarizes information on wood as an engineering material. Presents properties of wood and wood-based products of particular concern to the architect and engineer. Includes discussion of designing with wood and wood-based products along with some pertinent uses.

Keywords: wood structure, physical properties (wood), mechanical properties (wood), lumber, wood-based composites, plywood, panel products, design, fastenings, wood moisture, drying, gluing, fire resistance, finishing, decay, sandwich construction, preservation, and wood-based products

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The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

On the cover: (Left to right, top to bottom)

1. Research at the Forest Products Laboratory, Madison, Wisconsin, contributes to maximizing benefits of the Nation's timber resource.
2. Testing the behavior of wood in fire helps enhance fire safety.
3. The all-wood, 162-m (530-ft) clear-span Tacoma Dome exemplifies the structural and esthetic potential of wood construction (photo courtesy of Western Wood Structures, Inc., Tualatin, Oregon).
4. Bending tests are commonly used to determine the engineering properties of wood.
5. Engineered wood trusses exemplify research that has led to more efficient use of wood.
6. The Teal River stress-laminated deck bridge is located in Sawyer County, Wisconsin.
7. Kiln drying of wood is an important procedure during lumber manufacturing.
8. Legging adhesive (photo courtesy of Air Products and Chemicals, Inc., Allentown Pennsylvania). Adhesive bonding is a critical component in the performance of many wood products.

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Caution: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife, if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Wood Handbook

Wood as an Engineering Material

Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

Contents

Preface

Efficient use of our nation's timber resource is a vital concern. Because a major use of wood in the United States is in construction, particularly housing construction, good practice in this endeavor can have a profound impact on the resource. This handbook is intended as an aid to more efficient use of wood as a construction material. It 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. Continuing research and evaluation techniques hold promise for wider and more efficient utilization of wood and for more advanced industrial, structural, and decorative uses.

This handbook was prepared by the Forest Products Laboratory (FPL), a unit of the research organization of the Forest Service, U.S. Department of Agriculture. The Laboratory, established in 1910, is maintained at Madison, Wisconsin, 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 accumulation of information that has resulted from its engineering and allied investigations of wood and wood products over nine decades—along with knowledge of everyday construction practices and problems—is the chief basis for this handbook.

The *Wood Handbook* was first issued in 1935, and slightly revised in 1939, as an unnumbered publication. Further revisions in 1955, 1974, and 1987 were published by the U.S. Department of Agriculture as Agriculture Handbook No. 72. This current work is a complete revision of the 1987 edition. This revision was necessary to reflect more recent research accomplishments and technological changes.

The audience for the *Wood Handbook* is fairly broad. Therefore, the coverage of each chapter is aimed at providing a general discussion of the topic, with references included for additional information. Past versions of the *Wood Handbook* tended to report only the findings and applications of FPL research. Although the handbook is not intended to be a state-of-the-art review, this approach would now leave significant gaps in some important areas. The current edition has broadened the sources of information to provide better coverage of important topics.

The organization of this version of the *Wood Handbook* is similar to previous ones, with some modifications:

- Plywood (chapter 11 in the previous version), insulation board, hardboard, medium-density fiberboard (part of chapter 21 in the previous version), and wood-based particle panel materials (chapter 22 in the previous version) are now included in a new chapter on wood-based composites and panel products.

- Structural sandwich construction (chapter 12 in the previous version) is now included in the chapter on glued structural members.

- Moisture movement and thermal insulation in light-frame structures (chapter 20 in the previous version) are now part of a new chapter on use of wood in buildings and bridges.

- Bent wood members (chapter 13 in the previous version), modified woods, and paper-based laminates (chapter 23 in the previous version) are now included in a chapter on specialty treatments.

Consistent with movement by many U.S. standards agencies and industry associations toward use of metric units and near-universal implementation of metric usage in the international community, units of measurement in this version of the handbook are provided primarily in metric units, with customary inch–pound equivalents as secondary units. All conversions in this handbook to metric units, including conversions of empirically derived equations, are direct (or soft) conversions from previously derived inch–pound values. At some future time, metric expressions may need to be derived from a reevaluation of original research.

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Chapter 1

Characteristics and Availability of Commercially Important Woods

Regis B. Miller

Contents

Throughout history, 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, hemicelluloses, and minor amounts (5% to 10%) of extraneous materials contained in a cellular structure. Variations in the characteristics and volume of these components and differences in cellular structure make woods heavy or light, stiff or flexible, and hard or soft. The properties of a single species 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, specific characteristics or physical properties must be considered.

Historically, some species filled many purposes, while other less available or less desirable species served only one or two needs. For example, because white oak is tough, strong, and durable, it was highly prized for shipbuilding, bridges, cooperage, barn timbers, farm implements, railroad crossties, fence posts, and flooring. Woods such as black walnut and cherry were used primarily for furniture and cabinets. Hickory was manufactured into tough, hard, and resilient striking-tool handles, and black locust was prized for barn timbers. What the early builder or craftsman learned by trial and error became the basis for deciding which species were appropriate for a given use in terms of their characteristics. It was commonly accepted that wood from trees grown in certain locations under certain conditions was stronger, more durable, more easily worked with tools, or finer grained than wood from trees in other locations. Modern research on wood has substantiated that location and growth conditions do significantly affect wood properties.

The gradual reductions in use of old-growth forests in the United States has reduced the 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 wood, the remaining old-growth forests, and imports continue to fill the needs for wood in the quality required. Wood is as valuable an engineering material as ever, and in many cases, technological advances have made it even more useful.

The inherent factors that keep wood in the forefront of raw materials are many and varied, but a chief attribute is its availability in many species, sizes, shapes, and conditions to suit almost every demand. Wood 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, and yet it is an incomparable material for such musical instruments as the violin. The grain patterns and colors of wood make it 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. Damaged wood is easily repaired, and wood structures are easily remodeled or altered. In addition, wood resists oxidation, acid, saltwater, and other corrosive agents, has high salvage value, has good shock resistance, can be treated with preservatives and fire retardants, and can be combined with almost any other material for both functional and esthetic uses.

Timber Resources and Uses

In the United States, more than 100 wood species are available to the prospective user, but all are unlikely to be available in any one locality. About 60 native woods are of major commercial importance. Another 30 species are commonly imported in the form of logs, cants, lumber, and veneer for industrial uses, the building trade, and crafts.

A continuing program of timber inventory is in effect in the United States through the cooperation of Federal and State agencies, and new information on wood resources is published in State and Federal reports. Two of the most valuable sourcebooks are *An Analysis of the Timber Situation in the United States 1989–2040* (USDA 1990) and *The 1993 RPA Timber Assessment Update* (Haynes and others 1995).

Current information on wood consumption, production, imports, and supply and demand is published periodically by the Forest Products Laboratory (Howard 1997) and is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC.

Hardwoods and Softwoods

Trees are divided into two broad classes, usually referred to as hardwoods and softwoods. These names can be confusing since some softwoods are actually harder than some hardwoods, and conversely some hardwoods are softer than some softwoods. For example, softwoods such as longleaf pine and Douglas-fir are typically harder than the hardwoods basswood and aspen. Botanically, hardwoods are Angiosperms; the seeds are enclosed in the ovary of the flower. Anatomically, hardwoods are porous; that is, they contain vessel elements. A vessel element is a wood cell with open ends; when vessel elements are set one above another, they form a continuous tube (vessel), which serves as a conduit for transporting water or sap in the tree. Typically, hardwoods are plants with broad leaves that, with few exceptions in the temperate region, lose their leaves in autumn or winter. Most imported tropical woods are hardwoods. Botanically, softwoods are Gymnosperms or conifers; the seeds are naked (not enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and do not contain vessels. Softwoods are usually cone-bearing plants with needle- or scale-like evergreen leaves. Some softwoods, such as larches and baldcypress, lose their needles during autumn or winter.

Major resources of softwood species are spread across the United States, except for the Great Plains where only small areas are forested. Softwood species are often loosely grouped in three general regions, as shown in Table 1–1. Hardwoods also occur in all parts of the United States, although most grow east of the Great Plains. Hardwood species are shown by region in Table 1–2.

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, moulding, paneling, cabinets, poles and piles, and many other building components. Softwoods may also appear in the form of shingles, sashes, doors, and other millwork, in addition to some rough products such as timber and round posts.

Hardwoods are used in construction for flooring, architectural woodwork, interior woodwork, and paneling. These items are usually available from lumberyards and building supply dealers. Most hardwood lumber and dimension stock are remanufactured into furniture, flooring, pallets, containers, dunnage, and blocking. Hardwood lumber and dimension

Table 1–1. Major resources of U.S. softwoods according to region

Western	Northern	Southern
Incense-cedar	Northern white-cedar	Atlantic white-cedar
Port-Orford-cedar	Balsam fir	Baldcypress
Douglas-fir	Eastern hemlock	Fraser fir
White firs	Fraser fir	Southern Pine
Western hemlock	Jack pine	Eastern redcedar
Western larch	Red pine	
Lodgepole pine	Eastern white pine	
Ponderosa pine	Eastern redcedar	
Sugar pine	Eastern spruces	
Western white pine	Tamarack	
Western redcedar		
Redwood		
Engelmann spruce		
Sitka spruce		
Yellow-cedar		

Table 1–2. Major resources of U.S. hardwoods according to region

Southern	Northern and Appalachia	Western
Ash	Ash	Red alder
Basswood	Aspen	Oregon ash
American beech	Basswood	Aspen
Butternut	Buckeye	Black cottonwood
Cottonwood	Butternut	California black oak
Elm	American beech	Oregon white oak
Hackberry	Birch	Bigleaf maple
Pecan hickory	Black cherry	Paper birch
True hickory	American chestnut[a]	Tanoak
Honeylocust	Cottonwood	
Black locust	Elm	
Magnolia	Hackberry	
Soft maple	True hickory	
Red oaks	Honeylocust	
White oaks	Black locust	
Sassafras	Hard maple	
Sweetgum	Soft maple	
American sycamore	Red oaks	
Tupelo	White oaks	
Black walnut	American sycamore	
Black willow	Black walnut	
Yellow-poplar	Yellow-poplar	

[a]American chestnut is no longer harvested, but chestnut lumber from salvaged timbers can still be found on the market.

stock are available directly from the manufacturer, through wholesalers and brokers, and from some retail yards.

Both softwood and hardwood products are distributed throughout the United States. Local 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 home use.

Use Classes and Trends

The production and consumption levels of some of the many use-classifications for wood are increasing with the overall national economy, and others are holding about the same. The most vigorously growing wood-based industries are those that convert wood to thin slices (veneer), particles (chips, flakes), or fiber pulps and reassemble the elements to produce various types of engineered panels such as plywood, particleboard, strandboard, veneer lumber, paper, paperboard, and fiberboard products. Another growing wood industry is the production of laminated wood. For a number of years, the lumber industry has produced almost the same volume of wood per year. Modest increases have occurred in the production of railroad crossties, cooperage, shingles, and shakes.

Species Descriptions

In this chapter, each species or group of species is described in terms of its principal location, characteristics, and uses. More detailed information on the properties of these and other species is given in various tables throughout this handbook. Information on historical and traditional uses is provided for some species. Common and botanical names follow the *Checklist of United States Trees* (Little 1979).

U.S. Wood Species

Hardwoods

Alder, Red

Red alder (*Alnus rubra*) grows along the Pacific coast between Alaska and California. It is the principal hardwood for commercial manufacture of wood products in Oregon and Washington and the most abundant commercial hardwood species in these two states.

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

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

Ash (White Ash Group)

Important species of the white ash group are American white ash (*Fraxinus americana)*, green ash (*F. pennsylvanica*), blue ash (*F. quadrangulata*), and Oregon ash (*F. latifolia*). The first three species grow in the eastern half of the United States. Oregon ash grows along the Pacific Coast.

The heartwood of the white ash group is brown, and the sapwood is light-colored or nearly white. Second-growth trees are particularly sought after because of the inherent qualities of the wood from these trees: it is heavy, strong, hard, and stiff, and it has high resistance to shock. Oregon ash has somewhat lower strength properties than American white ash, but it is used for similar purposes on the West Coast.

American white ash is used principally for nonstriking tool handles, oars, baseball bats, and other sporting and athletic goods. For handles of the best grade, some handle specifications call for not less than 2 nor more than 7 growth rings per centimeter (not less than 5 nor more than 17 growth rings per inch). The additional weight requirement of 690 kg/m^3 (43 lb/ft^3) or more at 12% moisture content ensures high quality material. Principal uses for the white ash group are decorative veneer, cabinets, furniture, flooring, millwork, and crates.

Ash (Black Ash Group)

The black ash group includes black ash (*F. nigra)* and pumpkin ash (*F. profunda*). Black ash grows in the Northeast and Midwest, and pumpkin ash in the South.

The heartwood of black ash is a darker brown than that of American white ash; the sapwood is light-colored or nearly white. The wood of the black ash group is lighter in weight (basic specific gravity of 0.45 to 0.48) than that of the white ash group (>0.50). Pumpkin ash, American white ash, and green ash that grow in southern river bottoms, especially in areas frequently flooded for long periods, produce buttresses that contain relatively lightweight and brash wood.

Principal uses for the black ash group are decorative veneer, cabinets, millwork, furniture, cooperage, and crates.

Aspen

Aspen is a generally recognized name that is applied to bigtooth (*Populus grandidentata*) and quaking (*P. tremuloides*) aspen. Aspen does not include balsam poplar (*P. balsamifera)* and the other species of *Populus* that are included in the cottonwoods. In lumber statistics of the U.S. Bureau of the Census, however, the term cottonwood includes all the preceding species. Also, the lumber of aspen and cottonwood may be mixed in trade and sold as either popple or cottonwood. The name popple 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, with 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 the heartwood without being clearly marked. Aspen wood is usually straight grained with a fine, uniform texture. It is easily worked. Well-dried 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, and moderately low in resistance to shock and has moderately high shrinkage.

Aspen is cut for lumber, pallets, boxes and crating, pulpwood, particleboard, strand panels, excelsior, matches, veneer, and miscellaneous turned articles. Today, aspen is one of the preferred species for use in oriented strandboard, a panel product that is increasingly being used as sheathing.

Basswood

American basswood (*Tilia americana*) is the most important of the native basswood species; next in importance is white basswood (*T. heterophylla*), and no attempt is made to distinguish between these species in lumber form. In commercial usage, "white basswood" is used to specify the white wood or sapwood of either species. 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.

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 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 high; however, basswood seldom warps in use.

Basswood lumber is used mainly in venetian blinds, sashes and door frames, moulding, apiary supplies, wooden ware, and boxes. Some basswood is cut for veneer, cooperage, excelsior, and pulpwood, and it is a favorite of wood carvers.

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. The greatest production of beech lumber is in the Central and Middle Atlantic States.

In some beech trees, color varies from nearly white sapwood to reddish-brown heartwood. Sometimes there is no clear line of demarcation between heartwood and sapwood. Sapwood may be roughly 7 to 13 cm (3 to 5 in.) wide. 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 suitable for steam bending. Beech shrinks substantially and therefore requires careful drying. It machines smoothly, is an excellent wood for turning, wears well, and is rather easily treated with preservatives.

Most beech is used for flooring, furniture, brush blocks, handles, veneer, woodenware, containers, and cooperage. When treated with preservative, beech is suitable for railway ties.

Birch

The three most important species are yellow birch (*Betula alleghaniensis*), sweet birch (*B. lenta*), and paper birch (*B. papyrifera*). These three species are the source of most birch lumber and veneer. Other birch species of some commercial importance are river birch (*B. nigra*), gray birch (*B. populifolia*), and western paper birch (*B. papyrifera* var. *commutata*). Yellow, sweet, and paper birch grow principally in the Northeast and the Lake States; yellow and sweet birch also grow along the Appalachian Mountains to northern Georgia.

Yellow birch has white sapwood and light reddish-brown heartwood. Sweet birch has light-colored sapwood and dark brown heartwood tinged with red. For both yellow and sweet birch, the wood is heavy, hard, and strong, and it 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 is used primarily for the manufacture of furniture, boxes, baskets, crates, wooden ware, cooperage, interior woodwork, and doors; veneer plywood is used for flush doors, furniture, paneling, cabinets, aircraft, and other specialty uses. Paper birch is used for toothpicks, tongue depressors, ice cream sticks, and turned products, including spools, bobbins, small handles, and toys.

Buckeye

Buckeye consists of two species, yellow buckeye (*Aesculus octandra*) and Ohio buckeye (*A. glabra*). These species 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 used for the same purposes as aspen (*Populus*), basswood (*Tilia*), and sapwood of yellow-poplar (*Liriodendron tulipifera*).

The white sapwood of buckeye merges gradually into the creamy or yellowish white 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 machinability such as shaping, mortising, boring, and turning.

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

Butternut

Also called white walnut, butternut (*Juglans cinerea*) 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 heartwood is 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, butternut resembles black walnut especially when stained, but it does not have the same strength or hardness.

Principal uses are for lumber and veneer, which are further manufactured into furniture, cabinets, paneling, interior woodwork, and miscellaneous rough items.

Cherry, Black

Black cherry (*Prunus serotina*) is sometimes known as cherry, wild black cherry, and wild cherry. It is the only native species of the genus *Prunus* of commercial importance for lumber production. Black cherry is found 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 nearly white sapwood is narrow in old-growth trees and wider in second-growth trees. The wood has a fairly uniform texture and very good machining properties. It is moderately heavy, strong, stiff, and moderately hard; it has high shock resistance and moderately high shrinkage. Black cherry is very dimensionally stable after drying.

Black cherry is used principally for furniture, fine veneer panels, and architectural woodwork. Other uses include burial caskets, wooden ware, novelties, patterns, and paneling.

Chestnut, American

American chestnut (*Castanea dentata*) is also known as sweet chestnut. Before this species was attacked by a blight in the 1920s, it grew in commercial quantities from New England to northern Georgia. Practically all standing chestnut has been killed by blight, and most supplies of the lumber come from salvaged timbers. Because of the species' natural resistance to decay, standing dead trees in the Appalachian Mountains continued to provide substantial quantities of lumber for several decades after the blight, but this source is now exhausted.

The heartwood of chestnut is grayish brown or brown and darkens with age. The sapwood is very narrow and almost white. The wood is coarse in texture; 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, moderately hard, moderately low in strength, moderately low in resistance to shock, and low in stiffness. It dries well and is easy to work with tools.

Chestnut was once used for poles, railroad crossties, furniture, caskets, boxes, shingles, crates, and corestock for veneer panels. At present, it appears most frequently as wormy chestnut for paneling, interior woodwork, and picture frames.

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; black cottonwood (*P. trichocarpa*); and balsam poplar (*P. balsamifera*). Eastern 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 on the West Coast and in western Montana, northern Idaho, and western Nevada. Balsam poplar grows from Alaska across Canada and in the northern Great Lakes States.

The heartwood of cottonwood 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 dried. Eastern cottonwood is moderately low in bending and compressive strength, moderately stiff, moderately soft, and moderately low in ability to resist shock. Most strength properties of black cottonwood are slightly lower than those of eastern cottonwood. Both eastern and black cottonwood have moderately high shrinkage. Some cottonwood is difficult to work with tools because of its fuzzy surface, which is mainly the result of tension wood (see discussion of Reaction Wood in Ch. 4).

Cottonwood is used principally for lumber, veneer, pulpwood, excelsior, and fuel. Lumber and veneer are used primarily for boxes, crates, baskets, and pallets.

Elm

Six species of elm grow in the eastern United States: American (*Ulmus americana*), slippery (*U. rubra*), rock (*U. thomasii*), winged (*U. alata*), cedar (*U. crassifolia*), and September (*U. serotina*) elm. American elm is also known as white, water, and gray elm; slippery elm as red elm; rock elm as cork and hickory elm; winged elm as wahoo; cedar elm as red and basket elm; and September elm as red elm. American elm is threatened by two diseases, Dutch Elm disease and phloem necrosis, which have killed hundreds of thousands of trees.

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

Historically, elm lumber was used for boxes, baskets, crates, and slack cooperage; furniture; agricultural supplies and implements; caskets and burial boxes; and wood components in vehicles. Today, elm lumber and veneer are used mostly for furniture and decorative panels. Hard elm is preferred for uses that require strength.

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 hackberry range and grows throughout the Southern and South Atlantic States.

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 grain, moderately hard to very hard, and high in shock resistance, but low in stiffness. Hackberry has high shrinkage but keeps its shape well during drying.

Most hackberry is cut into lumber; small amounts are used for furniture parts, dimension stock, and veneer.

Hickory (Pecan Group)

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

The sapwood of this group is white or nearly white and relatively wide. The heartwood is somewhat darker. The wood is heavy and sometimes has very high shrinkage.

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

Hickory (True Group)

True hickories are found throughout 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, with the Southern and South Atlantic States rapidly expanding to handle nearly half of all hickory lumber.

The sapwood of the true hickory group is white and usually quite wide, except in old, slow-growing trees. The heartwood is reddish. The wood is exceptionally tough, heavy, hard, and strong, and shrinks considerably in drying. For some purposes, both rings per centimeter (or inch) and weight are limiting factors where strength is important.

The major use for high quality hickory is for tool handles, which require high shock resistance. It is also used for ladder rungs, athletic goods, agricultural implements, dowels, gymnasium apparatuses, poles, and furniture. Lower grade hickory is not suitable for the special uses of high quality hickory because of knottiness or other growth features and low density. However, the lower grade is useful for pallets and similar items. Hickory sawdust, chips, and some solid wood are used to flavor meat by smoking.

Honeylocust

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

Sapwood is generally wide and yellowish, in contrast to the light red to reddish-brown heartwood. The wood is very heavy, very hard, strong in bending, stiff, resistant to shock, and durable when in contact with the ground.

When available, honeylocust is primarily used locally for fence posts and general construction. It is occasionally used with other species in lumber for pallets and crating.

Locust, Black

Black locust (*Robinia pseudoacacia*) is sometimes called yellow or post locust. This species grows from Pennsylvania along the Appalachian Mountains to northern Georgia and Alabama. It is also native to western Arkansas and southern Missouri. 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 resistant to shock, and very strong and stiff. It has moderately low shrinkage. The heartwood has high decay resistance.

Black locust is used for round, hewed, or split mine timbers as well as fence posts, poles, railroad crossties, stakes, and fuel. Other uses are for rough construction, crating, and mine equipment. Historically, black locust was important for the manufacture of insulator pins and wooden pegs used in the construction of ships, for which the wood was well adapted because of its strength, decay resistance, and moderate shrinkage and swelling.

Magnolia

Commercial magnolia consists of three species: southern magnolia (*Magnolia grandiflora*), sweetbay (*M. virginiana*), and cucumbertree (*M. acuminata*). Other names for southern magnolia are evergreen magnolia, big laurel, bull bay, and laurel bay. Sweetbay is sometimes called swamp magnolia. The lumber produced by all three species is simply called magnolia. The natural range of sweetbay extends along the Atlantic and Gulf Coasts from Long Island to Texas, and that of southern magnolia extends from North Carolina to Texas. Cucumbertree grows from the Appalachians to the Ozarks northward to Ohio. Louisiana leads in the production of magnolia lumber.

Sapwood of southern magnolia is yellowish white, and 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 (*Liriodendron tulipifera*). 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 much like southern magnolia. The wood of cucumbertree is similar to that of yellow-poplar (*L. tulipifera*); cucumbertree that grows 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, sashes, doors, veneer, and millwork.

Maple, Hard

Hard maple includes sugar maple (*Acer saccharum*) and black maple (*A. nigrum*). Sugar maple is also known as hard and rock maple, and black maple as black sugar maple. Maple lumber is manufactured principally in the Middle Atlantic and Great Lake States, which together account for about two-thirds of production.

The heartwood is usually light reddish brown but sometimes considerably darker. The sapwood is commonly white with a slight reddish-brown tinge. It is roughly 7 to 13 cm or more (3 to 5 in. or more) wide. Hard maple has a fine, uniform texture. It is heavy, strong, stiff, hard, and resistant to shock and has high shrinkage. The grain of sugar maple is generally straight, but birdseye, curly, or fiddleback grain is often selected for furniture or novelty items.

Hard maple is used principally for lumber and veneer. A large proportion is manufactured into flooring, furniture, cabinets, cutting boards and blocks, pianos, billiard cues, handles, novelties, bowling alleys, dance and gymnasium floors, spools, and bobbins.

Maple, Soft

Soft maple includes silver maple (*Acer saccharinum*), red maple (*A. rubrum*), boxelder (*A. negundo*), and bigleaf maple (*A. macrophyllum*). Silver maple is also known as white, river, water, and swamp maple; red maple as soft, water, scarlet, white, and swamp maple; boxelder as ash-leaved, three-leaved, and cut-leaved maple; and bigleaf maple as Oregon maple. Soft maple is found in the eastern United States except for bigleaf maple, which comes from the Pacific Coast.

Heartwood and sapwood are similar in appearance to hard maple: heartwood of soft maple is somewhat lighter in color and the sapwood, somewhat wider. The wood of soft maple, primarily silver and red maple, resembles that of hard maple but is not as heavy, hard, and strong.

Soft maple is used for railroad crossties, boxes, pallets, crates, furniture, veneer, wooden ware, and novelties.

Oak (Red Oak Group)

Most red oak comes from the Eastern States. The principal species are northern red (*Quercus rubra*), scarlet (*Q. coccinea)*, Shumard (*Q. shumardii*), pin (*Q. palustris*), Nuttall (*Q. nuttallii*), black (*Q. velutina*), southern red (*Q. falcata*), cherrybark (*Q. falcata* var. *pagodaefolia*), water (*Q. nigra*), laurel (*Q. laurifolia*), and willow (*Q. phellos*) oak.

The sapwood is nearly white and roughly 2 to 5 cm (1 to 2 in.) wide. The heartwood is brown with a tinge of red. Sawn lumber of the red oak group cannot be separated by species on the basis of wood characteristics alone.

Red oak lumber can be separated from white oak by the size and arrangement of pores in latewood and because it generally lacks tyloses in the pores. The open pores of red oak make this species group unsuitable for tight cooperage, unless the barrels are lined with sealer or plastic. Quartersawn lumber of the oaks is distinguished by the broad and conspicuous rays. Wood of the red oaks is heavy. Rapidly grown second-growth wood is generally harder and tougher than finer textured old-growth wood. The red oaks have fairly high shrinkage in drying.

The red oaks are primarily cut into lumber, railroad crossties, mine timbers, fence posts, veneer, pulpwood, and fuelwood. Ties, mine timbers, and fence posts require preservative treatment for satisfactory service. Red oak lumber is remanufactured into flooring, furniture, general millwork, boxes, pallets and crates, agricultural implements, caskets, wooden ware, 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 (*Quercus alba*), chestnut (*Q. prinus*), post (*Q. stellata*), overcup (*Q. lyrata*), swamp chestnut (*Q. michauxii*), bur (*Q. macrocarpa*), chinkapin (*Q. muehlenbergii*), swamp white (*Q. bicolor*), and live (*Q. virginiana*) oak.

The sapwood of the white oaks is nearly white and roughly 2 to 5 cm or more (1 to 2 in. or more) wide. The heartwood is generally grayish brown. Heartwood pores are usually plugged with tyloses, which tend to make the wood impenetrable by liquids. Consequently, most white oaks are suitable for tight cooperage. Many heartwood pores of chestnut oak lack tyloses. The wood of white oak is heavy, averaging somewhat greater in weight than red oak wood. The heartwood has good decay resistance.

White oaks are usually cut into lumber, railroad crossties, cooperage, mine timbers, fence posts, 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 it was formerly used extensively for ship timbers. An important use of white oak is for planking and bent parts of ships and boats; heartwood is often specified because of its decay resistance. White oak is also used for furniture, flooring, pallets, agricultural implements, railroad cars, truck floors, furniture, doors, and millwork.

Sassafras

Sassafras (*Sassafras albidum*) ranges through most of the eastern half of the United States, from southeastern Iowa and eastern Texas eastward.

Sassafras is easily confused with black ash, which it resembles in color, grain, and texture. Sapwood is light yellow, and heartwood varies from dull grayish brown to dark brown, sometimes with a reddish tinge. Freshly cut surfaces have the characteristic odor of sassafras. The wood is moderately heavy, moderately hard, moderately weak in bending and endwise compression, quite high in shock resistance, and resistant to decay.

Sassafras was highly prized by the Indians for dugout canoes, and some sassafras lumber is still used for small boats. Locally, sassafras is used for fence posts and rails and for general millwork.

Sweetgum

Sweetgum (*Liquidambar styraciflua*) grows from southwestern Connecticut westward into Missouri and southward to the Gulf Coast. Almost all lumber is produced in the Southern and South Atlantic States.

The lumber from sweetgum is usually marked as sap gum (the light-colored sapwood) or redgum (the reddish-brown heartwood). Sweetgum often has a form of cross grain called interlocked grain, and it must be dried slowly. When quartersawn, interlocked grain produces a ribbon-type stripe that is desirable for interior woodwork and furniture. The wood is 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 crossties, fuel, pulpwood, boxes and crates, furniture, interior moulding, and millwork.

Sycamore, American

American sycamore (*Platanus occidentalis*) is known as sycamore and sometimes as buttonwood, buttonball-tree, and in the United Kingdom, planetree. Sycamore grows from Maine to Nebraska, southward to Texas, and eastward to Florida.

The heartwood of sycamore is reddish brown; the sapwood is lighter in color and from 4 to 8 cm (1-1/2 to 3 in.) wide. The wood has a fine texture and interlocked grain. It has high shrinkage in drying; is moderately heavy, moderately hard, moderately stiff, and moderately strong; and has good resistance to shock.

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

Tanoak

Tanoak (*Lithocarpus densiflorus*) has recently gained some commercial value, primarily in California and Oregon. It is also known as tanbark–oak because high-grade tannin was once obtained from the bark in commercial quantities. This species is found in southwestern Oregon and south to Southern California, mostly near the coast but also in the Sierra Nevadas.

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

Because of its hardness and abrasion resistance, tanoak is excellent 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, and it is also suitable for veneer, both decorative and industrial, and for high quality furniture.

Tupelo

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

Wood of the different tupelo species is quite similar in appearance and properties. The heartwood is light brownish gray and merges gradually into the lighter-colored sapwood, which is generally many centimeters wide. The wood has fine, uniform texture and interlocked grain. Tupelo wood is moderately heavy, 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. Because of interlocked grain, tupelo lumber requires care in drying.

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

Walnut, Black

Black walnut (*Juglans nigra*), also known as American black walnut, ranges from Vermont to the Great Plains and southward into Louisiana and Texas. About three-quarters of walnut wood is grown in the Central States.

The heartwood of black walnut varies from light to dark brown; the sapwood is nearly white and up to 8 cm (3 in.) wide in open-grown trees. Black walnut is normally straight grained, easily worked with tools, and stable in use. It is heavy, hard, strong, and stiff, and has good resistance to shock. Black walnut is well suited for natural finishes.

Because of its good properties and interesting grain pattern, black walnut is much valued for furniture, architectural woodwork, and decorative panels. Other important uses are gunstocks, cabinets, and interior woodwork.

Willow, Black

Black willow (*Salix nigra*) is the most important of the many willows that grow in the United States. It is the only willow marketed under its own name. Most black willow comes from the Mississippi Valley, from Louisiana to southern Missouri and Illinois.

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

Black willow is principally cut into lumber. Small amounts are used for slack cooperage, veneer, excelsior, charcoal, pulpwood, artificial limbs, and fence posts. The lumber is remanufactured principally into boxes, pallets, crates, caskets, and furniture.

Yellow-Poplar

Yellow-poplar (*Liriodendron tulipifera*) is also known as poplar, tulip-poplar, and tulipwood. 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 and Southeast.

Yellow-poplar sapwood is white and frequently several centimeters wide. 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. Slow-grown wood is moderately light in weight and moderately low in bending strength, moderately soft, and moderately low in shock resistance. The wood has moderately high shrinkage when dried from a green condition, but it is not difficult to dry and is stable after drying. Much of the second-growth wood is heavier, harder, and stronger than that of older trees that have grown more slowly.

The lumber is used primarily for furniture, interior moulding, siding, cabinets, musical instruments, and structural components. Boxes, pallets, and crates are made from lower-grade stock. Yellow-poplar is also made into plywood for paneling, furniture, piano cases, and various other special products.

Figure 1–1. Cypress-tupelo swamp near New Orleans, LA. Species include baldcypress (*Taxodium distichum*)), tupelo (*Nyssa*), ash (*Fraxinus*), willow (*Salix*), and elm (*Ulmus*). Swollen buttresses and "knees" are typically present in cypress.

Softwoods

Baldcypress

Baldcypress or cypress (*Taxodium distichum*) is also known as southern-cypress, red-cypress, yellow-cypress, and white-cypress. Commercially, the terms tidewater red-cypress, gulf-cypress, red-cypress (coast type), and yellow-cypress (inland type) are frequently used. About half of the cypress lumber comes from the Southern States and about a fourth from the South Atlantic States (Fig. 1–1). Old-growth baldcypress is no longer readily available, but second-growth wood is available.

Sapwood of baldcypress is narrow and nearly white. The color of heartwood varies widely, ranging from light yellowish brown to dark brownish red, brown, or chocolate. The wood is moderately heavy, moderately strong, and moderately hard. The heartwood of old-growth baldcypress is one of the most decay resistant of U.S. species, but second-growth wood is only moderately resistant to decay. Shrinkage is moderately low but somewhat higher than that of the cedars and lower than that of Southern Pine. The wood of certain baldcypress trees frequently contains pockets or localized areas that have been attacked by a fungus. Such wood is known as pecky cypress. The decay caused by this fungus is stopped when the wood is cut into lumber and dried. Pecky cypress is therefore durable and useful where water tightness is unnecessary, appearance is not important, or a novel effect is desired.

When old-growth wood was available, baldcypress was used principally for building construction, especially where resistance to decay was required. It was also used for caskets, sashes, doors, blinds, tanks, vats, ship and boat building, and cooling towers. Second-growth wood is used for siding and millwork, including interior woodwork and paneling. Pecky cypress is used for paneling in restaurants, stores, and other buildings.

Douglas-Fir

Douglas-fir (*Pseudotsuga menziesii*) is also known locally as red-fir, Douglas-spruce, and yellow-fir. Its range extends from the Rocky Mountains to the Pacific Coast and from Mexico to central British Columbia.

Sapwood of Douglas-fir is narrow in old-growth trees but may be as much as 7 cm (3 in.) wide in second-growth trees of commercial size. Young trees of moderate to rapid growth have reddish heartwood and are called red-fir. Very narrow-ringed heartwood of old-growth trees may be yellowish brown and is known on the market as yellow-fir. The wood of Douglas-fir varies widely in weight and strength. When lumber of high strength is needed for structural uses, selection can be improved by selecting wood with higher density.

Douglas-fir is used mostly for building and construction purposes in the form of lumber, marine fendering (Fig. 1–2), piles, and plywood. Considerable quantities are used for railroad crossties, cooperage stock, mine timbers, poles, and fencing. Douglas-fir lumber is used in the manufacture of various products, including sashes, doors, laminated beams, general millwork, railroad-car construction, boxes, pallets, and crates. Small amounts are used for flooring, furniture, ship and boat construction, and tanks. Douglas-fir plywood has found application in construction, furniture, cabinets, marine use, and other products.

Firs, True (Eastern Species)

Balsam fir (*Abies balsamea*) grows principally in New England, New York, Pennsylvania, and the Great Lake States. Fraser fir (*A. fraseri*) grows in the Appalachian Mountains of Virginia, North Carolina, and Tennessee.

The wood of the eastern true firs, as well as the western true firs, is creamy white to pale brown. The heartwood and sapwood are generally indistinguishable. The similarity of wood structure in the true firs makes it impossible to distinguish the species by examination of the wood alone. Balsam and Fraser firs are lightweight, have low bending and compressive strength, are moderately low in stiffness, are soft, and have low resistance to shock.

The eastern firs are used mainly for pulpwood, although some lumber is produced for structural products, especially in New England and the Great 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 true firs are cut for lumber primarily in Washington, Oregon, California, western Montana, and northern Idaho, and they are marketed as white fir throughout the United States.

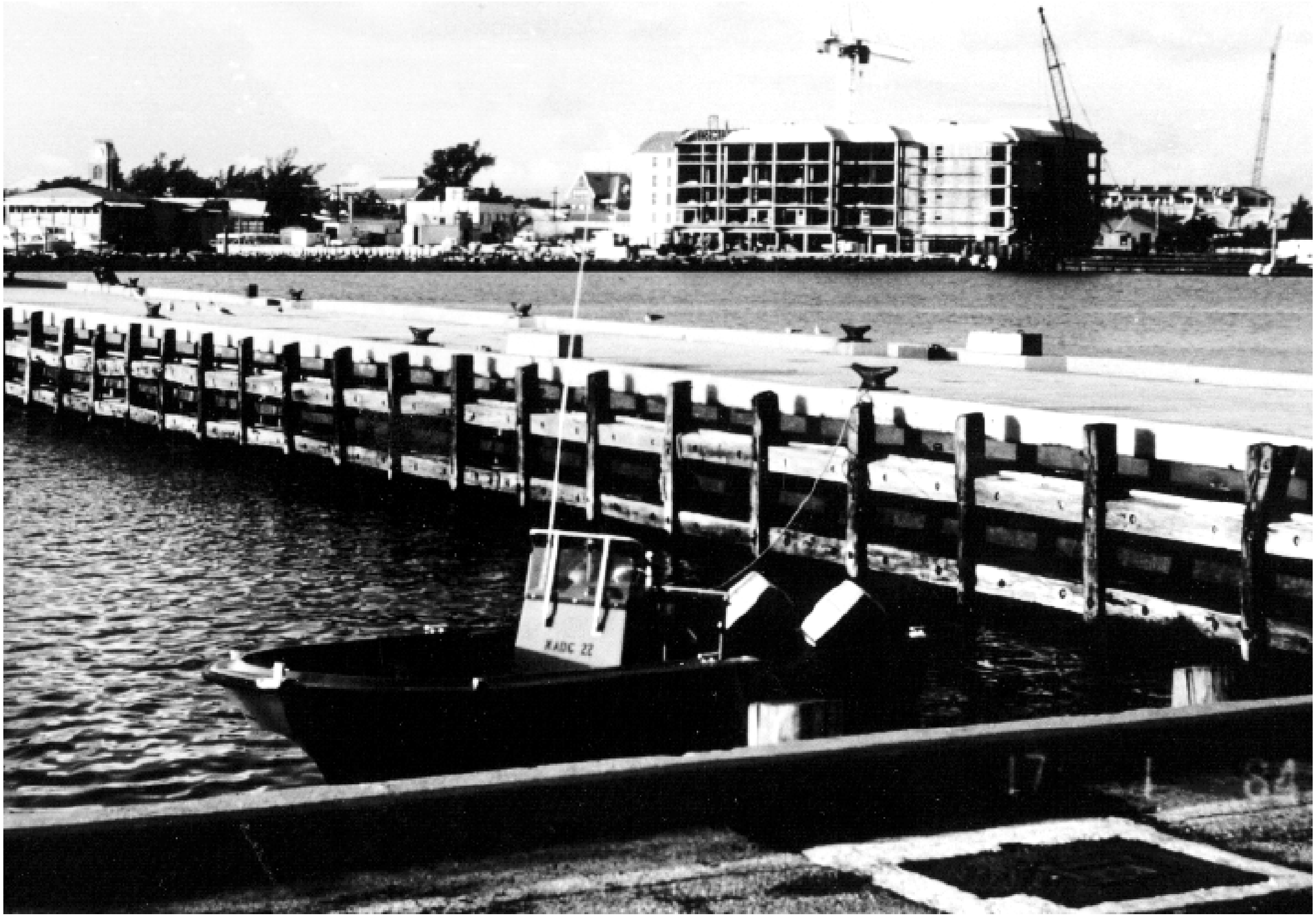

Figure 1–2. Wood is favored for waterfront structures, particularly fendering, because of its shock-absorbing qualities. The fendering on this dock in Key West, FL, is made of creosote-treated Douglas-fir (*Pseudotsuga menziesii*). Some tropical species are resistant to attack by decay fungi and marine borers and are used for marine construction without preservative treatment.

The wood of the western true firs is similar to that of the eastern true firs, which makes it impossible to distinguish the true fir species by examination of the wood alone. Western true firs are light in weight but, with the exception of subalpine fir, have somewhat higher strength properties than does balsam fir. Shrinkage of the wood is low to moderately high.

Lumber of the western true firs is primarily used for building construction, boxes and crates, planing-mill products, sashes, doors, and general millwork. In house construction, the lumber is used for framing, subflooring, and sheathing. Some western true fir lumber is manufactured into boxes and crates. High-grade lumber from noble fir is used mainly for interior woodwork, moulding, siding, and sash and door stock. Some of the highest quality material is suitable for aircraft construction. Other special uses of noble fir are venetian blinds and ladder rails.

Hemlock, Eastern

Eastern hemlock (*Tsuga canadensis*) grows from New England to northern Alabama and Georgia, and in the Great Lake States. Other names are Canadian hemlock and hemlock–spruce. The production of hemlock lumber is divided fairly evenly among the New England States, Middle Atlantic States, and Great 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 lightweight, moderately hard, moderately low in strength, moderately stiff, and moderately low in shock resistance.

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

Hemlock, Western and Mountain

Western hemlock (*Tsuga heterophylla*) is also known as West Coast hemlock, Pacific hemlock, British Columbia hemlock, hemlock–spruce, and western hemlock–fir. It grows along the Pacific coast of Oregon and Washington and in the northern Rocky Mountains north to Canada and Alaska. A relative of western hemlock, mountain hemlock (*T. mertensiana*) grows in 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 than the heartwood, is generally not more than 2.5 cm (1 in.) wide. The wood often contains small, sound, black knots that are usually tight and dimensionally stable. Dark streaks are often found in the lumber; these are caused by hemlock bark maggots and generally do not reduce strength. Western hemlock is moderately light in weight and moderate in strength. It is also moderate in hardness, stiffness, and shock resistance. Shrinkage of western hemlock is moderately high, about the same as that of Douglas-fir (*Pseudotsuga menziesii*). Green hemlock lumber contains considerably more water than does Douglas-fir and requires longer kiln-drying time. Mountain hemlock has approximately the same density as that of western hemlock but is somewhat lower in bending strength and stiffness.

Western hemlock and mountain hemlock are used principally for pulpwood, lumber, and plywood. The lumber is used primarily for building material, such as sheathing, siding, subflooring, joists, studding, planking, and rafters, as well as in the manufacture of boxes, pallets, crates, flooring, furniture, and ladders.

Incense-Cedar

Incense-cedar (*Calocedrus decurrens* (synonym *Libocedrus decurrens*)) grows in California, southwestern Oregon, and extreme western Nevada. Most incense-cedar lumber comes from the northern half of California.

Sapwood of incense-cedar is white or cream colored, and 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 low shrinkage and is easy to dry, with little checking or warping.

Incense-cedar is used principally for lumber and fence posts. Nearly all the high-grade lumber is used for pencils and venetian blinds; some is used for chests and toys. Much incense-cedar wood 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 decay once the lumber is dried. This low-quality lumber is used locally for rough construction where low cost and decay resistance are important. Because of its resistance to decay, incense-cedar is well suited for fence posts. Other uses are railroad crossties, 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 2.5 cm (1 in.) wide. The wood is stiff, moderately strong and hard, moderately high in shock resistance, and moderately heavy. It has moderately high shrinkage. The wood is usually straight grained, splits easily, and is subject to ring shake. Knots are common but generally small and tight.

Western larch is used mainly for rough dimension wood in building construction, small timbers, planks and boards, and railroad crossties and mine timbers. It is used also for piles, poles, and posts. Some high-grade material is manufactured into interior woodwork, flooring, sashes, and doors. The properties of western larch are similar to those of Douglas-fir (*Pseudotsuga menziesii*), and these species are sometimes sold mixed.

Pine, Eastern White

Eastern white pine (*Pinus strobus*) grows from Maine to northern Georgia and in the Great 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 New England, about one-third in the Great 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 darker on exposure to air. The wood has comparatively uniform texture and is straight grained. It is easily kiln dried, has low shrinkage, and ranks high in stability. It is also easy to work and can be readily glued. Eastern white pine is lightweight, moderately soft, moderately low in strength, low in shock resistance, and low in stiffness.

Practically all eastern white pine is converted into lumber, which is used in a great variety of ways. A large proportion, mostly second-growth knotty wood or lower grades, is used for structural lumber. High-grade lumber is used for patterns for castings. Other important uses are sashes, doors, furniture, interior woodwork, knotty paneling, caskets, shade and map rollers, and toys.

Pine, Jack

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

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

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

Pine, Jeffrey (see Pine, Ponderosa)

Pine, Lodgepole

Lodgepole pine (*Pinus contorta*), also known as knotty, black, and spruce pine, grows in the Rocky Mountain and Pacific Coast regions as far northward as Alaska. Wood for lumber and other products is produced primarily in 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 lightweight, is fairly easy to work, and has moderately high shrinkage. It is moderately low in strength, moderately soft, moderately stiff, and moderately low in shock resistance.

Lodgepole pine is used for lumber, mine timbers, railroad crossties, and poles. Less important uses include posts and fuel. Lodgepole pine is being used increasingly for framing, siding, millwork, flooring, and cabin logs.

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 wide and light yellow. The wood of pitch pine is moderately heavy to heavy, moderately strong, stiff, and hard, and moderately high in shock resistance. Shrinkage ranges from moderately low to moderately high.

Pitch pine is used for lumber, fuel, and pulpwood. The lumber is classified as a minor species in grading rules for the Southern Pine species group.

Pine, Pond

Pond pine (*Pinus serotina*) grows in the coastal region from New Jersey to Florida. It occurs in small groups or singly, mixed with other pines on low flats.

Sapwood of pond pine is wide and pale yellow; heartwood is dark orange. The wood is heavy, coarse grained, and resinous. Shrinkage is moderately high. The wood is moderately strong, stiff, moderately hard, and moderately high in shock resistance.

Figure 1–3. Ponderosa pine (*Pinus ponderosa*) growing in an open or park-like habitat.

Pond pine is used for general construction, railway crossties, posts, and poles. The lumber of this species is also graded as a minor species in grading rules for the Southern Pine species group.

Pine, Ponderosa

Ponderosa pine (*Pinus ponderosa*) is also known as ponderosa, western soft, western yellow, bull, and blackjack pine. 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 ponderosa pine producing areas are in Oregon, Washington, and California (Fig. 1–3). Other important producing areas are in Idaho and Montana; lesser amounts come from the southern Rocky Mountain region, the Black Hills of South Dakota, and Wyoming.

The heartwood of ponderosa pine 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 low 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 railroad crossties. The clear wood is used for sashes, doors, blinds, moulding, paneling, interior woodwork, and built-in cases and cabinets. Low-grade lumber is used for boxes and crates. Much intermediate- or low-grade lumber is used for sheathing, subflooring, and roof boards. Knotty ponderosa pine is used for interior woodwork.

Pine, Red

Red pine (*Pinus resinosa*) is frequently called Norway pine and occasionally known as hard pine and pitch pine. This species grows in New England, New York, Pennsylvania, and the Great Lake States.

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 5 to 10 cm (2 to 4 in.) wide. The wood resembles the lighter weight wood of the Southern Pine species group. 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 as uniform in texture as eastern white pine (*Pinus strobus*), and somewhat resinous. The wood has moderately high shrinkage, but it is not difficult to dry and is dimensionally stable when dried.

Red pine is used principally for lumber, cabin logs, and pulpwood, and to a lesser extent for piles, poles, posts, and fuel. The lumber is used for many of the same purposes as for eastern white pine (*Pinus strobus*). Red pine lumber is used primarily for building construction, including treated lumber for decking, siding, flooring, sashes, doors, general millwork, and boxes, pallets, and crates.

Pine, Southern

A number of species are included in the group marketed as Southern Pine lumber. The four major Southern Pine species and their growth ranges are as follows: (a) longleaf pine (*Pinus palustris*), eastern North Carolina southward into Florida and westward into eastern Texas; (b) shortleaf pine (*P. echinata*), southeastern New York and New Jersey southward to northern Florida and westward into eastern Texas and Oklahoma; (c) loblolly pine (*P. taeda*), Maryland southward through the Atlantic Coastal Plain and Piedmont Plateau into Florida and westward into eastern Texas; (d) slash pine (*P. elliottii*), Florida and southern South Carolina, Georgia, Alabama, Mississippi, and Louisiana east of the Mississippi River. Lumber from these four species is classified as Southern Pine by the grading standards of the industry. These standards also classify lumber produced from the longleaf and slash pine species as longleaf pine if the lumber conforms to the growth-ring and latewood requirements of such standards. Southern Pine lumber is produced principally in the Southern and South Atlantic States. Georgia, Alabama, North Carolina, Arkansas, and Louisiana lead in Southern Pine lumber production.

The wood of these southern pines is quite similar in appearance. Sapwood is yellowish white and heartwood, reddish brown. The sapwood is usually wide in second-growth stands. The heartwood begins to form when the tree is about 20 years old. In old, slow-growth trees, sapwood may be only 2 to 5 cm (1 to 2 in.) wide.

Longleaf and slash pine are classified as heavy, strong, stiff, hard, and moderately high in shock resistance. Shortleaf and loblolly pine are usually somewhat lighter in weight than is longleaf. All the southern pines have moderately high shrinkage but are dimensionally stable when properly dried. To obtain heavy, strong wood of the southern pines for structural purposes, a density rule has been written that specifies a certain percentage of latewood and growth rates for structural timbers.

The denser and higher strength southern pines are extensively used in the form of stringers in construction of factories, warehouses, bridges, trestles, and docks, and also for roof trusses, beams, posts, joists, and piles. Lumber of lower density and strength is also used for building material, such as interior woodwork, sheathing, and subflooring, as well as boxes, pallets, and crates. Southern Pine is used also for tight and slack cooperage. When used for railroad crossties, piles, poles, mine timbers, and exterior decking, it is usually treated with preservatives. The manufacture of structural-grade plywood from Southern Pine is a major wood-using industry, as is the production of preservative-treated lumber.

Pine, Spruce

Spruce pine (*Pinus glabra*), also known as cedar, poor, Walter, and bottom white pine, is classified as a minor species in the Southern Pine species group. Spruce pine grows most commonly on low moist lands of the coastal regions of southeastern South Carolina, Georgia, Alabama, Mississippi, and Louisiana, and northern and northwestern Florida.

The heartwood of spruce pine is light brown, and the wide sapwood is nearly white. Spruce pine wood is lower in most strength values than the wood of the major Southern Pine species group. Spruce pine compares favorably with the western true firs in important bending properties, crushing strength (perpendicular and parallel to grain), and hardness. It is similar to denser species such as coast Douglas-fir (*Pseudotsuga menziesii*) and loblolly pine (*Pinus taeda*) in shear parallel to grain.

In the past, spruce pine was principally used locally for lumber, pulpwood, and fuelwood. The lumber reportedly was used for sashes, doors, and interior woodwork because of its low specific gravity and similarity of earlywood and latewood. In recent years, spruce pine has been used for plywood.

Pine, Sugar

Sugar pine (*Pinus lambertiana*), the world's largest species of pine, is sometimes called California sugar pine. Most sugar pine lumber grows in California and 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 low shrinkage, is readily dried without warping or checking, and is dimensionally stable. Sugar pine is lightweight, moderately low in strength, moderately soft, low in shock resistance, and low in stiffness.

Sugar pine is used almost exclusively for lumber products. The largest volume is used for boxes and crates, sashes, doors, frames, blinds, general millwork, building construction, and foundry patterns. Like eastern white pine (*Pinus strobus*), sugar pine is suitable for use in nearly every part of a house because of the ease with which it can be cut, its dimensional stability, and its good nailing properties.

Pine, Virginia

Virginia pine (*Pinus virginiana*), also known as Jersey and scrub pine, grows from New Jersey and Virginia throughout the Appalachian region to Georgia and the Ohio Valley. It is classified as a minor species in the grading rules for the Southern Pine species group.

The heartwood is orange, and the sapwood is nearly white and relatively wide. The wood is moderately heavy, moderately strong, moderately hard, and moderately stiff and has moderately high shrinkage and high shock resistance.

Virginia pine is used for lumber, railroad crossties, mine timbers, and pulpwood.

Pine, Western White

Western white pine (*Pinus monticola*) is also known as Idaho white pine or white pine. About four-fifths of the wood for lumber from this species is from Idaho and Washington; small amounts are cut in Montana and Oregon.

The heartwood of western white pine is cream colored to light reddish brown and darkens on exposure to air. The sapwood is yellowish white and generally from 2 to 8 cm (1 to 3 in.) wide. The wood is straight grained, easy to work, easily kiln-dried, and stable after drying. This species is moderately lightweight, moderately low in strength, moderately soft, moderately stiff, and moderately low in shock resistance and has moderately high shrinkage.

Practically all western white pine is sawn into lumber, which is used mainly for building construction, matches, boxes, patterns, and millwork products, such as sashes and door frames. In building construction, lower-grade boards are used for sheathing, knotty paneling, and subflooring. High-grade material is made into siding of various kinds, exterior and interior woodwork, and millwork. Western white pine has practically the same uses as eastern white pine (*Pinus strobus*) and sugar pine (*Pinus lambertiana*).

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, Oregon, southward to California. It does not extend more than 64 km (40 mi) inland.

The heartwood of Port-Orford-cedar is light yellow to pale brown. The sapwood is narrow and hard to distinguish from the heartwood. The wood has fine texture, generally straight grain, and a pleasant spicy odor. It is moderately lightweight, 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 drying.

Some high-grade Port-Orford-cedar was once used in the manufacture of storage battery separators, matchsticks, and specialty millwork. Today, other uses are archery supplies, sash and door construction, stadium seats, flooring, interior woodwork, furniture, and boats.

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.

The heartwood of redcedar is bright or dull red, and the narrow 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 low shrinkage and is dimensionally stable after drying. The texture is fine and uniform, and the wood commonly has numerous small knots. Eastern redcedar heartwood is very resistant to decay.

The greatest quantity of eastern redcedar is used for fence posts. 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. Eastern redcedar is reputed to repel moths, but this claim has not been supported by research.

Redcedar, Western

Western redcedar (*Thuja plicata*) grows in the Pacific Northwest and along the Pacific Coast to Alaska. It 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 is nearly white. The sapwood is narrow, often not more than 2.5 cm (1 in.) wide. The wood is generally straight grained and has a uniform but rather coarse texture. It has very low shrinkage. This species is lightweight, moderately soft, low in strength when used as a beam or posts, and low in shock resistance. The 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, decking, interior woodwork, greenhouse construction, ship and boat building, boxes and crates, sashes, and doors.

Redwood

Redwood (*Sequoia sempervirens*) grows on the coast of California and some trees are among the tallest in the world. A closely related species, giant sequoia (*Sequoiadendron giganteum*), is volumetrically larger and grows in a limited area in the Sierra Nevadas of California, but its wood 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 the market is nationwide.

The heartwood of redwood varies from light "cherry" red to dark mahogany. The narrow sapwood is almost white. Typical old-growth redwood is moderately lightweight, moderately strong and stiff, and moderately hard. The wood is easy to work, generally straight grained, and shrinks and swells comparatively little. The heartwood from old-growth trees has high decay resistance; heartwood from second-growth trees generally has low to moderate decay resistance.

Most redwood lumber is used for building. It is remanufactured extensively into siding, sashes, doors, blinds, millwork, casket stock, and containers. Because of its durability, redwood is useful for cooling towers, decking, 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. Redwood splits readily and plays an important role in the manufacture of split products, such as posts and fence material. Some redwood veneer is produced for decorative plywood.

Spruce, Eastern

The term eastern spruce includes three species: red (*Picea rubens*), white (*P. glauca*), and black (*P. mariana*). White and black spruce grow principally in the Great Lake States and New England, and red spruce grows in New England and the Appalachian Mountains.

The wood is light in color, and there is little difference between heartwood and sapwood. All three species have about the same properties, and they are not distinguished from each other in commerce. The wood dries easily and is stable after drying, is moderately lightweight and easily worked, has moderate shrinkage, and is moderately strong, stiff, tough, and hard.

The greatest use of eastern spruce is for pulpwood. Eastern spruce lumber is used for framing material, general millwork, boxes and crates, 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 also known 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 and most of the remainder in 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 2 to 5 cm (3/4 to 2 in.) in width and is often difficult to distinguish from the heartwood. The wood has medium to fine texture and is without characteristic odor. Engelmann spruce is rated as lightweight, and it is low in strength as a beam or post. It is also soft and low in stiffness, shock resistance, and shrinkage. The lumber typically contains many small knots.

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

Spruce, Sitka

Sitka spruce (*Picea sitchensis*) is a large tree that grows along the northwestern coast of North America from California to Alaska. It is also known as yellow, tideland, western, silver, and west coast spruce. Much Sitka spruce timber is grown in Alaska, but most logs are sawn into cants for export to Pacific Rim countries. Material for U.S. consumption is produced primarily in Washington and Oregon.

The heartwood of Sitka spruce is a light pinkish brown. The sapwood is creamy white and shades gradually into the heartwood; the sapwood may be 7 to 15 cm (3 to 6 in.) 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 lightweight, moderately low in bending and compressive strength, moderately stiff, moderately soft, and moderately low in resistance to shock. It has moderately low shrinkage. On the basis of weight, Sitka spruce rates high in strength properties and can be obtained in long, 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, sashes, 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*), also known as eastern larch and locally as hackmatack, is a small to medium tree with a straight, round, slightly tapered trunk. It grows from Maine to Minnesota, with the bulk of the stand in the Great Lake States.

The heartwood of tamarack is yellowish brown to russet brown. The sapwood is whitish, generally less than 2.5 cm (1 in.) 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 crossties, mine timbers, fuel, fence posts, and poles. Lumber is used for framing material, tank construction, and boxes, pallets, and crates. The production of tamarack lumber has declined in recent years.

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 as cedar. Atlantic white-cedar is also known as southern white-cedar, swamp-cedar, and boat-cedar. Northern white-cedar grows from Maine along the Appalachians and westward through the northern part of the Great 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 greatest in Maine and the Great Lake States. 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 narrow. The wood is lightweight, rather soft, and low in strength and shock resistance. It shrinks little in drying. It is easily worked and holds paint well, and the heartwood is highly resistant to decay. Northern and Atlantic white-cedar are used for similar purposes, primarily for poles, cabin logs, railroad crossties, lumber, posts, and decorative fencing. White-cedar lumber is used principally where a high degree of durability is needed, as in tanks and boats, and for wooden ware.

Yellow-Cedar

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

The heartwood of yellow-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 shock resistance. Yellow-cedar shrinks little in drying and is stable after drying, and the heartwood is very resistant to decay. The wood has a mild, distinctive odor.

Yellow-cedar is used for interior woodwork, furniture, small boats, cabinetwork, and novelties.

Imported Woods

This section does not purport to describe all the woods that have been at one time or another imported into the United States. It includes only those species that at present are considered to be commercially important. The same species may be marketed in the United States under other common names. Because of the variation in common names, many cross-references are included. Text information is necessarily brief, but when used in conjunction with the shrinkage and strength data tables (Ch. 3 and 4), a reasonably good picture may be obtained of a particular wood. The references at the end of this chapter contain information on many species not described in this section.

Hardwoods

Afara (see Limba)

Afrormosia

Afrormosia or kokrodua (*Pericopsis elata*), a large West African tree, is sometimes used as a substitute for teak (*Tectona grandis*).

The heartwood is fine textured, with straight to interlocked grain. The wood is brownish yellow with darker streaks and moderately hard and heavy, weighing about 700 kg/m^3 (43 lb/ft^3) at 15% moisture content. The wood strongly resembles teak in appearance but lacks its oily nature and has a different texture. The wood dries readily with little degrade and has good dimensional stability. It is somewhat heavier and stronger than teak. The heartwood is highly resistant to decay fungi and termite attack and is extremely durable under adverse conditions.

Afrormosia is often used for the same purposes as teak, such as boat construction, joinery, flooring, furniture, interior woodwork, and decorative veneer.

Albarco

Albarco, or jequitiba as it is known in Brazil, is the common name applied to species in the genus *Cariniana*. The 10 species are distributed from eastern Peru and northern Bolivia through central Brazil to Venezuela and Colombia.

The heartwood is reddish or purplish brown and sometimes has dark streaks. It is usually not sharply demarcated from the pale brown sapwood. The texture is medium and the grain straight to interlocked. Albarco can be worked satisfactorily with only slight blunting of tool cutting edges because of the presence of silica. Veneer can be cut without difficulty. The wood is rather strong and moderately heavy, weighing about 560 kg/m^3 (35 lb/ft^3) at 12% moisture content. In general, the wood has about the same strength as that of U.S. oaks (*Quercus* spp.). The heartwood is durable, particularly the deeply colored material. It has good resistance to drywood termite attack.

Albarco is primarily used for general construction and carpentry wood, but it can also be used for furniture components, shipbuilding, flooring, veneer for plywood, and turnery.

Amaranth (see Purpleheart)

Anani (see Manni)

Anaura (see Marishballi)

Andiroba

Because of the widespread distribution of andiroba (*Carapa guianensis*) in tropical America, the wood is known under a variety of names, including 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 varies from medium to dark reddish brown. The texture is like that of true mahogany (*Swietenia macrophylla*), and andiroba is sometimes substituted for true mahogany. The grain is usually interlocked but is rated 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 true mahogany and accordingly is markedly superior in all static bending properties, compression parallel to grain, hardness, shear, and durability.

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, utility and decorative veneer, and plywood.

Angelin (see Sucupira)

Angelique

Angelique (*Dicorynia guianensis*) comes from French Guiana and Suriname.

Because of the variability in heartwood color between different trees, two forms are commonly recognized by producers. The heartwood that is russet-colored when freshly cut and becomes superficially dull brown with a purplish cast is referred to as “gris.” The heartwood that is more distinctly reddish and frequently shows wide purplish bands is called “angelique rouge.” The texture of the wood is somewhat coarser than that of black walnut (*Juglans nigra*), and the grain is generally straight or slightly interlocked. In strength, angelique is superior to teak (*Tectona grandis*) and white oak (*Quercus alba*), when 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 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 also suitable for ship decking, planking, boat frames, industrial flooring, and parquet blocks and strips.

Apa (see Wallaba)

Apamate (see Roble)

Apitong (see Keruing)

Avodire

Avodire (*Turraeanthus africanus*) has a rather extensive range in Africa, from Sierra Leone westward to the Congo region and southward to Zaire and Angola. It is most common in the eastern region of the Ivory Coast and is scattered elsewhere. Avodire is a medium-size tree of the rainforest where it forms fairly dense but localized and discontinuous timber stands.

The wood is cream to pale yellow with high natural luster; it eventually darkens to a golden yellow. The grain is sometimes straight but more often wavy or irregularly interlocked, which produces an unusual and attractive mottled figure when sliced or cut on the quarter. Although avodire weighs less than northern red oak (*Quercus rubra*), it has almost identical strength properties except that it is lower in shock resistance and 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. Other uses include furniture, fine joinery, cabinetwork, and paneling.

Azobe (Ekki)

Azobe or ekki (*Lophira alata*) is found in West Africa and extends into the Congo basin.

The heartwood is dark red, chocolate-brown, or purple–brown with conspicuous white deposits in the pores (vessels). The texture is coarse, and the grain is usually interlocked. The wood is strong, and its density averages about 1,120 kg/m^3 (70 lb/ft^3) at 12% moisture content. It is very difficult to work with hand and machine tools, and tools are severely blunted if the wood is machined when dry. Azobe can be dressed to a smooth finish, and gluing properties are usually good. Drying is very difficult without excessive degrade. The heartwood is rated as very durable against decay but only moderately resistant to termite attack. Azobe is very resistant to acid and has good weathering properties. It is also resistant to teredo attack. The heartwood is extremely resistant to preservative treatment.

Azobe is excellent for heavy construction work, harbor construction, heavy-duty flooring, and railroad crossties.

Bagtikan (see Seraya, White)

Balata

Balata or bulletwood (*Manilkara bidentata*) is widely distributed throughout the West Indies, Central America, and northern South America.

The heartwood of balata is light to dark reddish brown and not sharply demarcated from the pale brown sapwood. Texture is fine and uniform, and the grain is straight to occasionally wavy or interlocked. Balata is a strong and very heavy wood; density of air-dried wood is 1,060 kg/m^3 (66 lb/ft^3). It is generally difficult to air dry, with a tendency to develop severe checking and warp. The wood is moderately easy to work despite its high density, and it is rated good to excellent in all machining operations. Balata is very resistant to attack by decay fungi and highly resistant to subterranean termites but only moderately resistant to dry-wood termites.

Balata is suitable for heavy construction, textile and pulpmill equipment, furniture parts, turnery, tool handles, flooring, boat frames and other bentwork, railroad crossties, violin bows, billiard cues, and other specialty uses.

Balau

Balau, red balau, and selangan batu constitute a group of species that are the heaviest of the 200 *Shorea* species. About 45 species of this group grow from Sri Lanka and southern India through southeast Asia to the Philippines.

The heartwood is light to deep red or purple–brown, and it is fairly distinct from the lighter and yellowish- to reddish- or purplish-brown sapwood. The texture is moderately fine to coarse, and the grain is often interlocked. The wood weighs more than 750 kg/m^3 (47 lb/ft^3) at 12% moisture content. Balau is a heavy, hard, and strong timber that dries slowly with moderate to severe end checks and splits. The heartwood is durable to moderately durable and very resistant to preservative treatments.

Balau is used for heavy construction, frames of boats, decking, flooring, and utility furniture.

Balau, Red (see Balau)

Balsa

Balsa (*Ochroma pyramidale*) is widely distributed throughout tropical America from southern Mexico to southern Brazil and Bolivia, but Ecuador has been the principal source of supply since the wood gained commercial importance. It is usually found at lower elevations, especially on bottomland soils along streams and in clearings and cutover forests. Today, it is often cultivated in plantations.

Several characteristics make balsa suitable for 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 weighs, on the average, about 180 kg/m^3 (11 lb/ft^3) when dry and often as little as 100 kg/m^3 (6 lb/ft^3). The wood is readily recognized by its light weight; nearly white or oatmeal color, often with a yellowish or pinkish hue; and unique velvety feel.

Because of its light weight and exceedingly porous composition, balsa is highly efficient in uses where buoyancy, insulation against heat or cold, or low propagation of sound and vibration are important. Principal uses are for life-saving equipment, floats, rafts, corestock, insulation, cushioning, sound modifiers, models, and novelties.

Banak (Cuangare)

Various species of banak (*Virola*) occur in tropical America, from Belize and Guatemala southward to Venezuela, the Guianas, the Amazon region of northern Brazil, and southern Brazil, and on the Pacific Coast to Peru and Bolivia. Most of the wood known as banak is *V. koschnyi* of Central America and *V. surinamensis* and *V. sebifera* of northern South America. Botanically, cuangare (*Dialyanthera*) is closely related to banak, and the woods are so similar that they are generally mixed in the trade. The main commercial supply of cuangare comes from Colombia and Ecuador. Banak and cuangare are common in swamp and marsh forests and may occur in almost pure stands in some areas.

The heartwood of both banak and cuangare is usually pinkish or grayish brown and is generally 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. Machining properties are very good, but when zones of tension wood are present, machining may result in surface fuzziness. The wood finishes readily and is easily glued. Strength properties of banak and cuangare are similar to those of yellow-poplar (*Liriodendron tulipifera*).

Banak is considered a general utility wood for lumber, veneer, and plywood. It is also used for moulding, millwork, and furniture components.

Benge (Ehie, Bubinga)

Although benge (*Guibourtia arnoldiana*), ehie or ovangkol (*Guibourtia ehie*), and bubinga (*Guibourtia* spp.) belong to the same West African genus, they differ rather markedly in color and somewhat in texture.

The heartwood of benge is pale yellowish brown to medium brown with gray to almost black stripes. Ehie heartwood tends to be more golden brown to dark brown with gray to almost black stripes. Bubinga heartwood is pink, vivid red, or red–brown with purple streaks, and it becomes yellow or medium brown with a reddish tint upon exposure to air. The texture of ehie is moderately coarse, whereas that of benge and bubinga is fine to moderately fine. All three woods are moderately hard and heavy, but they can be worked well with hand and machine tools. They are listed as moderately durable and resistant to preservative treatment. Drying may be difficult, but with care, the wood dries well.

These woods are used in turnery, flooring, furniture components, cabinetwork, and decorative veneers.

Brown Silverballi (see Kaneelhart)

Bubinga (see Benge)

Bulletwood (see Balata)

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.

Sapwood may be very pale pink or distinctly reddish, and it is usually wide. In trees up to 76 cm (30 in.) in diameter, heartwood may be only 18 cm (7 in.) in diameter. The grain is straight and the texture of the wood is uniform, comparable with that of true mahogany (*Swietenia macrophylla*). On flat-sawn surfaces, the figure is rather subdued as a result of exposure of the narrow bands of parenchyma tissue. The wood can be dried rapidly and easily with very little degrade. Dimensional stability is very good—practically equal to that of true mahogany. Cativo is classified as a nondurable wood with respect to decay and insects. It may contain appreciable quantities of gum. In wood that has been properly dried, however, the aromatics in the gum are removed and there is no difficulty in finishing.

Considerable quantities of cativo are used for interior woodwork, and resin-stabilized veneer is an important pattern material. Cativo is widely used for furniture and cabinet parts, lumber core for plywood, picture frames, edge banding for doors, joinery, and millwork.

Cedro (see Spanish-Cedar)

Cedro Macho (see Andiroba)

Cedro-Rana (see Tornillo)

Ceiba

Ceiba (*Ceiba pentandra*) is a large tree, which grows to 66 m (200 ft) in height with a straight cylindrical bole 13 to 20 m (40 to 60 ft) long. Trunk diameters of 2 m (6 ft) or more are common. Ceiba grows in West Africa, from the Ivory Coast and Sierra Leone to Liberia, Nigeria, and the Congo region. A related species is lupuna (*Ceiba samauma*) from South America.

Sapwood and heartwood are not clearly demarcated. The wood is whitish, pale brown, or pinkish brown, often with yellowish or grayish streaks. The texture is coarse, and the grain is interlocked or occasionally irregular. Ceiba is very soft and light; density of air-dried wood is 320 kg/m^3 (20 lb/ft^3). In strength, the wood is comparable with basswood (*Tilia americana*). Ceiba dries rapidly without marked deterioration. It is difficult to saw cleanly and dress smoothly because of the high percentage of tension wood. It provides good veneer and is easy to nail and glue. Ceiba is very susceptible to attack by decay fungi and insects. It requires rapid harvest and conversion to prevent deterioration. Treatability, however, is rated as good.

Ceiba is available in large sizes, and its low density combined with a rather high degree of dimensional stability make it ideal for pattern and corestock. Other uses include blockboard, boxes and crates, joinery, and furniture components.

Chewstick (see Manni)

Courbaril (Jatoba)

The genus *Hymenaea* consists of about 25 species that occur 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 is often called jatoba in Brazil.

Sapwood of courbaril is gray–white and usually quite wide. The heartwood, which is sharply differentiated from the sapwood, is salmon red to orange–brown when freshly cut and becomes russet or reddish brown when dried. The heartwood is often marked with dark streaks. The texture is medium to rather coarse, and the grain is mostly interlocked. The wood is hard and heavy (about 800 kg/m^3 (50 lb/ft^3) at 12% moisture content). The strength properties of courbaril are quite high and very similar to those of shagbark hickory (*Carya ovata*), a species of lower specific gravity. Courbaril is rated as moderately to very resistant to attack by decay fungi and dry-wood termites. The heartwood is not treatable, but the sapwood is treatable with preservatives. Courbaril is moderately difficult to saw and machine because of its high density, but it can be machined to a smooth surface. Turning, gluing, and finishing properties are satisfactory. Planing, however, is somewhat difficult because of the interlocked grain. Courbaril compares favorably with white oak (*Quercus alba*) in steam bending behavior.

Courbaril is used for tool handles and other applications that require good shock resistance. It is also used for steam-bent parts, flooring, turnery, furniture and cabinetwork, veneer and plywood, railroad crossties, and other specialty items.

Crabwood (see Andiroba)

Cristobal (see Macawood)

Cuangare (see Banak)

Degame

Degame or lemonwood (*Calycophyllum candidissimum*) grows in Cuba and ranges from southern Mexico through Central America to Colombia and Venezuela. It may grow in pure stands and is common on shaded hillsides and along waterways.

The heartwood of degame ranges from light brown to oatmeal-colored and is sometimes grayish. The sapwood is lighter in color and merges gradually with the heartwood. The texture is fine and uniform. The grain is usually straight or infrequently shows shallow interlocking, which may produce a narrow and indistinct stripe on quartered faces. In strength, degame is above the average for woods of similar density; density of air-dried wood is 817 kg/m^3 (51 lb/ft^3). Tests show degame superior to persimmon (*Diospyros virginiana*) in all respects but hardness. Natural durability is low when degame is used under conditions favorable to stain, decay, and insect attack. However, degame is reported to be highly resistant to marine borers. Degame is moderately difficult to machine because of its density and hardness, although it does not dull cutting tools to any extent. Machined surfaces are very smooth.

Degame is little used in the United States, but its characteristics have made it particularly adaptable for shuttles, picker sticks, and other textile industry items that require resilience and strength. Degame was once prized for the manufacture of archery bows and fishing rods. It is also suitable for tool handles and turnery.

Determa

Determa (*Ocotea rubra*) is native to the Guianas, Trinidad, and the lower Amazon region of Brazil.

The heartwood is light reddish brown with a golden sheen and distinct from the dull gray or pale yellowish brown sapwood. The texture is rather coarse, and the grain is interlocked to straight. Determa is a moderately strong and heavy wood (density of air-dried wood is 640 to 720 kg/m^3 (40 to 45 lb/ft^3)); this wood is moderately difficult to air dry. It can be worked readily with hand and machine tools with little dulling effect. It can be glued readily and polished fairly well. The heartwood is durable to very durable in resistance to decay fungi and moderately resistant to dry-wood termites. Weathering characteristics are excellent, and the wood is highly resistant to moisture absorption.

Uses for determa include furniture, general construction, boat planking, tanks and cooperage, heavy marine construction, turnery, and parquet flooring.

Ehie (see Benge)

Ekki (see Azobe)

Ekop

Ekop or gola (*Tetraberlinia tubmaniana*) grows only in Liberia.

The heartwood is light reddish brown and is distinct from the lighter colored sapwood, which may be up to 5 cm (2 in.) wide. The wood is medium to coarse textured, and the grain is interlocked, with a narrow striped pattern on quartered surfaces. The wood weighs about 735 kg/m^3 (46 lb/ft^3) at 12% moisture content. It dries fairly well but with a marked tendency to end and surface checks. Ekop works well with hand and machine tools and is an excellent wood for turnery. It also slices well into veneer and has good gluing properties. The heartwood is only moderately durable and is moderately resistant to impregnation with preservative treatments.

Ekop is a general utility wood that is used for veneer, plywood, and furniture components.

Encino (see Oak)

Gola (see Ekop)

Goncalo Alves

Most imports of goncalo alves (*Astronium graveolens* and *A. fraxinifolium*) have been from Brazil. These species range from southern Mexico through Central America into the Amazon basin.

Freshly cut heartwood is russet brown, orange–brown, or reddish brown to red with narrow to wide, irregular, medium- to very-dark brown stripes. After exposure to air, the heartwood becomes brown, red, or dark reddish brown with nearly black stripes. The sapwood is grayish white and sharply demarcated from the heartwood. The texture is fine to medium and uniform. The grain varies from straight to interlocked and wavy.

Goncalo alves turns readily, finishes very smoothly, and takes a high natural polish. The heartwood is highly resistant to moisture absorption; pigmented areas may present some difficulties in gluing because of their high density. The heartwood is very durable and resistant to both white- and brown-rot organisms. The high density (1,010 kg/m^3 (63 lb/ft^3)) of the air-dried wood is accompanied by equally high strength values, which are considerably higher in most respects than those of any U.S. species. Despite its strength, however, goncalo alves is imported primarily for its beauty.

In the United States, goncalo alves has the greatest value for specialty items such as archery bows, billiard cue butts, brushbacks, and cutlery handles, and in turnery and carving applications.

Greenheart

Greenheart (*Chlorocardium rodiei* [= *Ocotea rodiei*]) is essentially a Guyana tree although small stands also occur in Suriname.

The heartwood varies from light to dark olive green or nearly black. The texture is fine and uniform, and the grain is straight to wavy. Greenheart is stronger and stiffer than white oak (*Quercus alba*) and generally more difficult to work with tools because of its high density; density of air-dried wood is more than 960 kg/m^3 (60 lb/ft^3). The heartwood is rated as very resistant to decay fungi and termites. It is also 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, vats, piling, planking, industrial flooring, bridges, and some specialty items (fishing rods and billiard cue butts).

Guatambu (see Pau Marfim)

Guayacan (see Ipe)

Hura

Hura (*Hura crepitans*) grows throughout the West Indies from Central America to northern Brazil and Bolivia.

It is a large tree, commonly reaching a height of 30 to 43 m (90 to 130 ft), with clear boles of 12 to 23 m (40 to 75 ft). The diameter often reaches 1 to 1.5 m (3 to 5 ft) and occasionally to 3 m (9 ft).

The pale yellowish-brown or pale olive-gray heartwood is indistinct from the yellowish-white sapwood. The texture is fine to medium and the grain straight to interlocked. Hura is a low-strength and low-density wood (density of air-dried wood is 240 to 448 kg/m^3 (15 to 28 lb/ft^3)); the wood is moderately difficult to air dry. Warping is variable and sometimes severe. The wood usually machines easily, but green material is somewhat difficult to work because of tension wood, which results in a fuzzy surface. The wood finishes well and is easy to glue and nail. Hura is variable in resistance to attack by decay fungi, but it is highly susceptible to blue stain and very susceptible to wood termites. However, the wood is easy to treat with preservative.

Hura is often used in general carpentry, boxes and crates, and lower grade furniture. Other important uses are veneer and plywood, fiberboard, and particleboard.

Ilomba

Ilomba (*Pycnanthus angolensis*) is a tree of the rainforest and ranges from Guinea and Sierra Leone through tropical West Africa to Uganda and Angola. Common names include pycnanthus, walele, and otie.

The wood is grayish white to pinkish brown and, in some trees, a uniform light brown. There is generally no distinction between heartwood and sapwood. The texture is medium to coarse, and the grain is generally straight. This species is generally similar to banak (*Virola*) but has a coarser texture. Air-dry density is about 512 kg/m^3 (31 lb/ft^3), and the wood is about as strong as yellow-poplar (*Liriodendron tulipifera*). Ilomba dries rapidly but is prone to collapse, warp, and splits. It is easily sawn and can be worked well with hand and machine tools. It is excellent for veneer and has good gluing and nailing characteristics. Green wood is subject to insect and fungal attack. Logs require rapid extraction and conversion to avoid degrade. Both sapwood and heartwood are permeable and can be treated with preservatives.

In the United States, this species is used only in the form of plywood for general utility purposes. However, ilomba is definitely suited for furniture components, interior joinery, and general utility purposes.

Ipe

Ipe, the common name for the lapacho group of the genus *Tabebuia*, consists of about 20 species of trees and occurs in practically every Latin America country except Chile. Other commonly used names are guayacan and lapacho.

Sapwood is relatively wide, yellowish gray or gray–brown, and sharply differentiated from heartwood, which is light to dark olive brown. The texture is fine to medium. The grain is straight to very irregular and often narrowly interlocked. The wood is very heavy and averages about 1,025 kg/m^3 (64 lb/ft^3) at 12% moisture content. Thoroughly air-dried heartwood specimens generally sink in water. Because of its high density and hardness, ipe is moderately difficult to machine, but glassy smooth surfaces can be produced. Ipe is very strong; in the air-dried condition, it is comparable with greenheart (*Chlorocardium rodiei*). Hardness is two to three times that of white oak (*Quercus alba*) or keruing (*Dipterocarpus*). The wood is highly resistant to decay and insects, including both subterranean and dry-wood termites, but susceptible to marine borer attack. The heartwood is impermeable, but the sapwood can be readily treated with preservatives.

Ipe is used almost exclusively for heavy-duty and durable construction. Because of its hardness and good dimensional stability, it is particularly well suited for heavy-duty flooring in trucks and boxcars. It is also used for decks, railroad crossties, turnery, tool handles, decorative veneers, and some specialty items in textile mills.

Ipil (see Merbau)

Iroko

Iroko consists of two species (*Milicia excelsa* [= *Chlorophora excelsa*] and *M. regia* [= *C. regia*]). *Milicia excelsa* grows across the entire width of tropical Africa from the Ivory Coast southward to Angola and eastward to East Africa. *Milicia regia*, however, is limited to extreme West Africa from Gambia to Ghana; it is less resistant to drought than is *M. excelsa*.

The heartwood varies from a pale yellowish brown to dark chocolate brown with light markings occurring most conspicuously on flat-sawn surfaces; the sapwood is yellowish white. The texture is medium to coarse, and the grain is typically interlocked. Iroko can be worked easily with hand or machine tools but with some tearing of interlocked grain. Occasional deposits of calcium carbonate severely damage cutting edges. The wood dries rapidly with little or no degrade. The strength is similar to that of red maple (*Acer rubrum*), and the weight is about 688 kg/m^3 (43 lb/ft^3) at 12% moisture content. The heartwood is very resistant to decay fungi and resistant to termite and marine borer attack.

Because of its color and durability, iroko has been suggested as a substitute for teak (*Tectona grandis*). Its durability makes it suitable for boat building, piles, other marine work, and railroad crossties. Other uses include joinery, flooring, furniture, veneer, and cabinetwork.

Jacaranda (see Rosewood, Brazilian)

Jarrah

Jarrah (*Eucalyptus marginata*) is native to the coastal belt of southwestern Australia and is one of the principal species for that country's sawmill industry.

The heartwood is a uniform pink to dark red, often turning to deep brownish red with age and exposure to air. The sapwood is pale and usually very narrow in old trees. The texture is even and moderately coarse, and the grain is frequently interlocked or wavy. The wood weighs about 865 kg/m^3 (54 lb/ft^3) at 12% 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 decay. The wood is difficult to work with hand and machine tools because of its high density and irregular grain.

Jarrah is used for decking and underframing of piers, jetties, and bridges, as well as piles and fenders for docks and harbors. As flooring, jarrah has high resistance to wear, but it is inclined to splinter under heavy traffic. It is also used for railroad crossties and other heavy construction.

Jatoba (see Courbaril)

Jelutong

Jelutong (*Dyera costulata*) is an important species in Malaysia where it is best known for its latex production in the manufacture of chewing gum rather than for its wood.

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 465 kg/m^3 (28 lb/ft^3) at 12% moisture content. The wood is very easy to dry with little tendency to split or warp, but staining may cause trouble. It is easy to work in all operations, finishes well, and glues satisfactorily. The wood is rated as nondurable but readily permeable to preservatives.

Because of its low density and ease of working, jelutong is well suited for sculpture and pattern making, wooden shoes, picture frames, and drawing boards.

Jequitiba (see Albarco)

Kakaralli (see Manbarklak)

Kaneelhart

Kaneelhart or brown silverballi are names applied to the genus *Licaria*. Species of this genus grow mostly in New Guinea and Papau New Guinea and are found in association with greenheart (*Chlorocardium rodiei*) on hilly terrain and wallaba (*Eperua*) in forests.

The orange or brownish yellow heartwood darkens to yellowish or coffee brown on exposure to air. The wood is sometimes tinged with red or violet. The texture is fine to medium, and the grain is straight to slightly interlocked. The wood has a fragrant odor, which is lost in drying. Kaneelhart is a very strong and very heavy wood (density of air-dried wood is 833 to 1,153 kg/m^3 (52 to 72 lb/ft^3)); the wood is difficult to work. It cuts smoothly and takes an excellent finish but requires care in gluing. Kaneelhart has excellent resistance to both brown- and white-rot fungi and is also rated very high in resistance to dry-wood termites.

Uses of kaneelhart include furniture, turnery, boat building, heavy construction, and parquet flooring.

Kapur

The genus *Dryobalanops* consists of nine species distributed over parts of Malaysia and Indonesia. For the export trade, the species are combined under the name kapur.

The heartwood is reddish brown and clearly demarcated from the pale sapwood. The wood is fairly coarse textured but uniform. In general, the wood resembles keruing (*Dipterocarpus*), but on the whole, kapur is straighter grained and not quite as coarse in texture. Density of the wood averages about 720 to 800 kg/m^3 (45 to 50 lb/ft^3) at 12% moisture content. Strength properties are similar to those of keruing at comparable specific gravity. The heartwood is rated resistant to attack by decay fungi; it is reported to be vulnerable to termites. Kapur is extremely resistant to preservative treatment. The wood works with moderate ease in most hand and machine operations, but blunting of cutters may be severe because of silica content, particularly when the dry wood is machined. A good surface can be obtained from various machining operations, but there is a tendency toward raised grain if dull cutters are used. Kapur takes nails and screws satisfactorily. The wood glues well with urea formaldehyde but not with phenolic adhesives.

Kapur provides good and very durable construction wood and is suitable for all purposes for which keruing (*Dipterocarpus*) is used in the United States. In addition, kapur is extensively used in plywood either alone or with species of *Shorea* (lauan–meranti).

Karri

Karri (*Eucalyptus diversicolor*) is a very large tree limited to southwestern Australia.

Karri resembles jarrah (*E. marginata*) in structure and general appearance. It is usually paler in color and, on average, slightly heavier (913 kg/m^3 (57 lb/ft^3)) at 12% moisture content. Karri is a heavy hardwood with mechanical properties of a correspondingly high order, even somewhat higher than that of jarrah. The heartwood is rated as moderately durable, though less so than that of jarrah. It is extremely difficult to treat with preservatives. The wood is fairly hard to machine and difficult to cut with hand tools. It is generally more resistant to cutting than is jarrah and has a slightly more dulling effect on tool edges.

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

Kauta (see Marishballi)

Kempas

Kempas (*Koompassia malaccensis*) is distributed throughout the lowland forest in rather swampy areas of Malaysia and Indonesia.

When exposed to air, the freshly cut brick-red heartwood darkens to an orange–red or red–brown with numerous yellow–brown streaks as a result of the soft tissue (axial parenchyma) associated with the pores. The texture is rather coarse, and the grain is typically interlocked. Kempas is a hard, heavy wood (density of air-dried wood is 880 kg/m^3 (55 lb/ft^3)); the wood is difficult to work with hand and machine tools. The wood dries well, with some tendency to warp and check. The heartwood is resistant to attack by decay fungi but vulnerable to termite activity. However, it treats readily with preservative retention as high as 320 kg/m^3 (20 lb/ft^3).

Kempas is ideal for heavy construction work, railroad crossties, and flooring.

Keruing (Apitong)

Keruing or apitong (*Dipterocarpus*) is widely scattered throughout the Indo-Malaysian region. Most of the more than 70 species in this genus are marketed under the name keruing. Other important species are marketed as apitong in the Philippine Islands and yang in Thailand.

The heartwood varies from light to dark red–brown or brown to dark brown, sometimes with a purple tint; the heartwood is usually well defined from the gray or buff-colored sapwood. Similar to kapur (*Dryobalanops*), the texture of keruing is moderately coarse and the grain is straight or shallowly interlocked. The wood is strong, hard, and heavy (density of air-dried wood is 720 to 800 kg/m^3 (45 to 50 lb/ft^3)); this wood is characterized by the presence of resin ducts, which occur singly or in short arcs as seen on end-grain surfaces. This resinous condition and the presence of silica can present troublesome problems. Sapwood and heartwood are moderately resistant to preservative treatments. However, the wood should be treated with preservatives when it is used in contact with the ground. Durability varies with species, but the wood is generally classified as moderately durable. Keruing generally takes to sawing and machining, particularly when green, but saws and cutters dull easily as a result of high silica content in the wood. Resin adheres to machinery and tools and may be troublesome. Also, resin may cause gluing and finishing difficulties.

Keruing is used for general construction work, framework for boats, flooring, pallets, chemical processing equipment, veneer and plywood, railroad crossties (if treated), truck floors, and boardwalks.

Khaya (see Mahogany, African)

Kokrodua (see Afrormosia)

Korina (see Limba)

Krabak (see Mersawa)

Kwila (see Merbau)

Lapacho (see Ipe)

Lapuna (see Ceiba)

Lauan (see Meranti Groups)

Lemonwood (see Degame)

Lignumvitae

For many years, the only species of lignumvitae used on a large scale was *Guaiacum officinale*, which is native to the West Indies, northern Venezuela, northern Colombia, and Panama. With the near exhaustion of *G. officinale*, harvesters turned to *G. sanctum*, which is now the principal commercial species. *Guaiacum sanctum* occupies the same range as *G. officinale* but is more extensive and includes the Pacific side of Central America as well as southern Mexico.

Lignumvitae 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 one-fourth of the air-dried weight of the heartwood.

Lignumvitae wood is used chiefly for bearing or bushing blocks for ship propeller shafts. The great strength and tenacity of lignumvitae, combined with self-lubricating properties resulting from 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 blocks, and turned products.

Limba

Limba (*Terminalia superba*), also referred to as afara, is widely distributed from Sierra Leone to Angola and Zaire in the rainforest and savanna forest. Limba is also favored as a plantation species in West Africa.

The heartwood varies from gray–white to creamy or yellow brown and may contain dark streaks that are nearly black, producing an attractive figure that is valued for decorative veneer. The light color of the 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 dry and shrinkage is reported to be rather low. Limba is not resistant to decay, insects, or termites. It is easy to work with all types of tools and is made into veneer without difficulty.

Principal uses include plywood, furniture, interior joinery, and sliced decorative veneer.

Macacauba (see Macawood)

Macawood (Trebol)

Macawood and trebol are common names applied to species in the genus *Platymiscium*. Other common names include cristobal and macacauba. This genus is distributed across continental tropical America from southern Mexico to the Brazilian Amazon region and Trinidad.

The bright red to reddish or purplish brown heartwood is more or less striped. Darker specimens look waxy, and the sapwood is sharply demarcated from the heartwood. The texture is medium to fine, and the grain is straight to curly or striped. The wood is not very difficult to work, and it finishes smoothly and takes on a high polish. Generally, macawood air dries slowly with a slight tendency to warp and check. Strength is quite high, and density of air-dried wood ranges from 880 to 1,170 kg/m^3 (55 to 73 lb/ft^3). The heartwood is reported to be highly resistant to attack by decay fungi, insects, and dry-wood termites. Although the sapwood absorbs preservatives well, the heartwood is resistant to treatment.

Macawood is a fine furniture and cabinet wood. It is also used in decorative veneers, musical instruments, turnery, joinery, and specialty items such as violin bows and billiard cues.

Machinmango (see Manbarklak)

Mahogany

The name mahogany is presently applied to several distinct kinds of commercial wood. The original mahogany wood, produced by *Swietenia mahagoni*, came from the American West Indies. This was the premier wood for fine furniture cabinet work and shipbuilding in Europe as early as the 1600s. Because the good reputation associated with the name mahogany is based on this wood, American mahogany is sometimes referred to as true mahogany. A related African wood, of the genus *Khaya*, has long been marketed as "African mahogany" and is used for much the same purposes as American mahogany because of its similar properties and overall appearance. A third kind of wood called mahogany, and the one most commonly encountered in the market, is "Philippine mahogany." This name is applied to a group of Asian woods belonging to the genus *Shorea*. In this chapter, information on the "Philippine mahoganies" is given under lauan and meranti groups.

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

The heartwood varies from pale pink to dark reddish brown. The grain is frequently interlocked, and the texture is medium to coarse, comparable with that of American mahogany (*Swietenia macrophylla*). The wood is easy to dry, but machining properties are rather variable. Nailing and gluing properties are good, and an excellent finish is readily obtained. The wood is easy to slice and peel. In decay resistance, African mahogany is generally rated as moderately durable, which is below the durability rating for American mahogany.

Principal uses for African mahogany include furniture and cabinetwork, interior woodwork, boat construction, and veneer.

Mahogany, American—True, American, or Honduras mahogany (*Swietenia macrophylla*) ranges from southern Mexico through Central America into South America as far south as Bolivia. Plantations have been established within its natural range and elsewhere throughout the tropics.

The heartwood varies from pale pink or salmon colored to dark reddish brown. The grain is generally straighter than that of African mahogany (*Khaya ivorensis*); however, a wide variety of grain patterns are obtained from American mahogany. The texture is rather fine to coarse. American mahogany is easily air or kiln dried without appreciable warp or checks, and it has excellent dimensional stability. It is rated as durable in resistance to decay fungi and moderately resistant to dry-wood termites. Both heartwood and sapwood are resistant to treatment with preservatives. The wood is very easy to work with hand and machine tools, and it slices and rotary cuts into fine veneer without difficulty. It also is easy to finish and takes an excellent polish. The air-dried strength of American mahogany is similar to that of American elm (*Ulmus americana*). Density of air-dried wood varies from 480 to 833 kg/m^3 (30 to 52 lb/ft^3).

The principal uses for mahogany are fine furniture and cabinets, interior woodwork, pattern woodwork, boat construction, fancy veneers, musical instruments, precision instruments, paneling, turnery, carving, and many other uses that call for an attractive and dimensionally stable wood.

Mahogany, Philippine (see Meranti Groups)

Manbarklak

Manbarklak is a common name applied to species in the genus *Eschweilera*. Other names include kakaralli machinmango, and mata–mata. About 80 species of this genus are distributed from eastern Brazil through the Amazon basin, to the Guianas, Trinidad, and Costa Rica.

The heartwood of most species is light, grayish, reddish brown, or brownish buff. The texture is fine and uniform, and the grain is typically straight. Manbarklak is a very hard and heavy wood (density of air-dried wood ranges from 768 to 1,185 kg/m^3 (48 to 74 lb/ft^3)) that is rated as fairly difficult to dry. Most species are difficult to work because of the high density and high silica content. Most species are highly resistant to attack by decay fungi. Also, most species have gained wide recognition for their high degree of resistance to marine borer attack. Resistance to dry-wood termite attack is variable depending on species.

Manbarklak is an ideal wood for marine and other heavy construction uses. It is also used for industrial flooring, mill equipment, railroad crossties, piles, and turnery.

Manni

Manni (*Symphonia globulifera*) is native to the West Indies, Mexico, and Central, North, and South America. It also occurs in tropical West Africa. Other names include ossol (Gabon), anani (Brazil), waika (Africa), and chewstick (Belize), a name acquired because of its use as a primitive toothbrush and flossing tool.

The heartwood is yellowish, grayish, or greenish brown and is distinct from the whitish sapwood. The texture is coarse and the grain straight to irregular. The wood is very easy to work with both hand and machine tools, but surfaces tend to roughen in planing and shaping. Manni air-dries rapidly with only moderate warp and checking. Its strength is similar to that of hickory (*Carya*), and the density of air-dried wood is 704 kg/m^3 (44 lb/ft^3). The heartwood is durable in ground contact but only moderately resistant to dry-wood and subterranean termites. The wood is rated as resistant to treatment with preservatives.

Manni is a general purpose wood that is used for railroad ties, general construction, cooperage, furniture components, flooring, and utility plywood.

Marishballi

Marishballi is the common name applied to species of the genus *Licania*. Other names include kauta and anaura. Species of *Licania* are widely distributed in tropical America but most abundant in the Guianas and the lower Amazon region of Brazil.

The heartwood is generally a yellowish to dark brown, sometimes with a reddish tinge. The texture is fine and close, and the grain is usually straight. Marishballi is strong and very heavy; density of air-dried wood is 833 to 1,153 kg/m^3 (52 to 72 lb/ft^3). The wood is rated as easy to moderately difficult to air dry. Because of its high density and silica content, marishballi is difficult to work. The use of hardened cutters is suggested to obtain smooth surfaces. Durability varies with species, but marishballi is generally considered to have low to moderately low resistance to attack by decay fungi. However, it is known for its high resistance to attack by marine borers. Permeability also varies, but the heartwood is generally moderately responsive to treatment.

Marishballi is ideal for underwater marine construction, heavy construction above ground, and railroad crossties (treated).

Mata–Mata (see Manbarklak)

Mayflower (see Roble)

Melapi (see Meranti Groups)

Meranti Groups

Meranti is a common name applied commercially to four groups of species of *Shorea* from southeast Asia, most commonly Malaysia, Indonesia, and the Philippines. There are thousands of common names for the various species of *Shorea*, but the names Philippine mahogany and lauan are often substituted for meranti. The four groups of meranti are separated on the basis of heartwood color and weight (Table 1–3). About 70 species of *Shorea* belong to the light and dark red meranti groups, 22 species to the white meranti group, and 33 species to the yellow meranti group.

Meranti species as a whole have a coarser texture than that of mahogany (*Swietenia macrophylla*) and do not have dark-colored deposits in pores. The grain is usually interlocked. All merantis have axial resin ducts aligned in long, continuous, tangential lines as seen on the end surface of the wood. These ducts sometimes contain white deposits that are visible to the naked eye, but the wood is not resinous like some keruing (*Dipterocarpus*) species that resemble meranti. All the meranti groups are machined easily except white meranti, which dulls cutters as a result of high silica content in the wood. The light red and white merantis dry easily without degrade, but dark red and yellow merantis dry more slowly with a tendency to warp. The strength and shrinkage properties of the meranti groups compare favorably with that of northern red oak (*Quercus rubra*). The light red, white, and yellow merantis are not durable in exposed conditions or in ground contact, whereas dark red meranti is moderately durable. Generally, heartwood is extremely resistant to moderately resistant to preservative treatments.

Species of meranti constitute a large percentage of the total hardwood plywood imported into the United States. Other uses include joinery, furniture and cabinetwork, moulding and millwork, flooring, and general construction. Some dark red meranti is used for decking.

Merbau

Merbau (Malaysia), ipil (Philippines), and kwila (New Guinea) are names applied to species of the genus *Intsia*, most commonly *I. bijuga*. *Intsia* is distributed throughout the Indo–Malaysian region, Indonesia, Philippines, and many western Pacific islands, as well as Australia.

Freshly cut yellowish to orange–brown heartwood turns brown or dark red–brown on exposure to air. The texture is rather coarse, and the grain is straight to interlocked or wavy. The strength of air-dried merbau is comparable with that of hickory (*Carya*), but density is somewhat lower (800 kg/m^3 (50 lb/ft^3) at 12% moisture content). The wood dries well with little degrade but stains black in the presence of iron and moisture. Merbau is rather difficult to saw because it sticks to saw teeth and dulls cutting edges. However, the wood dresses smoothly in most operations and finishes well. Merbau has good durability and high resistance to termite attack. The heartwood resists treatment, but the sapwood can be treated with preservatives.

Table 1–3. Woods belonging to *Shorea* and *Parashorea* genera

Name	Color	Density of air-dried wood
Dark red meranti (also called tanguile and dark red seraya)	Dark brown; medium to deep red, sometimes with a purplish tinge	640+ kg/m^3 (40+ lb/ft^3)
Light red meranti (also called red seraya)	Variable—from almost white to pale pink, dark red, pale brown, or deep brown	400 to 640 kg/m^3, averaging 512 kg/m^3 (25 to 40 lb/ft^3, averaging 32 lb/ft^3)
White meranti (also called melapi)	Whitish when freshly cut, becoming light yellow-brown on exposure to air	480 to 870 kg/m^3 (30 to 54 lb/ft^3)
Yellow meranti (also called yellow seraya)	Light yellow or yellow-brown, sometimes with a greenish tinge; darkens on exposure to air	480 to 640 kg/m^3 (30 to 40 lb/ft^3)

Merbau is used in furniture, fine joinery, turnery, cabinets, flooring, musical instruments, and specialty items.

Mersawa

Mersawa is one of the common names applied to the genus *Anisoptera*, which has about 15 species distributed from the Philippine Islands and Malaysia to east Pakistan. Names applied to this wood vary with the source, and three names are generally used in the lumber trade: krabak (Thailand), mersawa (Malaysia), and palosapis (Philippines).

Mersawa wood is light in color and has a moderately coarse texture. Freshly sawn heartwood is pale yellow or yellowish brown and darkens on exposure to air. Some wood may show a pinkish cast or pink streaks, but these eventually disappear on exposure to air. The wood weighs between 544 and 752 kg/m^3 (34 and 47 lb/ft^3) at 12% moisture content and about 945 kg/m^3 (59 lb/ft^3) when green. The sapwood is susceptible to attack by powderpost beetles, and the heartwood is not resistant to termites. The heartwood is rated as moderately resistant to fungal decay and should not be used under conditions that favor decay. The heartwood does not absorb preservative solutions readily. The wood machines easily, but because of the presence of silica, the wood severely dulls the cutting edges of ordinary tools and is very hard on saws.

The major volume of mersawa will probably be used as plywood because conversion in this form presents considerably less difficulty than does the production of lumber.

Mora

Mora (*Mora excelsa* and *M. gonggrijpii*) is widely distributed in the Guianas and also occurs in the Orinoco Delta of Venezuela.

The yellowish red–brown, reddish brown, or dark red heartwood with pale streaks is distinct from the yellowish to pale brown sapwood. The texture is moderately fine to rather coarse, and the grain is straight to interlocked. Mora is a strong and heavy wood (density of air-dried wood is 945 to 1,040 kg/m^3 (59 to 65 lb/ft^3)); this wood is moderately difficult to work but yields smooth surfaces in sawing, planing, turning, and boring. The wood is generally rated as moderately difficult to dry. Mora is rated as durable to very durable in resistance to brown- and white-rot fungi. *Mora gonggrijpii* is rated very resistant to dry-wood termites, but *M. excelsa* is considerably less resistant. The sapwood responds readily to preservative treatments, but the heartwood resists treatment.

Mora is used for industrial flooring, railroad crossties, shipbuilding, and heavy construction.

Oak (Tropical)

The oaks (*Quercus*) are abundantly represented in Mexico and Central America with about 150 species, which are nearly equally divided between the red and white oak groups. More than 100 species occur in Mexico and about 25 in Guatemala; the number diminishes southward to Colombia, which has two species. The usual Spanish name applied to the oaks is encino or roble, and both names are used interchangeably irrespective of species or use of the wood.

In heartwood color, texture, and grain characteristics, tropical oaks are similar to the oaks in the United States, especially live oak (*Quercus virginiana*). In most cases, tropical oaks are heavier (density of air-dried wood is 704 to 993 kg/m^3 (44 to 62 lb/ft^3)) than the U.S. species. Strength data are available for only four species, and the values fall between those of white oak (*Q. alba*) and live oak (*Q. virginiana*) or are equal to those of live oak. Average specific gravity for the tropical oaks is 0.72 based on volume when green and ovendry weight, with an observed maximum average of 0.86 for one species from Guatemala. The heartwood is rated as very resistant to decay fungi and difficult to treat with preservatives.

Utilization of the tropical oaks is very limited at present because of difficulties encountered in the drying of the wood. The major volume is used in the form of charcoal, but the wood is used for flooring, railroad crossties, mine timbers, tight cooperage, boat and ship construction, and decorative veneers.

Obeche

Obeche (*Triplochiton scleroxylon*) trees of west–central Africa reach a height of 50 m (150 ft) or more and a diameter of up to 2 m (5 ft). The trunk is usually free of branches for a considerable height so that clear lumber of considerable size can be obtained.

The wood is creamy white to pale yellow with little or no difference between sapwood and heartwood. The wood is fairly soft, of uniform medium to coarse texture, and the grain is usually interlocked but sometimes straight. Air-dry wood weighs about 385 kg/m^3 (24 lb/ft^3). Obeche dries readily with little degrade. It is not resistant to decay, and green sapwood is subject to blue stain. The wood is easy to work and machine, veneers and glues well, and takes nails and screws without splitting.

The characteristics of obeche make it especially suitable for veneer and corestock. Other uses include furniture, components, millwork, blockboard, boxes and crates, particleboard and fiberboard, patterns, and artificial limbs.

Ofram (see Limba)

Okoume

The natural distribution of okoume (*Aucoumea klaineana*) is rather restricted; the species is found only in west–central Africa and Guinea. However, okoume is extensively planted throughout its natural range.

The heartwood is salmon-pink in color, and the narrow sapwood is whitish or pale gray. The wood has a high luster and uniform texture. The texture is slightly coarser than that of birch (*Betula*). The nondurable heartwood dries readily with little degrade. Sawn lumber is somewhat difficult to machine because of the silica content, but the wood glues, nails, and peels into veneer easily. Okoume offers unusual flexibility in finishing because the color, which is of medium intensity, permits toning to either lighter or darker shades.

In the United States, okoume is generally used for decorative plywood paneling, general utility plywood, and doors. Other uses include furniture components, joinery, and light construction.

Opepe

Opepe (*Nauclea diderrichii*) is widely distributed in Africa from Sierra Leone to the Congo region and eastward to Uganda. It is often found in pure stands.

The orange or golden yellow heartwood darkens on exposure to air and is clearly defined from the whitish or pale yellow sapwood. The texture is rather coarse, and the grain is usually interlocked or irregular. The density of air-dried wood (752 kg/m^3 (47 lb/ft^3)) is about the same as that of true hickory (*Carya*), but strength properties are somewhat lower. Quartersawn stock dries rapidly with little checking or warp, but flat-sawn lumber may develop considerable degrade. The wood works moderately well with hand and machine tools. It also glues and finishes satisfactorily. The heartwood is rated as very resistant to decay and moderately resistant to termite attacks. The sapwood is permeable to preservatives, but the heartwood is moderately resistant to preservative treatment.

Opepe is a general construction wood that is used in dock and marine work, boat building, railroad crossties, flooring, and furniture.

Ossol (see Manni)

Otie (see Ilomba)

Ovangkol (see Benge)

Palosapis (see Mersawa)

Para–Angelim (see Sucupira)

Pau Marfim

The 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, pau marfim wood is very similar to birch (*Betula*) or sugar maple (*Acer saccharum*) sapwood. Although growth rings are present, they do not show as distinctly as those in birch and maple. There is no apparent difference in color between heartwood and sapwood. The wood is straight grained and easy to work and finish, but it is not considered resistant to decay. In Brazil, average specific gravity of pau marfim is about 0.73 based on volume of green wood and ovendry weight. Average density of air-dried wood is about 802 kg/m^3 (50 lb/ft^3). On the basis of specific gravity, strength values are higher than those of sugar maple, which has an average specific gravity of 0.56.

In its areas of growth, pau marfim is used for much the same purposes as are sugar maple and birch in the United States. Introduced to the U.S. market in the late 1960s, pau marfim has been very well received and is especially esteemed for turnery.

Peroba, White (see Peroba de Campos)

Peroba de Campos

Peroba de campos (*Paratecoma peroba*), also referred to as white peroba, grows in the coastal forests of eastern Brazil, ranging from Bahia to Rio de Janeiro. It is the only species in the genus *Paratecoma*.

The heartwood varies in color but is generally shades of brown with tendencies toward olive and red. The sapwood is a yellowish gray and is clearly defined from the heartwood. The texture is relatively fine and approximates that of birch (*Betula*). The grain is commonly interlocked, with a narrow stripe or wavy figure. The wood machines easily; however, particular care must be taken in planing to prevent excessive grain tearing of quartered surfaces. There is some evidence that the fine dust from machining operations may produce allergic responses in certain individuals. Density of air-dried wood averages about 738 kg/m^3 (46 lb/ft^3). Peroba de campos is heavier than teak (*Tectona grandis*) or white oak (*Quercus alba*), and it is proportionately stronger than either of these species. The heartwood of peroba de campos is rated as very durable with respect to decay and difficult to treat with preservatives.

In Brazil, peroba de campos is used in the manufacture of fine furniture, flooring, and decorative paneling. The principal use in the United States is shipbuilding, where peroba de campos serves as substitute for white oak (*Quercus alba*) for all purposes except bent members.

Peroba Rosa

Peroba rosa is the common name applied to a number of similar species in the genus *Aspidosperma*. These species occur in southeastern Brazil and parts of Argentina.

The heartwood is a distinctive rose-red to yellowish, often variegated or streaked with purple or brown, and becomes brownish yellow to dark brown upon exposure to air; the heartwood is often not demarcated from the yellowish sapwood. The texture is fine and uniform, and the grain is straight to irregular. The wood is moderately heavy; weight of air-dried wood is 752 kg/m^3 (47 lb/ft^3). Strength properties are comparable with those of U.S. oak (*Quercus*). The wood dries with little checking or splitting. It works with moderate ease, and it glues and finishes satisfactorily. The heartwood is resistant to decay fungi but susceptible to dry-wood termite attack. Although the sapwood takes preservative treatment moderately well, the heartwood resists treatment.

Peroba is suited for general construction work and is favored for fine furniture and cabinetwork and decorative veneers. Other uses include flooring, interior woodwork, sashes and doors, and turnery.

Pilon

The two main species of pilon are *Hyeronima alchorneoides* and *H. laxiflora*, also referred to as suradan. These species range from southern Mexico to southern Brazil including the Guianas, Peru, and Colombia. Pilon species are also found throughout the West Indies.

The heartwood is a light reddish brown to chocolate brown or sometimes dark red; the sapwood is pinkish white. The texture is moderately coarse and the grain interlocked. The wood air-dries rapidly with only a moderate amount of warp and checking. It has good working properties in all operations except planing, which is rated poor as a result of the characteristic interlocked grain. The strength of pilon is comparable with that of true hickory (*Carya*), and the density of air-dried wood ranges from 736 to 849 kg/m^3 (46 to 53 lb/ft^3). Pilon is rated moderately to very durable in ground contact and resistant to moderately resistant to subterranean and dry-wood termites. Both heartwood and sapwood are reported to be treatable with preservatives by both open tank and pressure vacuum processes.

Pilon is especially suited for heavy construction, railway crossties, marinework, and flooring. It is also used for furniture, cabinetwork, decorative veneers, turnery, and joinery.

Piquia

Piquia is the common name generally applied to species in the genus *Caryocar*. This genus is distributed from Costa Rica southward into northern Colombia and from the upland forest of the Amazon valley to eastern Brazil and the Guianas.

The yellowish to light grayish brown heartwood is hardly distinguishable from the sapwood. The texture is medium to rather coarse, and the grain is generally interlocked. The wood dries at a slow rate; warping and checking may develop, but only to a minor extent. Piquia is reported to be easy to moderately difficult to saw; cutting edges dull rapidly. The heartwood is very durable and resistant to decay fungi and dry-wood termites but only moderately resistant to marine borers.

Piquia is recommended for general and marine construction, heavy flooring, railway crossties, boat parts, and furniture components. It is especially suitable where hardness and high wear resistance are needed.

Primavera

The natural distribution of primavera (*Tabebuia donnell–smithii* [=*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 has been limited because of its rather restricted range and relative scarcity of naturally grown trees. Recent plantations have increased the availability of this species and have provided a more constant source of supply. The quality of the plantation-grown wood is equal in all respects to the wood obtained from naturally grown trees.

The heartwood is whitish to straw-yellow, and in some logs, it may be tinted with pale brown or pinkish streaks. The texture is medium to rather coarse, and the grain is straight to wavy, which produces a wide variety of figure patterns. The wood also has a very high luster. Shrinkage is rather low, and the wood shows a high degree of dimensional stability. Despite considerable grain variation, primavera machines remarkably well. The density of air-dried wood is 465 kg/m^3 (29 lb/ft^3), and the wood is comparable in strength with water tupelo (*Nyssa aquatica*). Resistance to both brown- and white-rot fungi varies. Weathering characteristics are good.

The dimensional stability, ease of working, and pleasing appearance make primavera a suitable choice for solid furniture, paneling, interior woodwork, and special exterior uses.

Purpleheart

Purpleheart, also referred to as amaranth, is the name applied to species in the genus *Peltogyne*. The center of distribution is in the north-central part of the Brazilian Amazon region, but the combined range of all species is from Mexico through Central America and southward to southern Brazil.

Freshly cut heartwood is brown. It turns a deep purple upon exposure to air and eventually dark brown upon exposure to light. The texture is medium to fine, and the grain is usually straight. This strong and heavy wood (density of air-dried wood is 800 to 1,057 kg/m^3 (50 to 66 lb/ft^3)) is rated as easy to moderately difficult to air dry. It is moderately difficult to work with using either hand or machine tools, and it dulls cutters rather quickly. Gummy resin exudes when the wood is heated by dull tools. A slow feed rate and specially hardened cutters are suggested for optimal cutting. The wood turns easily, is easy to glue, and takes finishes well. The heartwood is rated as highly resistant to attack by decay fungi and very resistant to dry-wood termites. It is extremely resistant to treatment with preservatives.

The unusual and unique color of purpleheart makes this wood desirable for turnery, marquetry, cabinets, fine furniture, parquet flooring, and many specialty items, such as billiard cue butts and carvings. Other uses include heavy construction, shipbuilding, and chemical vats.

Pycnanthus (see Ilomba)

Ramin

Ramin (*Gonystylus bancanus*) is native to southeast Asia from the Malaysian Peninsula to Sumatra and Borneo.

Both the heartwood and sapwood are the color of pale straw, yellow, or whitish. The grain is straight or shallowly interlocked. The texture is even, moderately fine, and similar to that of American mahogany (*Swietenia macrophylla*). The wood is without figure or luster. Ramin is moderately hard and heavy, weighing about 672 kg/m^3 (42 lb/ft^3) in the air-dried condition. The wood is easy to work, finishes well, and glues satisfactorily. Ramin is rated as not resistant to decay but permeable with respect to preservative treatment.

Ramin is used for plywood, interior woodwork, furniture, turnery, joinery, moulding, flooring, dowels, and handles of nonstriking tools (brooms), and as a general utility wood.

Roble

Roble, a species in the roble group of *Tabebuia* (generally *T. rosea*), ranges from southern Mexico through Central America to Venezuela and Ecuador. The name roble comes from the Spanish word for oak (*Quercus*). In addition, *T. rosea* is called roble because the wood superficially resembles U.S. oak. Other names for *T. rosea* are mayflower and apamate.

The sapwood becomes a pale brown upon exposure to air. The heartwood varies from golden brown to dark brown, and it has no distinctive odor or taste. The texture is medium and the grain narrowly interlocked. The wood weighs about 642 kg/m^3 (40 lb/ft^3) at 12% moisture content. Roble has excellent working properties in all machine operations. It finishes attractively in natural color and takes finishes with good results. It weighs less than the average of U.S. white oaks (*Quercus*) but is comparable with respect to bending and compression parallel to grain. The heartwood of roble is generally rated as moderately to very durable with respect to decay; the darker and heavier wood is regarded as more resistant than the lighter-colored woods.

Roble is used extensively for furniture, interior woodwork, doors, flooring, boat building, ax handles, and general construction. The wood veneers well and produces attractive paneling. For some applications, roble is suggested as a substitute for American white ash (*Fraxinus americana*) and oak (*Quercus*).

Rosewood, Brazilian

Brazilian rosewood (*Dalbergia nigra*), also referred to as jacaranda, occurs in eastern Brazilian forests from the State of Bahia to Rio de Janeiro. Since it was exploited for a long time, Brazilian rosewood is no longer abundant.

The heartwood varies with respect to color, through shades of brown, red, and violet, and it is irregularly and conspicuously streaked with black. It is sharply demarcated from the white sapwood. Many kinds of rosewood are distinguished locally on the basis of prevailing color. The texture is coarse, and the grain is generally straight. The heartwood has an oily or waxy appearance and feel, and its odor is fragrant and distinctive. The wood is hard and heavy (weight of air-dried wood is 752 to 897 kg/m^3 (47 to 56 lb/ft^3)); thoroughly air-dried wood will barely float in water. Strength properties of Brazilian rosewood are high and are more than adequate for the purposes for which this wood is used. For example, Brazilian rosewood is harder than any U.S. native hardwood species used for furniture and veneer. The wood machines and veneers well. It can be glued satisfactorily, provided the necessary precautions are taken to ensure good glue bonds, with respect to oily wood. Brazilian rosewood has an excellent reputation for durability with respect to fungal and insect attack, including termites, although the wood is not used for purposes where durability is necessary.

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 turnery.

Rosewood, Indian

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

The heartwood varies in color from golden brown to dark purplish brown with denser blackish streaks at the end of growth zones, giving rise to an attractive figure on flat-sawn surfaces. The narrow sapwood is yellowish. The average weight is about 849 kg/m^3 (53 lb/ft^3) at 12% moisture content. The texture is uniform and moderately coarse. Indian rosewood is quite similar in appearance to Brazilian (*Dalbergia nigra*) and Honduran (*Dalbergia stevensonii*) rosewood. The wood is reported to kiln-dry well though slowly, and the color improves during drying. Indian rosewood is a heavy wood with high strength properties; after drying, it is particularly hard for its weight. The wood is moderately hard to work with hand tools and offers a fair resistance in machine operations. Lumber with calcareous deposits tends to dull tools rapidly. The wood turns well and has high screw-holding properties. If a very smooth surface is required for certain purposes, pores (vessels) may need to be filled.

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

Sande

Practically all commercially available sande (mostly *Brosimum utile*) comes from Pacific Ecuador and Colombia. However, the group of species ranges from the Atlantic Coast in Costa Rica southward to Colombia and Ecuador.

The sapwood and heartwood show no distinction; the wood is uniformly yellowish white to yellowish or light brown. The texture is medium to moderately coarse and even, and the grain can be widely and narrowly interlocked. The density of air-dried wood ranges from 384 to 608 kg/m^3 (24 to 38 lb/ft^3), and the strength is comparable with that of U.S. oak (*Quercus*). The lumber air dries rapidly with little or no degrade. However, material containing tension wood is subject to warp, and the tension wood may cause fuzzy grain as well as overheating of saws as a result of pinching. The wood is not durable with respect to stain, decay, and insect attack, and care must be exercised to prevent degrade from these agents. The wood stains and finishes easily and presents no gluing problems.

Sande is used for plywood, particleboard, fiberboard, carpentry, light construction, furniture components, and moulding.

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 fine and slightly darker striping on flat-sawn surfaces. The sapwood is lighter in color and generally distinct from the heartwood. The texture is medium and fairly uniform, and the grain is generally interlocked. The heartwood is rather similar in appearance to dark red meranti (*Shorea*). The wood is moderately easy to work and good surfaces can be obtained when attention is paid to machining operations. The wood averages about 608 kg/m^3 (38 lb/ft^3) at 12% moisture content. Santa Maria is in the density class of sugar maple (*Acer saccharum*), and its strength properties are generally similar; the hardness of sugar maple is superior to that of Santa Maria. The heartwood is generally rated as moderately durable to durable in contact with the ground, but it apparently has no resistance against termites and marine borers.

The inherent natural durability, color, and figure on the quarter-sawn face suggest that Santa Maria could be used as veneer for plywood in boat construction. Other uses are flooring, furniture, cabinetwork, millwork, and decorative plywood.

Sapele

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

The heartwood ranges in color from that of American mahogany (*Swietenia macrophylla*) to a dark reddish or purplish brown. The lighter-colored and distinct sapwood may be up to 10 cm (4 in.) wide. The texture is rather fine. The grain is interlocked and produces narrow and uniform striping on quarter-sawn surfaces. The wood averages about 674 kg/m^3 (42 lb/ft^3) at 12% moisture content, and its mechanical properties are in general higher than those of white oak (*Quercus alba*). The wood works fairly easily with machine tools, although the interlocked grain makes it difficult to plane. Sapele finishes and glues well. The heartwood is rated as moderately durable and is resistant to preservative treatment.

As lumber, sapele is used for furniture and cabinetwork, joinery, and flooring. As veneer, it is used for decorative plywood.

Selangan Batu (see Balau)

Sepetir

The name sepetir applies to species in the genus *Sindora* and to *Pseudosindora palustris*. These species are distributed throughout Malaysia, Indochina, and the Philippines.

The heartwood is brown with a pink or golden tinge that darkens on exposure to air. Dark brown or black streaks are sometimes present. The sapwood is light gray, brown, or straw-colored. The texture is moderately fine and even, and the grain is narrowly interlocked. The strength of sepetir is similar to that of shellbark hickory (*Carya laciniosa*), and the density of the air-dried wood is also similar (640 to 720 kg/m^3 (40 to 45 lb/ft^3)). The wood dries well but rather slowly, with a tendency to end-split. The wood is difficult to work with hand tools and has a rather rapid dulling effect on cutters. Gums from the wood tend to accumulate on saw teeth, which causes additional problems. Sepetir is rated as nondurable in ground contact under Malaysian exposure. The heartwood is extremely resistant to preservative treatment; however, the sapwood is only moderately resistant.

Sepetir is a general carpentry wood that is also used for furniture and cabinetwork, joinery, flooring (especially truck flooring), plywood, and decorative veneers.

Seraya, Red and Dark Red (see Meranti Groups)

Seraya, White

White seraya or bagtikan, as it is called in the Philippines, is a name applied to the 14 species of *Parashorea*, which grow in Sabah and the Philippines.

The heartwood is light brown or straw-colored, sometimes with a pinkish tint. The texture is moderately coarse and the grain interlocked. White seraya is very similar in appearance and strength properties to light red meranti, and sometimes the two are mixed in the market. White seraya dries easily with little degrade, and works fairly well with hand and machine tools. The heartwood is not durable to moderately durable in ground contact, and it is extremely resistant to preservative treatments.

White seraya is used for joinery, light construction, moulding and millwork, flooring, plywood, furniture, and cabinet work.

Seraya, Yellow (see Meranti Groups)

Silverballi, Brown (see Kaneelhart)

Spanish-Cedar

Spanish-cedar or cedro consists of a group of about seven species in the genus *Cedrela* that are widely distributed in tropical America from southern Mexico to northern Argentina.

Spanish-cedar is one of only a few tropical species that are ring-porous. The heartwood varies from light to dark reddish brown, and the sapwood is pinkish to white. The texture is rather fine and uniform to coarse and uneven. The grain is not interlocked. The heartwood is characterized by a distinctive odor. The wood dries easily. Although Spanish-cedar is not high in strength, most other properties are similar to those of American mahogany (*Swietenia macrophylla*), except for hardness and compression perpendicular to the grain, where mahogany is definitely superior. Spanish-cedar is considered decay resistant; it works and glues well.

Spanish-cedar is used locally for all purposes that require an easily worked, light but straight grained, and durable wood. In the United States, the wood is favored for millwork, cabinets, fine furniture, boat building, cigar wrappers and boxes, humidores, and decorative and utility plywood.

Sucupira (Angelin, Para-Angelim)

Sucupira, angelin, and para-angelim apply to species in four genera of legumes from South America. Sucupira applies to *Bowdichia nitida* from northern Brazil, *B. virgilioides* from Venezuela, the Guianas, and Brazil, and *Diplotropis purpurea* from the Guianas and southern Brazil. Angelin (*Andira inermis*) is a widespread species that occurs throughout the West Indies and from southern Mexico through Central America to northern South America and Brazil. Para-angelim (*Hymenolobium excelsum*) is generally restricted to Brazil.

The heartwood of sucupira is chocolate-brown, red–brown, or light brown (especially in *Diplotropis purpurea*). Angelin heartwood is yellowish brown to dark reddish brown; para-angelim heartwood turns pale brown upon exposure to air. The sapwood is generally yellowish to whitish and is sharply demarcated from the heartwood. The texture of all three woods is coarse and uneven, and the grain can be interlocked. The density of air-dried wood of these species ranges from 720 to 960 kg/m^3 (45 to 60 lb/ft^3), which makes them generally heavier than true hickory (*Carya*). Their strength properties are also higher than those of true hickory. The heartwood is rated very durable to durable in resistance to decay fungi but only moderately resistant to attack by drywood termites. Angelin is reported to be difficult to treat with preservatives, but para-angelim and sucupira treat adequately. Angelin can be sawn and worked fairly well, except that it is difficult to plane to a smooth surface because of alternating hard (fibers) and soft (parenchyma) tissue. Para-angelim works well in all operations. Sucupira is difficult to moderately difficult to work because of its high density, irregular grain, and coarse texture.

Sucupira, angelin, and para-angelim are ideal for heavy construction, railroad crossties, and other uses that do not require much fabrication. Other suggested uses include flooring, boat building, furniture, turnery, tool handles, and decorative veneer.

Suradan (see Pilon)

Tangare (see Andiroba)

Tanguile (see Lauan–Meranti Groups)

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 in tropical areas of Latin America and Africa, and many of these are now producing teakwood.

The heartwood varies from yellow–brown to dark golden–brown and eventually turns a rich brown upon exposure to air. Teakwood has a coarse uneven texture (ring porous), is usually straight grained, and has a distinctly oily feel. The heartwood has excellent dimensional stability and a very high degree of natural durability. Although teak is not generally used in the United States where strength is of prime importance, its properties are generally on par with those of U.S. oaks (*Quercus*). Teak is generally worked with moderate ease with hand and machine tools. However, the presence of silica often dulls tools. Finishing and gluing are satisfactory, although pretreatment may be necessary to ensure good bonding of finishes and glues.

Teak is one of the most valuable woods, but its use is limited by scarcity and high cost. Because teak does not cause rust or corrosion when in contact with metal, it is extremely useful in the shipbuilding industry, for tanks and vats, and for fixtures that require high acid resistance. Teak is currently used in the construction of boats, furniture, flooring, decorative objects, and decorative veneer.

Tornillo

Tornillo (*Cedrelinga cateniformis*), also referred to as cedrorana, grows in the Loreton Huanuco provinces of Peru and in the humid terra firma of the Brazilian Amazon region. Tornillo can grow up to 52.5 m (160 ft) tall, with trunk diameters of 1.5 to 3 m (5 to 9 ft). Trees in Peru are often smaller in diameter, with merchantable heights of 15 m (45 ft) or more.

The heartwood is pale brown with a golden luster and prominently marked with red vessel lines; the heartwood gradually merges into the lighter-colored sapwood. The texture is coarse. The density of air-dried material collected in Brazil averages 640 kg/m^3 (40 lb/ft^3); for Peruvian stock, average density is about 480 kg/m^3 (30 lb/ft^3). The wood is comparable in strength with American elm (*Ulmus americana*). Tornillo cuts easily and can be finished smoothly, but areas of tension wood may result in woolly surfaces. The heartwood is fairly durable and reported to have good resistance to weathering.

Tornillo is a general construction wood that can be used for furniture components in lower-grade furniture.

Trebol (see Macawood)

Virola (see Banak)

Waika (see Manni)

Walele (see Ilomba)

Wallaba

Wallaba is a common name applied to the species in the genus *Eperua*. Other names include wapa and apa. The center of distribution is in the Guianas, but the species extends into Venezuela and the Amazon region of northern Brazil. Wallaba generally occurs in pure stands or as the dominant tree in the forest.

The heartwood ranges from light to dark red to reddish or purplish brown with characteristically dark, gummy streaks. The texture is rather coarse and the grain typically straight. Wallaba is a hard, heavy wood; density of air-dried wood is 928 kg/m^3 (58 lb/ft^3). Its strength is higher than that of shagbark hickory (*Carya ovata*). The wood dries very slowly with a marked tendency to check, split, and warp. Although the wood has high density, it is easy to work with hand and machine tools. However, the high gum content clogs sawteeth and cutters. Once the wood has been kiln dried, gum exudates are not a serious problem in machining. The heartwood is reported to be very durable and resistant to subterranean termites and fairly resistant to dry-wood termites.

Wallaba is well suited for heavy construction, railroad crossties, poles, industrial flooring, and tank staves. It is also highly favored for charcoal.

Wapa (see Wallaba)

Yang (see Keruing)

Softwoods

Cypress, Mexican

Native to Mexico and Guatemala, Mexican cypress (*Cupressus lusitanica*) is now widely planted at high elevations throughout the tropical world.

The heartwood is yellowish, pale brown, or pinkish, with occasional streaking or variegation. The texture is fine and uniform, and the grain is usually straight. The wood is fragrantly scented. The density of air-dried wood is 512 kg/m^3 (32 lb/ft^3), and the strength is comparable with that of yellow-cedar (*Chamaecyparis nootkatensis*) or western hemlock (*Tsuga heterophylla*). The wood is easy to work with hand and machine tools, and it nails, stains, and polishes well. Mexican cypress air dries very rapidly with little or no end- or surface-checking. Reports on durability are conflicting. The heartwood is not treatable by the open tank process and seems to have an irregular response to pressure–vacuum systems.

Mexican cypress is used mainly for posts and poles, furniture components, and general construction.

Parana Pine

The wood commonly called parana pine (*Araucaria angustifolia*) is a softwood but not a true pine. It grows in southeastern Brazil and adjacent areas of Paraguay and Argentina.

Parana pine has many desirable characteristics. It is available in large-size clear boards with uniform texture. The small pinhead knots (leaf traces) that appear on flat-sawn surfaces and the light or reddish-brown heartwood provide a desirable figure for matching in paneling and interior woodwork. Growth rings are fairly distinct and similar to those of eastern white pine (*Pinus strobus*). The grain is not interlocked, and the wood takes paint well, glues easily, and is free from resin ducts, pitch pockets, and pitch streaks. Density of air-dried wood averages 545 kg/m^3 (34 lb/ft^3). The strength of parana pine compares favorably with that of U.S. softwood species of similar density and, in some cases, approaches that of species with higher density. Parana pine is especially strong in shear strength, hardness, and nail-holding ability, but it is notably deficient in strength in compression across the grain. The tendency of the kiln-dried wood to split and warp is caused by the presence of compression wood, an abnormal type of wood 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 woodwork, sashes and door stock, furniture case goods, and veneer.

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. This low-elevation tree is widely introduced as a plantation species throughout the world tropics.

The heartwood is golden- to red-brown and distinct from the sapwood, which is light yellow and roughly 2 to 5 cm (1 to 2 in.) wide. This softwood species has a strong resinous odor and a greasy feel. The weight varies considerably and may range from 416 to 817 kg/m^3 (26 to 51 lb/ft^3) at 12% moisture content. Caribbean pine may be appreciably heavier than slash pine (*P. elliottii*), but the mechanical properties of these two species are rather similar. The lumber can be kiln dried satisfactorily. Caribbean pine is easy to work in all machining operations, but its high resin content may cause resin to accumulate on the equipment. Durability and resistance to insect attack vary with resin content; in general, the heartwood is rated as moderately durable. The sapwood is highly permeable and is easily treated by open tank or pressure–vacuum systems. The heartwood is rated as moderately resistant to preservative treatment, depending on resin content.

Caribbean pine is used for the same purposes as are the southern pines (*Pinus* spp.).

Pine, Ocote

Ocote pine (*Pinus oocarpa*) is a high-elevation species that occurs from northwestern Mexico southward through Guatemala into Nicaragua. The largest and most extensive stands occur in Guatemala, Nicaragua, and Honduras.

The sapwood is a pale yellowish brown and generally up to 7 cm (3 in.) wide. The heartwood is a light reddish brown. The grain is not interlocked. The wood has a resinous odor, and it weighs about 656 kg/m^3 (41 lb/ft^3) at 12% moisture content. The strength properties of ocote pine are comparable in most respects with those of longleaf pine (*P. palustris*).

Decay resistance studies have shown ocote pine heartwood to be very durable with respect to white-rot fungal attack and moderately durable with respect to brown rot.

Ocote pine is comparable with the southern pines (*Pinus*) in workability and machining characteristics. It is a general construction wood suited for the same uses as are the southern pines.

Pine, Radiata

Radiata pine (*Pinus radiata*), also known as Monterey pine, is planted extensively in the southern hemisphere, mainly in Chile, New Zealand, Australia, and South Africa. Plantation-grown trees may reach a height of 26 to 30 m (80 to 90 ft) in 20 years.

The heartwood from plantation-grown trees is light brown to pinkish brown and is distinct from the paler cream-colored sapwood. Growth rings are primarily wide and distinct. False rings may be common. The texture is moderately even and fine, and the grain is not interlocked. Plantation-grown radiata pine averages about 480 kg/m^3 (30 lb/ft^3) at 12% moisture content. Its strength is comparable with that of red pine (*P. resinosa*), although location and growth rate may cause considerable variation in strength properties. The wood air or kiln dries rapidly with little degrade. The wood machines easily although the grain tends to tear around large knots. Radiata pine nails and glues easily, and it takes paint and finishes well. The sapwood is prone to attack by stain fungi and vulnerable to boring insects. However, plantation-grown stock is mostly sapwood, which treats readily with preservatives. The heartwood is rated as durable above ground and is moderately resistant to preservative treatment.

Radiata pine can be used for the same purposes as are the other pines grown in the United States. These uses include veneer, plywood, pulp, fiberboard, construction, boxes, and millwork.

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Chapter 2

Structure of Wood

Regis B. Miller

Contents

The fibrous nature of wood strongly influences how it is used. Wood is primarily composed of hollow, elongate, spindle-shaped cells that are arranged parallel to each other along the trunk of a tree. When lumber and other products are cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage as well as the grain pattern of the wood. This chapter briefly describes some elements of wood structure.

Bark, Wood, Branches, and Cambium

A cross section of a tree (Fig. 2–1) shows the following well-defined features (from outside to center): bark, which may be divided into an outer corky dead part (A), whose thickness varies greatly with species and age of trees, and an inner thin living part (B), which carries food from the leaves to growing parts of the tree; wood, which in merchantable trees of most species is clearly differentiated into sapwood (D) and heartwood (E); and pith (F), a small core of tissue located at the center of tree stems, branches, and twigs about which initial wood growth takes place. Sapwood contains both living and dead tissue and carries sap from the roots to the leaves. Heartwood is formed by a gradual change in the sapwood and is inactive. The wood rays (G), horizontally oriented tissue through the radial plane of the tree, vary in size from one cell wide and a few cells high to more than 15 cells wide and several centimeters high. The rays connect various layers from pith to bark for storage and transfer of food. The cambium layer (C), which is inside the inner bark and forms wood and bark cells, can be seen only with a microscope.

As the tree grows in height, branching is initiated by lateral bud development. The lateral branches are intergrown with the wood of the trunk as long as they are alive. After a branch dies, the trunk continues to increase in diameter and surrounds that portion of the branch projecting from the trunk when the branch died. If the dead branches drop from the tree, the dead stubs become overgrown and clear wood is formed.

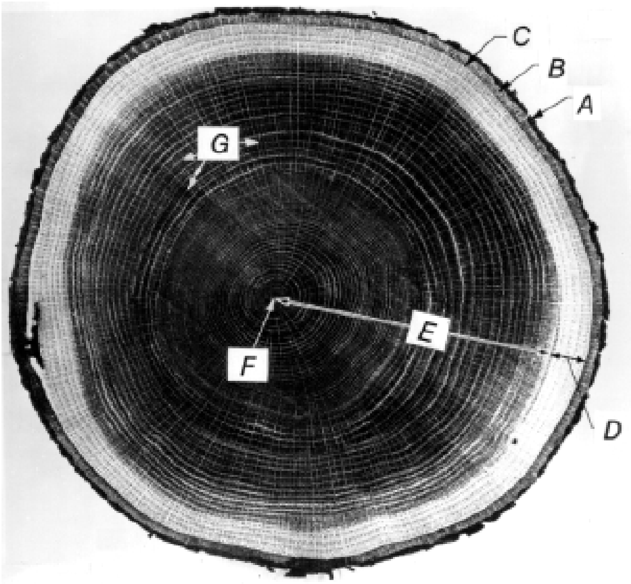

Figure 2–1. Cross section of white oak tree trunk: (A) outer bark (dry dead tissue), (B) inner bark (living tissue), (C) cambium, (D) sapwood, (E) heartwood, (F) pith, and (G) wood rays.

Most growth in thickness of bark and wood is caused by cell division in the cambium (Fig. 2–1C). No growth in diameter takes place in wood outside the cambial zone; new growth is purely the addition and growth of new cells, not the further development of old ones. New wood cells are formed on the inside of the cambium and new bark cells on the outside. Thus, new wood is laid down to the outside of old wood and the diameter of the woody trunk increases.

In most species, the existing bark is pushed outward by the formation of new bark, and the outer bark layers become stretched, cracked, and ridged and are finally sloughed off.

Sapwood and Heartwood

Sapwood is located between the cambium and heartwood (Fig. 2–1D). Sapwood contains both living and dead cells and functions primarily in the storage of food; in the outer layers near the cambium, sapwood handles the transport of water or sap. The sapwood may vary in thickness and number of growth rings. Sapwood commonly ranges from 4 to 6 cm (1-1/2 to 2 in.) in radial thickness. In certain species, such as catalpa and black locust, the sapwood contains few growth rings and usually does not exceed 1 cm (1/2 in.) in thickness. The maples, hickories, ashes, some southern pines, and ponderosa pine of North America and cativo (*Prioria copaifera*), ehie (*Guibourtia ehie*), and courbaril (*Hymenaea courbaril*) of tropical origin may have sapwood 8 to 15 cm (3 to 6 in.) or more in thickness, especially in second-growth trees. As a rule, the more vigorously growing trees have wider sapwood. Many second-growth trees of merchantable size consist mostly of sapwood.

In general, heartwood consists of inactive cells that do not function in either water conduction or food storage. The transition from sapwood to heartwood is accompanied by an increase in extractive content. Frequently, these extractives darken the heartwood and give species such as black walnut and cherry their characteristic color. Lighter colored heartwood occurs in North American species such as the spruces (except Sitka spruce), hemlocks, true firs, basswood, cottonwood, and buckeye, and in tropical species such as ceiba (*Ceiba pentandra*), obeche (*Triplochiton scleroxylon*), and ramin (*Gonystylus bancanus*). In some species, such as black locust, western redcedar, and redwood, heartwood extractives make the wood resistant to fungi or insect attack. All dark-colored heartwood is not resistant to decay, and some nearly colorless heartwood is decay resistant, as in northern white-cedar. However, none of the sapwood of any species is resistant to decay. Heartwood extractives may also affect wood by (a) reducing permeability, making the heartwood slower to dry and more difficult to impregnate with chemical preservatives, (b) increasing stability in changing moisture conditions, and (c) increasing weight (slightly). However, as sapwood changes to heartwood, no cells are added or taken away, nor do any cells change shape. The basic strength of the wood is essentially not affected by the transition from sapwood cells to heartwood cells.

In some species, such as the ashes, hickories, and certain oaks, the pores (vessels) become plugged to a greater or lesser extent with ingrowths known as tyloses. Heartwood in which the pores are tightly plugged by tyloses, as in white oak, is suitable for tight cooperage, because the tyloses prevent the passage of liquid through the pores. Tyloses also make impregnation of the wood with liquid preservatives difficult.

Growth Rings

In most species in temperate climates, the difference between wood that is formed early in a growing season and that formed later is sufficient to produce well-marked annual growth rings (Fig. 2–2). 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. However, if the growth in diameter is interrupted, by drought or defoliation by insects for example, 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 an incomplete growth layer, sometimes called a discontinuous ring.

The inner part of the growth ring formed first in the growing season is called earlywood and the outer part formed later in the growing season, latewood. Actual time of formation of these two parts of a ring may vary with environmental and weather conditions. Earlywood is characterized by cells with 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

Figure 2–2. Cross section of ponderosa pine log showing growth rings. Light bands are earlywood, dark bands latewood. An annual (growth) ring is composed of an inner earlywood zone and outer latewood zone.

the kind of wood and the growing conditions at the time it was formed.

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

When growth rings are prominent, as in most softwoods and ring-porous hardwoods, earlywood differs markedly from latewood in physical properties. Earlywood is lighter in weight, softer, and weaker than latewood. Because of the greater density of latewood, the proportion of latewood is sometimes used to judge the strength of the wood. This method is useful with such species as the southern pines, Douglas-fir, and the ring-porous hardwoods (ash, hickory, and oak).

Wood Cells

Wood cells—the structural elements of wood tissue—are of various sizes and shapes and are quite firmly cemented together. Dry wood cells may be empty or partly filled with deposits, such as gums and resins, or with tyloses. The majority of wood cells are considerably elongated and pointed at the ends; these cells are customarily called fibers or tracheids. The length of wood fibers is highly variable within a tree and among species. Hardwood fibers average about 1 mm (1/25 in.) in length; softwood fibers range from 3 to 8 mm (1/8 to 1/3 in.) in length.

In addition to fibers, hardwoods have cells of relatively large diameter known as vessels or pores. These cells form the main conduits in the movement of sap. Softwoods do not contain 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 or tissues) that are oriented horizontally in the direction from pith toward bark. These groups of cells conduct sap radially across the grain and are called rays or wood rays (Fig. 2–1G). The rays are most easily seen on edge-grained or quartersawn surfaces, and 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. Rays also represent planes of weakness along which seasoning checks readily develop.

Another type of wood cells, known as longitudinal or axial parenchyma cells, function mainly in the storage of food.

Chemical Composition

Dry wood is primarily composed of cellulose, lignin, hemicelluloses, and minor amounts (5% to 10%) of extraneous materials. Cellulose, the major component, constitutes approximately 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of chains of 1 to more than 4 β-linked glucose monomers. During growth of the tree, the cellulose molecules are arranged into ordered strands called fibrils, which in turn are organized into the larger structural elements that make up the cell wall of wood fibers. Most of the cell wall cellulose is crystalline. Delignified wood fibers, which consist mostly of cellulose, have great commercial value when formed into paper. Delignified fibers may also be chemically altered to form textiles, films, lacquers, and explosives.

Lignin constitutes 23% to 33% of the wood substance in softwoods and 16% to 25% in hardwoods. Although lignin occurs in wood throughout the cell wall, it is concentrated toward the outside of the cells and between cells. Lignin is often called the cementing agent that binds individual cells together. Lignin is a three-dimensional phenylpropanol polymer, and its structure and distribution in wood are still not fully understood. On a commercial scale, it is necessary to remove lignin from wood to make high-grade paper or other paper products.

Theoretically, lignin might be converted to a variety of chemical products, but in commercial practice a large percentage of the lignin removed from wood during pulping operations is a troublesome byproduct, which is often burned for heat and recovery of pulping chemicals. One sizable commercial use for lignin is in the formulation of oil-well drilling muds. Lignin is also used in rubber compounding and concrete mixes. Lesser amounts are processed to yield vanillin for flavoring purposes and to produce solvents. Current research is examining the potential of using lignin in the manufacture of wood adhesives.

The hemicelluloses are associated with cellulose and are branched, low-molecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. The relative amounts of these sugars vary markedly with species. 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 of wood, extraneous materials are not structural components. Both organic and inorganic extraneous materials are found in wood. The organic component takes the form of extractives, which contribute to such wood properties as color, odor, taste, decay resistance, density, hygroscopicity, and flammability. Extractives include tannins and other polyphenolics, coloring matter, essential oils, fats, resins, waxes, gum starch, and simple metabolic intermediates. This component is termed extractives because it can be removed from wood by extraction with solvents, such as water, alcohol, acetone, benzene, or ether. Extractives may constitute roughly 5% to 30% of the wood substance, depending on such factors as species, growth conditions, and time of year when the tree is cut.

The inorganic component of extraneous material generally constitutes 0.2% to 1.0% of the wood substance, although greater values are occasionally reported. Calcium, potassium, and magnesium are the more abundant elemental constituents. Trace amounts (<100 parts per million) of phosphorus, sodium, iron, silicon, manganese, copper, zinc, and perhaps a few other elements are usually present.

Valuable nonfibrous products produced from wood include naval stores, pulp byproducts, vanillin, ethyl alcohol, charcoal, extractives, and products made from bark.

Species Identification

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

General wood identification can often be made quickly on the basis of readily visible characteristics such as color, odor, density, presence of pitch, or grain pattern. Where more positive identification is required, a laboratory investigation must be made of the microscopic anatomy of the wood. Identifying characteristics are described in publications such as the *Textbook of Wood Technology* by Panshin and de Zeeuw and *Identifying Wood: Accurate Results With Simple Tools* by R.B. Hoadley.

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Physical Properties and Moisture Relations of Wood

William Simpson and Anton TenWolde

Contents

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 among the many species of wood. In many cases, more than one property of wood is important to the end product. For example, to select a wood 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, dimensional stability, or decay resistance.

Wood exchanges moisture with air; the amount and direction of the exchange (gain or loss) depend on the relative humidity and temperature of the air and the current amount of water in the wood. This moisture relationship has an important influence on wood properties and performance. This chapter discusses the physical properties of most 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 independent of species. The thoroughness of sampling and the degree of variability influence 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 used 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 detail relative to mechanical properties in Chapter 4. Wood finishers refer to wood as open grained and close grained, which are terms reflecting the relative size of the pores, which determines whether the surface needs a filler. Earlywood and latewood within a growth increment usually consist of different kinds and sizes of wood cells. The difference in cells results in difference in appearance of the growth rings, and the resulting appearance is the texture of the wood. Coarse texture can result from wide bands of large vessels, such as in oak.

“Even” texture generally means uniformity in cell dimensions. Fine-textured woods have small, even-textured cells. Woods that have larger even-sized cells are considered medium-textured woods. When the words grain or texture are used in connection with wood, the meaning intended should be made clear (see Glossary).

Plainsawn and Quartersawn

Lumber can be cut from a log in two distinct ways: (a) tangential to the annual rings, producing flatsawn or plainsawn lumber in hardwoods and flatsawn or slash-grained lumber in softwoods, and (b) radially from the pith or parallel to the rays, producing quartersawn lumber in hardwoods and edge-grained or vertical-grained lumber in softwoods (Fig. 3–1). Quartersawn lumber is not usually cut strictly parallel with the rays. In plainsawn boards, the surfaces next to the edges are often far from tangential to the rings. In commercial practice, lumber with rings at angles of 45° to 90° to the wide surface is called quartersawn, and lumber with rings at angles of 0° to 45° to the wide surface is called plainsawn. Hardwood lumber in which annual rings form angles of 30° to 60° to the wide faces is sometimes called bastard sawn.

For many purposes, either plainsawn or quartersawn lumber is satisfactory. Each type has certain advantages that can be important for a particular use. Some advantages of plainsawn and quartersawn lumber are given in Table 3–1.

Decorative Features

The decorative value of wood depends upon its color, figure, and luster, as well as 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 color descriptions of the various kinds of wood. Sapwood of most species is light in color; in some species, sapwood is practically white.

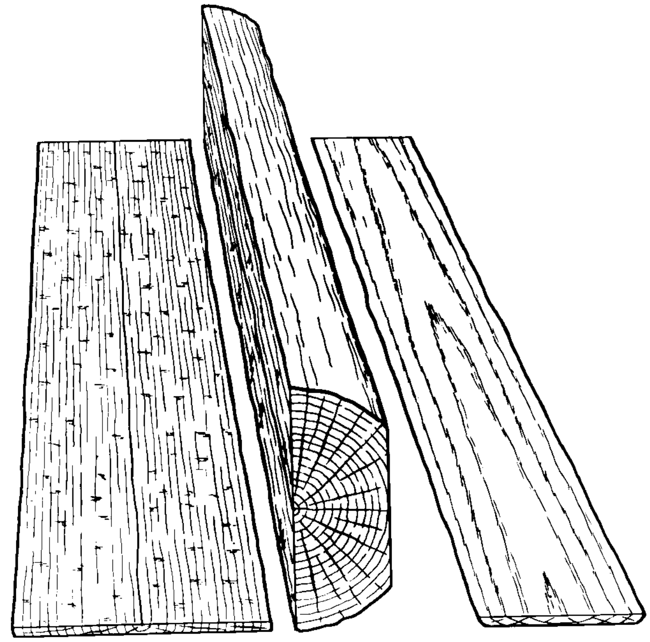

Figure 3–1. Quartersawn (A) and plainsawn (B) boards cut from a log.

White sapwood of certain species, such as maple, may be preferred to the heartwood for specific uses. In most species, heartwood is darker and fairly uniform in color. In some species, such as hemlock, spruce, the true firs, basswood, cottonwood, and beech, there is little or no difference in color between sapwood and heartwood. Table 3–2 describes the color and figure of several common domestic woods.

On the surface of plainsawn boards and rotary-cut veneer, the annual growth rings frequently form elliptic and parabolic patterns that make striking figures, especially when the rings are irregular in width and outline on the cut surface.

Table 3–1. Some advantages of plainsawn and quartersawn lumber

Plainsawn	Quartersawn
Shrinks and swells less in thickness	Shrinks and swells less in width
Surface appearance less affected by round or oval knots compared to effect of spike knots in quartersawn boards; boards with round or oval knots not as weak as boards with spike knots	Cups, surface-checks, and splits less in seasoning and in use
Shakes and pitch pockets, when present, extend through fewer boards	Raised grain caused by separation in annual rings does not become as pronounced
Figure patterns resulting from annual rings and some other types of figure brought out more conspicuously	Figure patterns resulting from pronounced rays, interlocked grain, and wavy grain are brought out more conspicuously
Is less susceptible to collapse in drying	Does not allow liquids to pass through readily in some species
Costs less because it is easy to obtain	Holds paint better in some species
	Sapwood appears in boards at edges and its width is limited by the width of the log

Table 3–2. Color and figure of several common domestic woods

Species	Color of dry heartwood[a]	Type of figure: Plainsawn lumber or rotary-cut veneer	Type of figure: Quartersawn 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, inconspicuous growth ring stripe; occasional burl
Ash, Oregon	Grayish brown, sometimes with reddish tinge	Conspicuous growth ring; occasional burl	Distinct, inconspicuous growth ring stripe; occasional burl
Ash, white	Grayish brown, sometimes with reddish tinge	Conspicuous growth ring; occasional burl	Distinct, inconspicuous growth ring stripe; occasional burl
Aspen	Light brown	Faint growth ring	None
Basswood	Creamy white to creamy brown, sometimes reddish	Faint growth ring	None
Beech, American	White with reddish to reddish brown tinge	Faint growth ring	Numerous small flakes up to 3.2 mm (1/8 in.) in height
Birch, paper	Light brown	Faint growth ring	None
Birch, sweet	Dark reddish brown	Distinct, inconspicuous growth ring; occasionally wavy	Occasionally wavy
Birch, yellow	Reddish brown	Distinct, inconspicuous growth ring; occasionally wavy	Occasionally wavy
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, inconspicuous growth ring stripe
Cottonwood	Grayish white to light grayish brown	Faint growth ring	None
Elm, American & rock	Light grayish brown, usually with reddish tinge	Distinct, inconspicuous grown ring with fine wavy pattern	Faint growth ring stripe
Elm, slippery	Dark brown with shades of red	Conspicuous growth ring with fine pattern	Distinct, inconspicuous growth ring stripe
Hackberry	Light yellowish or greenish gray	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
Hickory	Reddish brown	Distinct, inconspicuous growth ring	Faint growth ring stripe
Honeylocust	Cherry red	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
Locust, black	Golden brown, sometimes with tinge of green	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
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 birds-eye, curly, and wavy	Occasionally curly and wavy
Oaks, all red oaks	Light brown, usually with pink or red tinge	Conspicuous growth ring	Pronounced flake; distinct, inconspicuous growth ring stripe
Oaks, all white oaks	Light to dark brown, rarely with reddish tinge	Conspicuous growth ring	Pronounced flake; distinct, inconspicuous growth ring stripe
Sweetgum	Reddish brown	Faint growth ring; occasional irregular streaks	Distinct, inconspicuous ribbon; occasional streak
Sycamore	Light to dark or reddish brown	Faint growth ring	Numerous pronounced flakes up to 6.4 mm (1/4 in.) in height
Tupelo, black and water	Pale to moderately dark brownish gray	Faint growth ring	Distinct, not pronounced ribbon
Walnut, black	Chocolate brown, occasionally with darker, sometimes purplish streaks	Distinct, inconspicuous growth ring; occasionally wavy, curly, burl, and other types	Distinct, inconspicuous 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

Table 3–2. Color and figure of several common domestic woods—con.

Species	Color of dry heartwood[a]	Type of figure: Plainsawn lumber or rotary-cut veneer	Type of figure: Quartersawn lumber or quarter-sliced veneer
Softwoods			
Baldcypress	Light yellowish to reddish brown	Conspicuous irregular growth ring	Distinct, inconspicuous growth ring stripe
Cedar, Atlantic White	Light brown with reddish tinge	Distinct, inconspicuous growth ring	None
Cedar, Eastern red	Brick red to deep reddish brown	Occasionally streaks of white sapwood alternating with heartwood	Occasionally streaks of white sapwood alternating with heartwood
Cedar, incense	Reddish brown	Faint growth ring	Faint growth ring stripe
Cedar, northern White	Light to dark brown	Faint growth ring	Faint growth ring stripe
Cedar, Port-Orford	Light yellow to pale brown	Faint growth ring	None
Cedar, western red	Reddish brown	Distinct, inconspicuous growth ring	Faint growth ring stripe
Cedar, yellow	Yellow	Faint growth ring	None
Douglas-fir	Orange red to red, sometimes yellow	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
Fir, balsam	Nearly white	Distinct, inconspicuous growth ring	Faint growth ring stripe
Fir, white	Nearly white to pale reddish brown	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
Hemlock, eastern	Light reddish brown	Distinct, inconspicuous growth ring	Faint growth ring stripe
Hemlock, western	Light reddish brown	Distinct, inconspicuous growth ring	Faint growth ring stripe
Larch, western	Russet to reddish brown	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
Pine, eastern white	Cream to light reddish brown	Faint growth ring	None
Pine, lodgepole	Light reddish brown	Distinct, inconspicuous growth ring; faint pocked appearance	None
Pine, ponderosa	Orange to reddish brown	Distinct, inconspicuous growth ring	Faint growth ring
Pine, red	Orange to reddish brown	Distinct, inconspicuous growth ring	Faint growth ring
Pine, Southern: longleaf, loblolly, shortleaf, and slash	Orange to reddish brown	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe
Pine, sugar	Light creamy brown	Faint growth ring	None
Pine, western white	Cream to light reddish brown	Faint growth ring	None
Redwood	Cherry red to deep reddish brown	Distinct, inconspicuous growth ring; occasionally wavy and burl	Faint growth ring stripe; occasionally wavy and burl
Spruce: black, Engelmann, red, and white	Nearly white	Faint growth ring	None
Spruce, Sitka	Light reddish brown	Distinct, inconspicuous growth ring	Faint growth ring stripe
Tamarack	Russet brown	Conspicuous growth ring	Distinct, inconspicuous growth ring stripe

[a]Sapwood of all species is light in color or virtually white unless discolored by fungus or chemical stains.

On quartersawn surfaces, these rings form stripes, which are not especially ornamental unless they are irregular in width and direction. The relatively large rays sometimes appear as flecks that can form a conspicuous figure in quartersawn oak and sycamore. With interlocked grain, which slopes in alternate directions in successive layers from the center of the tree outward, quartersawn 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 plainsawn lumber.

In open-grained hardwoods, the appearance of both plainsawn and quartersawn 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 by applying a stain. The visual effect of applying stain to softwood is an overall darkening and a contrast reversal with earlywood of initially lighter color absorbing more stain, thus becoming darker than latewood. The final contrast is often greater than that in unstained softwood and sometimes appears unnatural.

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 a percentage, of the weight of ovendry wood. Weight, shrinkage, strength, and other properties depend upon the moisture content of wood.

In trees, moisture content can range from about 30% to more than 200% of the weight of wood substance. In softwoods, the moisture content of sapwood is usually greater than that of heartwood. In hardwoods, the difference in moisture content between heartwood and sapwood depends on the species. The average moisture content of heartwood and sapwood of some domestic species is given in Table 3–3. 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. Additional information on moisture in wood is given in Chapter 12.

Green Wood and Fiber Saturation Point

Moisture can exist in wood as liquid water (free water) or water vapor in cell lumens and cavities and as water held chemically (bound water) within cell walls. Green wood is often defined as freshly sawn 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 both the cell lumens and cell walls are completely saturated with water is the maximum possible moisture content. Specific gravity is the major determinant of maximum moisture content. Lumen volume decreases as specific gravity increases, so maximum moisture content also decreases as specific gravity increases because there is less room available for free water. Maximum moisture content M_{max} for any specific gravity can be calculated from

$$M_{\text{max}} = 100(1.54 - G_{\text{b}})/1.54G_{\text{b}} \qquad (3\text{–}1)$$

where G_{b} is basic specific gravity (based on ovendry weight and green volume) and 1.54 is specific gravity of wood cell walls. Maximum possible moisture content varies from 267% at specific gravity of 0.30 to 44% at specific gravity 0.90. Maximum possible moisture content is seldom attained in trees. However, green moisture content can be quite high in some species naturally or through waterlogging. The moisture content at which wood will sink in water can be calculated by

$$M_{\text{sink}} = 100(1 - G_{\text{b}})/G_{\text{b}} \qquad (3\text{–}2)$$

Conceptually, the moisture content at which only the cell walls are completely saturated (all bound water) but no water exists in cell lumens is called the fiber saturation point. While a useful concept, the term fiber saturation point is not very precise. In concept, it distinguishes between the two ways water is held in wood. In fact, it is possible for all cell lumens to be empty and have partially dried cell walls in one part of a piece of wood, while in another part of the same piece, cell walls may be saturated and lumens partially or completely filled with water. It is even probable that a cell wall will begin to dry before all the water has left the lumen of that same cell. The fiber saturation point of wood averages about 30% moisture content, but in individual species and individual pieces of wood it can vary by several percentage points from that value. The fiber saturation point also is often considered as that moisture content below which the physical and mechanical properties of wood begin to change as a function of moisture content. During drying, the outer parts of a board can be less than fiber saturation while the inner parts are still greater than fiber saturation.

Equilibrium Moisture Content

The moisture content of wood below the fiber saturation point is a function of both relative humidity and temperature of the surrounding air. Equilibrium moisture content (EMC) 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 EMC, relative humidity, and temperature is shown in Table 3–4. For most practical purposes, the values in Table 3–4 may be applied to wood of any species. Data in Table 3–4 can be approximated by the following:

$$M = \frac{1{,}800}{W}\left[\frac{Kh}{1-Kh} + \frac{K_1Kh + 2K_1K_2K^2h^2}{1 + K_1Kh + K_1K_2K^2h^2}\right] \qquad (3\text{–}3)$$

where h is relative humidity (%/100), and M is moisture content (%).

For temperature T in Celsius,

$$W = 349 + 1.29T + 0.0135T^2$$

$$K = 0.805 + 0.000736T - 0.00000273T^2$$

$$K_1 = 6.27 - 0.00938T - 0.000303T^2$$

$$K_2 = 1.91 + 0.0407T - 0.000293T^2$$

and for temperature in Fahrenheit,

$$W = 330 + 0.452T + 0.00415T^2$$

$$K = 0.791 + 0.000463T - 0.000000844T^2$$

$$K_1 = 6.34 + 0.000775T - 0.0000935T^2$$

$$K_2 = 1.09 + 0.0284T - 0.0000904T^2$$

Wood in service is exposed to both long-term (seasonal) and short-term (daily) changes in relative humidity and temperature of the surrounding air. Thus, wood is always 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 can be retarded, but not prevented, by protective coatings, such as varnish, lacquer, or paint. The objective of wood drying is to bring the wood close to the moisture content a finished product will have in service (Chs. 12 and 15).

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

Species	Moisture content[a] (%) Heartwood	Sapwood
Hardwoods		
Alder, red	—	97
Apple	81	74
Ash, black	95	—
Ash, green	—	58
Ash, white	46	44
Aspen	95	113
Basswood, American	81	133
Beech, American	55	72
Birch, paper	89	72
Birch, sweet	75	70
Birch, yellow	74	72
Cherry, black	58	—
Chestnut, American	120	—
Cottonwood	162	146
Elm, American	95	92
Elm, cedar	66	61
Elm, rock	44	57
Hackberry	61	65
Hickory, bitternut	80	54
Hickory, mockernut	70	52
Hickory, pignut	71	49
Hickory, red	69	52
Hickory, sand	68	50
Hickory, water	97	62
Magnolia	80	104
Maple, silver	58	97
Maple, sugar	65	72
Oak, California black	76	75
Oak, northern red	80	69
Oak, southern red	83	75
Oak, water	81	81
Oak, white	64	78
Oak, willow	82	74
Sweetgum	79	137
Sycamore, American	114	130
Tupelo, black	87	115
Tupelo, swamp	101	108
Tupelo, water	150	116
Walnut, black	90	73
Yellow-poplar	83	106

Species	Moisture content[a] (%) Heartwood	Sapwood
Softwoods		
Baldcypress	121	171
Cedar, eastern red	33	—
Cedar, incense	40	213
Cedar, Port-Orford	50	98
Cedar, western red	58	249
Cedar, yellow	32	166
Douglas-fir, coast type	37	115
Fir, balsam	88	173
Fir, grand	91	136
Fir, noble	34	115
Fir, Pacific silver	55	164
Fir, white	98	160
Hemlock, eastern	97	119
Hemlock, western	85	170
Larch, western	54	119
Pine, loblolly	33	110
Pine, lodgepole	41	120
Pine, longleaf	31	106
Pine, ponderosa	40	148
Pine, red	32	134
Pine, shortleaf	32	122
Pine, sugar	98	219
Pine, western white	62	148
Redwood, old growth	86	210
Spruce, black	52	113
Spruce, Engelmann	51	173
Spruce, Sitka	41	142
Tamarack	49	—

[a]Based on weight when ovendry.

Table 3–4. Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature		Moisture content (%) at various relative humidity values																		
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
–1.1	(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
4.4	(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
10.0	(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
15.6	(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
21.1	(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
26.7	(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
32.2	(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
37.8	(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
43.3	(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
48.9	(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
54.4	(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
60.0	(140)	0.9	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
65.6	(150)	0.9	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
71.1	(160)	0.8	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
76.7	(170)	0.7	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
82.2	(180)	0.7	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
87.8	(190)	0.6	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
93.3	(200)	0.5	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
98.9	(210)	0.5	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
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Sorption Hysteresis

The amount of water adsorbed from a dry condition to equilibrium with any relative humidity is always less than the amount retained in the process of drying from a wetter condition to equilibrium with that same relative humidity. The ratio of adsorption EMC to desorption EMC is constant at about 0.85. Furthermore, EMC in the initial desorption (that is, from the original green condition of the tree) is always greater than in any subsequent desorptions. Data in Table 3–4 were derived primarily under conditions described as oscillating desorption (Stamm and Loughborough 1935), which is thought to represent a condition midway between adsorption and desorption and a suitable and practical compromise for use when the direction of sorption is not always known. Hysteresis is shown in Figure 3–2.

Shrinkage

Wood is dimensionally stable when the moisture content is greater than 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 can result in warping, checking, splitting, and loosening of tool handles, gaps in strip flooring, or performance problems that detract from the usefulness of the wood product. Therefore, it is important that these phenomena be understood and considered when they can affect a product in which wood is used.

With respect to shrinkage characteristics, wood is an anisotropic material. It shrinks most in the direction of the annual growth rings (tangentially), about 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. The major types of distortion as a result of these effects are illustrated in Figure 3–3.

Transverse and Volumetric

Data have been collected to represent the average radial, tangential, and volumetric shrinkage of numerous domestic species by methods described in American Society for Testing and Materials (ASTM) D143—Standard Method of Testing Small Clear Specimens of Timber (ASTM 1997). Shrinkage values, expressed as a percentage of the green dimension, are listed in Table 3–5. Shrinkage values

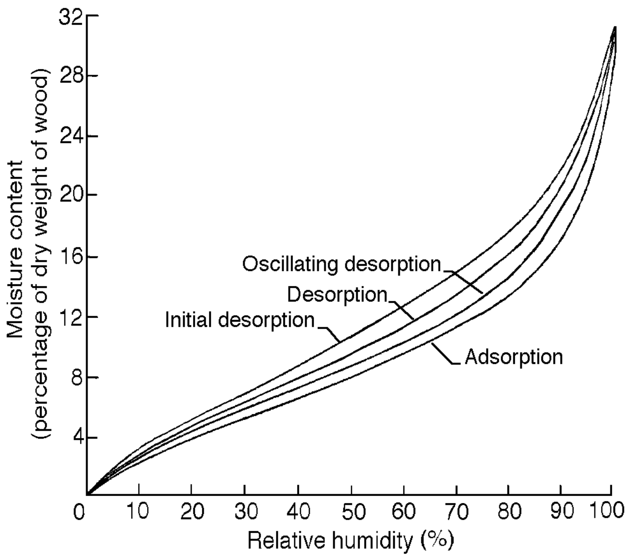

Figure 3–2. Moisture content–relative humidity relationship for wood under adsorption and various desorption conditions.

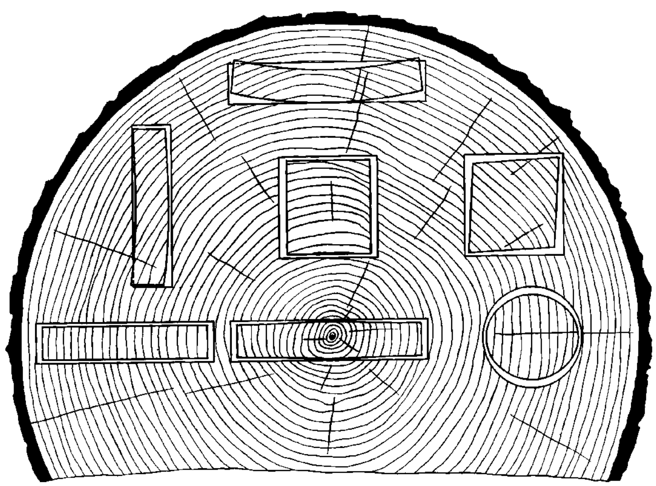

Figure 3–3. Characteristic shrinkage and distortion of flat, square, and round pieces as affected by direction of growth rings. Tangential shrinkage is about twice as great as radial.

collected from the world literature for selected imported species are listed 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 can affect shrinkage, and the rate of drying for some species can affect shrinkage. Transverse and volumetric shrinkage variability can be expressed by a coefficient of variation of approximately 15%.

Longitudinal

Longitudinal shrinkage of wood (shrinkage parallel to the grain) is generally quite small. Average values for shrinkage from green to ovendry are between 0.1% and 0.2% for most species of wood. However, certain types of wood 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 parallel to the grain. Wood from near the center of trees (juvenile wood) of some species also shrinks excessively lengthwise. Reaction wood and juvenile wood can shrink 2% from green to ovendry. Wood with cross grain exhibits increased shrinkage along the longitudinal axis of the piece.

Reaction wood exhibiting excessive longitudinal shrinkage can 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 can develop in the zones of high shrinkage.

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, the surface of the wood dries first. When the surface gets below the fiber saturation point, it begins to shrink. Meanwhile, the interior can still be quite wet and not shrink. The result is that shrinkage of lumber can begin before the average moisture content of the entire piece is below the fiber saturation point, and the moisture content–shrinkage curve can actually look like the one in Figure 3–4. The exact form of the curve depends on several variables, principally size and shape of the piece, species of wood, and drying conditions used.

Considerable variation in shrinkage occurs for any species. Shrinkage data for Douglas-fir boards, 22.2 by 139.7 mm (7/8 by 5-1/2 in.) in cross section, are given in Figure 3–5. The material was grown in one locality and dried under mild conditions from green to near equilibrium at 18°C (65°F) and 30% relative humidity. The figure shows that it is impossible to accurately predict 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, data in Tables 3–5 and 3–6 can be used to estimate shrinkage from the green condition to any moisture content using

$$S_m = S_0\left(\frac{30 - M}{30}\right) \qquad (3\text{–}4)$$

where S_m is shrinkage (%) from the green condition to moisture content M (<30%), and S_0 is total shrinkage (radial, tangential, or volumetric (%)) from Table 3–5 or 3–6.

Table 3–5. Shrinkage values of domestic woods

Species	Shrinkage[a] (%) from green to ovendry moisture content			Species	Shrinkage[a] (%) from green to ovendry moisture content		
	Radial	Tangential	Volumetric		Radial	Tangential	Volumetric
Hardwoods				Oak, white—con.			
Alder, red	4.4	7.3	12.6	Chestnut			
Ash				Live	6.6	9.5	14.7
Black	5.0	7.8	15.2	Overcup	5.3	12.7	16.0
Blue	3.9	6.5	11.7	Post	5.4	9.8	16.2
Green	4.6	7.1	12.5	Swamp, chestnut	5.2	10.8	16.4
Oregon	4.1	8.1	13.2	White	5.6	10.5	16.3
Pumpkin	3.7	6.3	12.0	Persimmon, common	7.9	11.2	19.1
White	4.9	7.8	13.3	Sassafras	4.0	6.2	10.3
Aspen				Sweetgum	5.3	10.2	15.8
Bigtooth	3.3	7.9	11.8	Sycamore, American	5.0	8.4	14.1
Quaking	3.5	6.7	11.5	Tanoak	4.9	11.7	17.3
Basswood, American	6.6	9.3	15.8	Tupelo			
Beech, American	5.5	11.9	17.2	Black	5.1	8.7	14.4
Birch				Water	4.2	7.6	12.5
Alaska paper	6.5	9.9	16.7	Walnut, black	5.5	7.8	12.8
Gray	5.2	—	14.7	Willow, black	3.3	8.7	13.9
Paper	6.3	8.6	16.2	Yellow-poplar	4.6	8.2	12.7
River	4.7	9.2	13.5	**Softwoods**			
Sweet	6.5	9.0	15.6	Cedar			
Yellow	7.3	9.5	16.8	Yellow	2.8	6.0	9.2
Buckeye, yellow	3.6	8.1	12.5	Atlantic white	2.9	5.4	8.8
Butternut	3.4	6.4	10.6	Eastern redcedar	3.1	4.7	7.8
Cherry, black	3.7	7.1	11.5	Incense	3.3	5.2	7.7
Chestnut, American	3.4	6.7	11.6	Northern white	2.2	4.9	7.2
Cottonwood				Port-Orford	4.6	6.9	10.1
Balsam poplar	3.0	7.1	10.5	Western redcedar	2.4	5.0	6.8
Black	3.6	8.6	12.4	Douglas-fir,			
Eastern	3.9	9.2	13.9	Coast[b]	4.8	7.6	12.4
Elm				Interior north[b]	3.8	6.9	10.7
American	4.2	9.5	14.6	Interior west[b]	4.8	7.5	11.8
Cedar	4.7	10.2	15.4	Fir			
Rock	4.8	8.1	14.9	Balsam	2.9	6.9	11.2
Slippery	4.9	8.9	13.8	California red	4.5	7.9	11.4
Winged	5.3	11.6	17.7	Grand	3.4	7.5	11.0
Hackberry	4.8	8.9	13.8	Noble	4.3	8.3	12.4
Hickory, pecan	4.9	8.9	13.6	Pacific silver	4.4	9.2	13.0
Hickory, true				Subalpine	2.6	7.4	9.4
Mockernut	7.7	11.0	17.8	White	3.3	7.0	9.8
Pignut	7.2	11.5	17.9	Hemlock			
Shagbark	7.0	10.5	16.7	Eastern	3.0	6.8	9.7
Shellbark	7.6	12.6	19.2	Mountain	4.4	7.1	11.1
Holly, American	4.8	9.9	16.9	Western	4.2	7.8	12.4
Honeylocust	4.2	6.6	10.8	Larch, western	4.5	9.1	14.0
Locust, black	4.6	7.2	10.2	Pine			
Madrone, Pacific	5.6	12.4	18.1	Eastern white	2.1	6.1	8.2
Magnolia				Jack	3.7	6.6	10.3
Cucumbertree	5.2	8.8	13.6	Loblolly	4.8	7.4	12.3
Southern	5.4	6.6	12.3	Lodgepole	4.3	6.7	11.1
Sweetbay	4.7	8.3	12.9	Longleaf	5.1	7.5	12.2
Maple				Pitch	4.0	7.1	10.9
Bigleaf	3.7	7.1	11.6	Pond	5.1	7.1	11.2
Black	4.8	9.3	14.0	Ponderosa	3.9	6.2	9.7
Red	4.0	8.2	12.6	Red	3.8	7.2	11.3
Silver	3.0	7.2	12.0	Shortleaf	4.6	7.7	12.3
Striped	3.2	8.6	12.3	Slash	5.4	7.6	12.1
Sugar	4.8	9.9	14.7	Sugar	2.9	5.6	7.9
Oak, red				Virginia	4.2	7.2	11.9
Black	4.4	11.1	15.1	Western white	4.1	7.4	11.8
Laurel	4.0	9.9	19.0	Redwood			
Northern red	4.0	8.6	13.7	Old growth	2.6	4.4	6.8
Pin	4.3	9.5	14.5	Young growth	2.2	4.9	7.0
Scarlet	4.4	10.8	14.7	Spruce			
Southern red	4.7	11.3	16.1	Black	4.1	6.8	11.3
Water	4.4	9.8	16.1	Engelmann	3.8	7.1	11.0
Willow	5.0	9.6	18.9	Red	3.8	7.8	11.8
Oak, white	4.4	8.8	12.7	Sitka	4.3	7.5	11.5
Bur	5.3	10.8	16.4	Tamarack	3.7	7.4	13.6

[a]Expressed as a percentage of the green dimension.
[b]Coast type 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.

Table 3–6. Shrinkage for some woods imported into the United States[a]

Species	Shrinkage[b] from green to ovendry moisture content (%) Radial	Tangential	Volumetric	Location[c]
Afrormosia (*Pericopsis elata*)	3.0	6.4	10.7	AF
Albarco (*Cariniana* spp.)	2.8	5.4	9.0	AM
Andiroba (*Carapa guianensis*)	3.1	7.6	10.4	AM
Angelin (*Andira inermis*)	4.6	9.8	12.5	AM
Angelique (*Dicorynia guianensis*)	5.2	8.8	14.0	AM
Apitong (*Dipterocarpus* spp.)	5.2	10.9	16.1	AS
Avodire (*Turreanthus africanus*)	4.6	6.7	12.0	AF
Azobe (*Lophira alata*)	8.4	11.0	17.0	AM
Balata (*Manilkara bidentata*)	6.3	9.4	16.9	AM
Balsa (*Ochroma pyramidale*)	3.0	7.6	10.8	AM
Banak (*Virola* spp.)	4.6	8.8	13.7	AM
Benge (*Guibourtia arnoldiana*)	5.2	8.6	13.8	AF
Bubinga (*Guibourtia* spp.)	5.8	8.4	14.2	AF
Bulletwood (*Manilkara bidentata*)	6.3	9.4	16.9	AM
Caribbean pine (*Pinus caribaea*)	6.3	7.8	12.9	AM
Cativo (*Prioria copaifera*)	2.4	5.3	8.9	AM
Ceiba (*Ceiba pentandra*)	2.1	4.1	10.4	AM
Cocobolo (*Dalbergia retusa*)	2.7	4.3	7.0	AM
Courbaril (*Hymenaea courbaril*)	4.5	8.5	12.7	AM
Cuangare (*Dialyanthera* spp.)	4.2	9.4	12.0	AM
Degame (*Calycophyllum cand idissimum*)	4.8	8.6	13.2	AM
Determa (*Ocotea rubra*)	3.7	7.6	10.4	AM
Ebony, East Indian (*Diospyros* spp.)	5.4	8.8	14.2	AS
Ebony, African (*Diospyros* spp.)	9.2	10.8	20.0	AF
Ekop (*Tetraberlinia tubmaniana*)	5.6	10.2	15.8	AF
Gmelina (*Gmelina arborea*)	2.4	4.9	8.8	AS
Goncalo alves (*Astronium graveolens*)	4.0	7.6	10.0	AM
Greenheart (*Ocotea rodiaei*)	8.8	9.6	17.1	AM
Hura (*Hura crepitans*)	2.7	4.5	7.3	AM
Ilomba (*Pycnanthus angolensis*)	4.6	8.4	12.8	AF
Imbuia (*Phoebe porosa*)	2.7	6.0	9.0	AM
Ipe (*Tabebuia* spp.)	6.6	8.0	13.2	AM
Iroko (*Chlorophora excelsa* and *C. regia*)	2.8	3.8	8.8	AF
Jarrah (*Eucalyptus marginata*)	7.7	11.0	18.7	AS
Jelutong (*Dyera costulata*)	2.3	5.5	7.8	AS
Kaneelhart (*Licaria* spp.)	5.4	7.9	12.5	AM
Kapur (*Dryobalanops* spp.)	4.6	10.2	14.8	AS
Karri (*Eucalyptus diversicolor*)	7.8	12.4	20.2	AS
Kempas (*Koompassia malaccensis*)	6.0	7.4	14.5	AS
Keruing (*Dipterocarpus* spp.)	5.2	10.9	16.1	AS
Lauan, light red and red (*Shorea* spp.)	4.6	8.5	14.3	AS
Lauan, dark red (*Shorea* spp.)	3.8	7.9	13.1	AS
Lauan, white (*Pentacme contorta*)	4.0	7.7	11.7	AS
Limba (*Terminalia superba*)	4.5	6.2	10.8	AF
Macawood (*Platymiscium* spp.)	2.7	3.5	6.5	AM
Mahogany, African (*Khaya* spp.)	2.5	4.5	8.8	AF
Mahogany, true (*Swietenia macrophylla*)	3.0	4.1	7.8	AM
Manbarklak (*Eschweilera* spp.)	5.8	10.3	15.9	AM
Manni (*Symphonia globulifera*)	5.7	9.7	15.6	AM
Marishballi (*Licania* spp.)	7.5	11.7	17.2	AM
Meranti, white (*Shorea* spp.)	3.0	6.6	7.7	AS
Meranti, yellow (*Shorea* spp.)	3.4	8.0	10.4	AS
Merbau (*Intsia bijuga* and *I. palembanica*)	2.7	4.6	7.8	AS
Mersawa (*Anisoptera* spp.)	4.0	9.0	14.6	AS
Mora (*Mora* spp.)	6.9	9.8	18.8	AM
Obeche (*Triplochiton scleroxylon*)	3.0	5.4	9.2	AF
Ocota pine (*Pinus oocarpa*)	4.6	7.5	12.3	AM
Okoume (*Aucoumea klaineana*)	4.1	6.1	11.3	AF
Opepe (*Nauclea* spp.)	4.5	8.4	12.6	AF
Ovangkol (*Guibourta ehie*)	4.5	8.2	12	AF
Para-angelium (*Hymenolobium excelsum*)	4.4	7.1	10.2	AM
Parana pine (*Araucaria angustifolia*)	4.0	7.9	11.6	AS
Pau Marfim (*Balfourodendron riedelianum*)	4.6	8.8	13.4	AM
Peroba de campos (*Paratecoma peroba*)	3.8	6.6	10.5	AM
Peroba Rosa (*Aspidosperma* spp.)	3.8	6.4	11.6	AM
Piquia (*Caryocar* spp.)	5.0	8.0	13.0	AM
Pilon (*Hyeronima* spp.)	5.4	11.7	17.0	AM
Primavera (*Cybistax donnell-smithii*)	3.1	5.1	9.1	AM
Purpleheart (*Peltogyne* spp.)	3.2	6.1	9.9	AM
Ramin (*Gonystylus* spp.)	4.3	8.7	13.4	AS
Roble (*Quercus* spp.)	6.4	11.7	18.5	AM
Roble (*Tabebuia* spp. Roble group)	3.6	6.1	9.5	AM
Rosewood, Brazilian (*Dalbergia nigra*)	2.9	4.6	8.5	AM
Rosewood, Indian (*Dalbergia latifolia*)	2.7	5.8	8.5	AS
Rubberwood (*Hevea brasiliensis*)	2.3	5.1	7.4	AM
Sande (*Brosimum* spp. Utile group)	4.6	8.0	13.6	AM
Sapele (*Entandrophragma cylindricum*)	4.6	7.4	14.0	AF
Sepetir (*Pseudosindora* spp. and *Sindora* spp.)	3.7	7.0	10.5	AS
Spanish-cedar (*Cedrela* spp.)	4.2	6.3	10.3	AM
Sucupira (*Diplotropis purpurea*)	4.6	7.0	11.8	AM
Teak (*Tectona grandis*)	2.5	5.8	7.0	AS
Wallaba (*Eperua* spp.)	3.6	6.9	10.0	AM

[a]Shrinkage values were obtained from world literature and may not represent a true species average.
[b]Expressed as a percentage of the green dimension.
[c]AF is Africa; AM is Tropical America; AS is Asia and Oceania.

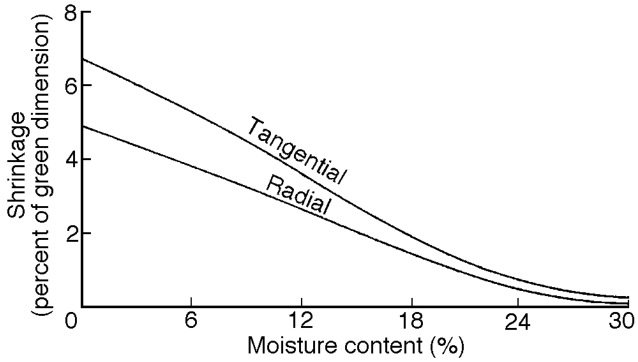

Figure 3–4. Typical moisture content–shrinkage curves.

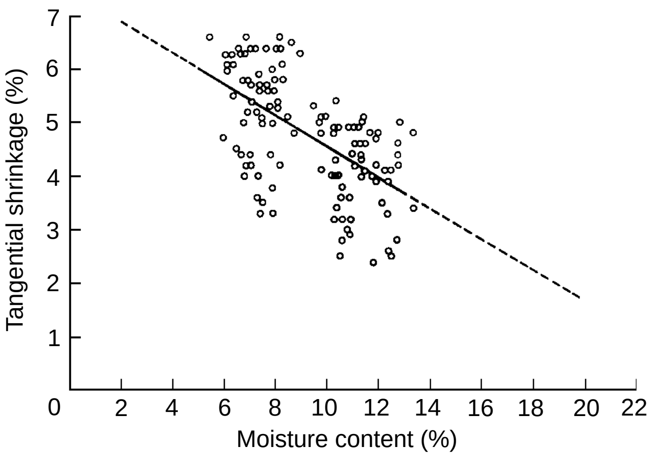

Figure 3–5. Variation in individual tangential shrinkage values of several Douglas-fir boards from one locality, dried from green condition.

If the moisture content at which shrinkage from the green condition begins is known to be other than 30% for a species, the shrinkage estimate can be improved by replacing the value of 30 in Equation (3–4) with the appropriate moisture content value.

Tangential values for S_0 should be used for estimating width shrinkage of flatsawn material and radial values for quartersawn material. For mixed or unknown ring orientations, tangential values are suggested. Shrinkage values for individual pieces will vary from predicted shrinkage values. As noted previously, shrinkage variability is characterized by a coefficient of variation of approximately 15%. This applies to pure tangential or radial ring orientation and is probably somewhat greater in commercial lumber, where ring orientation is seldom aligned perfectly parallel or perpendicular to board faces. Chapter 12 contains additional discussion of shrinkage–moisture content relationships, including a method to estimate shrinkage for the relatively small moisture content changes of wood in service. Shrinkage assumptions for commercial lumber, which typically is not perfectly plainsawn or quartersawn, are discussed in Chapter 6.

Weight, Density, and Specific Gravity

Two primary factors affect the weight of wood products: density of the basic wood structure and moisture content. A third factor, 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. Although the density of most species falls between about 320 and 720 kg/m^3 (20 and 45 lb/ft^3), the range of density actually extends from about 160 kg/m^3 (10 lb/ft^3) for balsa to more than 1,040 kg/m^3 (65 lb/ft^3) for some other imported woods. A coefficient of variation of about 10% is considered suitable for describing the variability of density within common domestic species.

Wood is used in a wide range of conditions and has a wide range of moisture content values in use. Moisture makes up part of the weight of each product in use; therefore, the density must reflect this fact. This has resulted in the density of wood often being determined and reported on the basis of moisture content in use.

The calculated density of wood, including the water contained in the wood, 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 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 the estimation of structural loads to the calculation of approximate shipping weights.

To standardize comparisons of species or products and estimations of product weight, 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 4.4°C (40°F)) where the density of water is 1.0000 g/cm^3). To reduce confusion introduced by the variable of moisture content, the specific gravity of wood usually is based on the ovendry weight and the volume at some specified moisture content.

Commonly used bases for determining specific gravity are ovendry weight and volume at (a) green, (b) ovendry, and (c) 12% moisture content. Ovendry weight and green volume are often used in databases to characterize specific gravity of species, which is referred to as basic specific gravity. Some specific gravity data are reported in Tables 4–3, 4–4, and 4–5 (Ch. 4) on both the 12% and green volume basis. A coefficient of variation of about 10% describes the variability inherent in many common domestic species.

Design specifications for wood, such as contained in the *National Design Specification for Wood Construction*, are based on ovendry weight and ovendry volume.

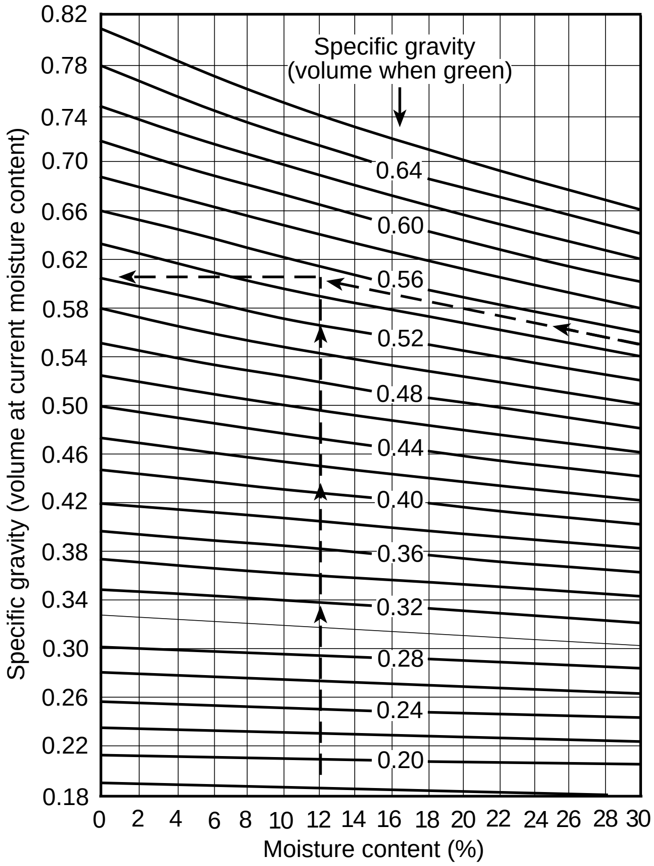

Figure 3–6. Relationship of specific gravity and moisture content.

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% can be approximated from Figure 3–6. This figure adjusts for average shrinkage and swelling that occurs below 30% moisture content and affects the volume of wood. The specific gravity of wood based on ovendry weight does not change at moisture content values above approximately 30% (the approximate fiber saturation point) because the volume does not change. To use Figure 3–6, locate the inclined line corresponding to the known specific gravity (volume when green). From this point, move left 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.

For example, to estimate the density of white ash at 12% moisture content, consult Table 4–3a in Chapter 4. The average green (basic) specific gravity G_b for this species is 0.55. Using Figure 3–6, the 0.55 green specific gravity curve is found to intersect with the vertical 12% moisture content line at a point corresponding to a specific gravity of 0.605 based on ovendry weight and volume at 12% moisture content, G_m (see dashed lines in Fig. 3–6). The density of wood including water at this moisture content can then be obtained from Table 3–7, which converts the specific gravity of 0.605 to a density of 675 kg/m^3 (42 lb/ft^3). An alternative to usage of Figure 3–6 is direct calculation of G_m using the following:

$$G_m = G_b / (1 - 0.265 a G_b) \qquad (3\text{–}5)$$

where G_m is specific gravity based on volume at moisture content M, G_b is basic specific gravity (based on green volume), and $a = (30 - M)/30$, where $M < 30$.

Alternatively, the density values in Table 3–7 can be calculated by

$$\rho = 1{,}000\ G_m(1 + M/100) \quad (\text{kg/m}^3) \qquad (3\text{–}6a)$$

$$\rho = 62.4\ G_m(1 + M/100) \quad (\text{lb/ft}^3) \qquad (3\text{–}6b)$$

It is often useful to know the weight of lumber on a volumetric basis. We can make these estimates using Table 3–7 or with equations only. These results assume an average shrinkage–specific gravity relationship and provide a good estimate. Both methods are illustrated. For weights based on the actual shrinkage of individual species, refer to the *Dry Kiln Operator's Manual* (Simpson 1991).

Method 1—Use of Table 3–7

Determine the weight per actual unit volume (cubic meter or 1,000 board feet) of sugar maple at 20% moisture content and at 50% moisture content. From Table 4–3a, the specific gravity G_b (ovendry weight–green volume) is 0.56. Because the specific gravity in Table 3–7 is based on volume at tabulated moisture content G_m, we must convert G_b to G_m by either Figure 3–6 or Equation (3–5):

At 20%,

$$G_m = 0.56/\{1 - 0.265[(30 - 20)/30]0.56\} = 0.59$$

Determine the density from Table 3–7 at $G_m = 0.59$ and 20% moisture content. The result is approximately 708 kg/m^3 (44.1 lb/ft^3) (by interpolation).

At 50%,

$$G_m = G_b = 0.56$$

Determine the density from Table 3–7 at $G_m = 0.56$ and 50% moisture content. The result is 840 kg/m^3 (52.4 lb/ft^3).

Method 2—Use of equations only

At 20%, G_m is calculated as 0.589 as in Method 1. Density is then calculated from Equation (3–6) as

$$\rho = 1{,}000\ G_m(1+M/100)$$
$$= 1{,}000\ (0.58\ (1+20/100) = 707\ \text{kg/m}^3$$

$$\rho = 62.4\ G_m(1+M/100)$$
$$= 62.4(0.589)\ (1+20/100) = 44.1\ \text{lb/ft}^3$$

At 50%,

$$\rho = 1{,}000\ (0.56)(1+50/100) = 840\ \text{kg/m}^3$$

$$\rho = 62.4(0.56)(1+50/100) = 52.4\ \text{lb/ft}^3$$

Table 3–7a. Density of wood as a function of specific gravity and moisture content (metric)

Moisture content of wood (%)	Density (kg/m³) when the specific gravity G_m 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	480	500	520	540	560	580	600	620	640	660	680	700
4	312	333	354	374	395	416	437	458	478	499	520	541	562	582	603	624	645	666	686	707	728
8	324	346	367	389	410	432	454	475	497	518	540	562	583	605	626	648	670	691	713	734	756
12	336	358	381	403	426	448	470	493	515	538	560	582	605	627	650	672	694	717	739	762	784
16	348	371	394	418	441	464	487	510	534	557	580	603	626	650	673	696	719	742	766	789	812
20	360	384	408	432	456	480	504	528	552	576	600	624	648	672	696	720	744	768	792	816	840
24	372	397	422	446	471	496	521	546	570	595	620	645	670	694	719	744	769	794	818	843	868
28	384	410	435	461	486	512	538	563	589	614	640	666	691	717	742	768	794	819	845	870	896
32	396	422	449	475	502	528	554	581	607	634	660	686	713	739	766	792	818	845	871	898	924
36	408	435	462	490	517	544	571	598	626	653	680	707	734	762	789	816	843	870	898	925	952
40	420	448	476	504	532	560	588	616	644	672	700	728	756	784	812	840	868	896	924	952	980
44	432	461	490	518	547	576	605	634	662	691	720	749	778	806	835	864	893	922	950	979	1,008
48	444	474	503	533	562	592	622	651	681	710	740	770	799	829	858	888	918	947	977	1,006	1,036
52	456	486	517	547	578	608	638	669	699	730	760	790	821	851	882	912	942	973	1,003	1,034	1,064
56	468	499	530	562	593	624	655	686	718	749	780	811	842	874	905	936	967	998	1,030	1,061	1,092
60	480	512	544	576	608	640	672	704	736	768	800	832	864	896	928	960	992	1,024	1,056	1,088	1,120
64	492	525	558	590	623	656	689	722	754	787	820	853	886	918	951	984	1,017	1,050	1,082	1,115	1,148
68	504	538	571	605	638	672	706	739	773	806	840	874	907	941	974	1,008	1,042	1,075	1,109	1,142	1,176
72	516	550	585	619	854	688	722	757	791	826	860	894	929	963	998	1,032	1,066	1,101	1,135	1,170	1,204
76	528	563	598	634	669	704	739	774	810	845	8B0	915	950	986	1,021	1,056	1,091	1,126	1,162	1,197	
80	540	576	612	648	684	720	756	792	828	864	900	936	972	1,008	1,044	1,080	1,116	1,152	1,188		
84	552	589	626	662	699	736	773	810	846	883	920	957	994	1030	1,067	1,104	1,141	1,178			
88	564	602	639	677	714	752	790	827	865	902	940	978	1,015	1,053	1,090	1,128	1,166				
92	576	614	653	691	730	768	806	845	883	922	960	998	1,037	1,075	1,114	1,152	1,190				
96	588	627	666	706	745	784	823	862	902	941	980	1,019	1,058	1,098	1,137	1,176					
100	600	640	680	720	760	800	840	880	920	960	l,000	1,040	1,080	1,120	1,160	1,200					
110	630	672	714	756	798	840	832	924	966	1,008	1,050	1,092	1,134	1,176	1,218						
120	660	704	748	792	836	880	924	968	1,012	1,056	1,100	1,144	1,188	1,232							
130	690	736	782	828	874	920	966	1,012	1,058	1,104	1,150	1,196	1,242	1,288							
140	720	768	816	864	912	960	1,008	1,056	1,104	1,152	1,200	1,248	1,296								
150	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350								

Table 3–7b. Density of wood as a function of specific gravity and moisture content (inch–pound)

Moisture content of wood (%)	Density (lb/ft^3) when the specific gravity G_m 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	36.6	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		
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		
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			
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				
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				
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					
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					
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						
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							
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							
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								
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								

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 4–3 and 4–5 (Ch. 4) list the specific gravity values for various native and imported species. These specific gravity values 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 U.S. 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, three major factors other than density can affect production of smooth surfaces during wood machining: interlocked and variable grain, hard mineral deposits, and reaction wood, particularly tension wood in hardwoods. Interlocked grain is characteristic of a few domestic species and many tropical species, and it presents difficulty in planing quartersawn boards unless attention is paid to feed rate, cutting angles, and sharpness of knives. Hard deposits in the cells, such as calcium carbonate and silica, can have a pronounced dulling effect on all cutting edges. This dulling effect becomes more pronounced as the wood is dried to the usual in-service requirements. Tension wood can cause fibrous and fuzzy surfaces. It can be very troublesome in species of lower density. Reaction wood can also be responsible for the pinching effect on saws as a result of stress relief. The pinching can result in burning and dulling of the saw teeth. Table 3–9 lists some imported species that have irregular grain, hard deposits, or tension wood.

Decay Resistance

Wood kept constantly dry does not decay. In addition, if wood is kept continuously submerged in water, even for long periods of time, it does not decay 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 that affect rate of 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 are low altitudes because the average temperatures at higher altitudes are lower and the growing season for fungi, which cause decay, is shorter. The heartwood of common native species of wood has 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 can be obtained from pieces of wood cut from the same species, 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 the southern and eastern pines and baldcypress, are becoming primarily second growth and contain a high percentage of sapwood. Consequently, substantial quantities of heartwood lumber of these species are not available.

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 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 lists such groupings for some domestic and imported woods, according to their average heartwood decay resistance. 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 treatment is often required. Even the very decay-resistant species may require preservative treatment for important structural uses or other uses where failure would endanger life or require expensive repairs. Preservative treatments and methods for wood are discussed in Chapter 14.

Thermal Properties

Four important thermal properties of wood are thermal conductivity, heat capacity, thermal diffusivity, and coefficient of thermal expansion.

Conductivity

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subjected to a temperature gradient. The thermal conductivity of common structural woods is much less than the conductivity of metals with which wood often is mated in construction. It is about two to four times that of common insulating material. For example, the conductivity of structural softwood lumber at 12% moisture content is in the range of 0.1 to 1.4 W/(m·K) (0.7 to 1.0 Btu·in/(h·ft^2·^{o}F)) compared with 216 (1,500) for aluminum, 45 (310) for steel, 0.9 (6) for concrete, 1 (7) for glass, 0.7 (5) for plaster, and 0.036 (0.25) for mineral wool.

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

Kind of wood[a]	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 (%)
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[b]	21	3	70	70	52	19	44	82	78
Elm, soft[b]	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[b]	51	28	86	92	58	23	67	69	69
Sycamore[b]	22	12	85	98	96	21	29	79	74
Tanoak	80	39	81	100	100	—	—	—	—
Tupelo, water[b]	55	52	79	62	33	34	46	64	63
Tupelo, black[b]	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

[a]Commercial lumber nomenclature.
[b]Interlocked grain present.

Table 3–9. Some characteristics of imported woods that may affect machining

Irregular and interlocked grain	Hard mineral deposits (silica or calcium carbonate)	Reaction wood (tension wood)
Avodire	Angelique	Andiroba
Courbaril	Iroko	Banak
Ekop	Kapur	Cativo
Goncalo alves	Keruing (Apitong)	Ceiba
Ipe	Manbarklak	Hura
Iroko	Marishballi	Mahogany, African
Jarrah	Mersawa	Mahogany, American
Kapur	Okoume	Sande
Karri	Rosewood, Indian	Spanish-cedar
Keruing (Apitong)	Teak	
Kokrodua		
Lauan/meranti		
Lignumvitae		
Limba		
Mahogany, African		
Merasawa		
Obeche		
Okoume		
Rosewood, Indian		
Santa Maria		
Sapele		

The thermal conductivity of wood is affected by a number of basic factors: density, moisture content, extractive content, grain direction, structural irregularities such as checks and knots, fibril angle, and temperature. Thermal conductivity increases as density, moisture content, temperature, or extractive content of the wood increases. Thermal conductivity is nearly the same in the radial and tangential directions with respect to the growth rings. Conductivity along the grain has been reported as 1.5 to 2.8 times greater than conductivity across the grain, with an average of about 1.8, but reported values vary widely.

For moisture content levels below 25%, approximate thermal conductivity k across the grain can be calculated with a linear equation of the form

$$k = G(B + CM) + A \qquad (3\text{–}7)$$

where G is specific gravity based on ovendry weight and volume at a given moisture content M (%) and A, B, and C are constants. For specific gravity >0.3, temperatures around 24°C (75°F), and moisture content values <25%, A = 0.01864, B = 0.1941, and C = 0.004064 (with k in W/(m·K)) (or A = 0.129, B = 1.34, and C = 0.028 with k in Btu·in/(h·ft^2·F)). Equation (3–7) was derived from measurements made by several researchers on a variety of species. Table 3–11 provides average approximate conductivity values for selected wood species, based on Equation (3–7). However, actual conductivity may vary as much as 20% from the tabulated values.

Although thermal conductivity measurements have been made at moisture content values >25%, measurements have been few in number and generally lacking in accuracy. Therefore, we do not provide values for moisture content values >25%.

The effect of temperature on thermal conductivity is relatively minor: conductivity increases about 2% to 3% per 10°C (1% to 2% per 10°F).

Heat Capacity

Heat capacity is defined as the amount of energy needed to increase one unit of mass (kg or lb) one unit in temperature (K or °F). The heat capacity of wood depends on the temperature and moisture content of the wood but is practically independent of density or species. Heat capacity of dry wood c_{p0} (kJ/kg·K, Btu/lb·°F) is approximately related to temperature t (K, °F) by

$$c_{p0} = 0.1031 + 0.003867t \quad \text{(metric)} \qquad (3\text{–}8a)$$

$$c_{p0} = 0.2605 + 0.0005132t \quad \text{(inch–pound)} \qquad (3\text{–}8b)$$

The heat capacity of wood that contains water is greater than that of dry wood. Below fiber saturation, it is the sum of the heat capacity of the dry wood and that of water (c_{pw}) and an additional adjustment factor A_c that accounts for the additional energy in the wood–water bond:

$$c_p = (c_{p0} + 0.01Mc_{pw})/(1 + 0.01M) + A_c \qquad (3\text{–}9)$$

where M is moisture content (%). The heat capacity of water is about 4.19 kJ/kg·K (1 Btu/lb·°F). The adjustment factor can be derived from

$$A_c = M(b_1 + b_2t + b_3M) \qquad (3\text{–}10)$$

with $b_1 = -0.06191$, $b_2 = 2.36 \times 10^{-4}$, and $b_3 = -1.33 \times 10^{-4}$ with temperature in kelvins ($b_1 = -4.23 \times 10^{-4}$, $b_2 = 3.12 \times 10^{-5}$, and $b_3 = -3.17 \times 10^{-5}$ with temperature in °F). These formulas are valid for wood below fiber saturation at temperatures between 7°C (45°F) and 147°C (297°F). Representative values for heat capacity can be found in Table 3–12. The moisture above fiber saturation contributes to specific heat according to the simple rule of mixtures.

Thermal Diffusivity

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 heat capacity. Diffusivity is defined as the ratio of conductivity to the product of heat capacity and density; therefore, conclusions regarding its variation with temperature and density are often based on calculating the effect of these variables on heat capacity and conductivity. Because of the low thermal conductivity and moderate density and heat capacity of wood, the thermal diffusivity of wood is much lower than that of other structural materials, such as metal, brick, and stone. A typical value for wood is 0.161×10^{-6} m^2/s (0.00025 in^2/s) compared with 12.9×10^{-6} m^2/s (0.02 in^2/s) for steel and 0.645×10^{-6} m^2/s (0.001 in^2/s) for mineral wool. For this reason, wood does not feel extremely hot or cold to the touch as do some other materials.

Table 3–10. Grouping of some domestic and imported woods according to average heartwood decay resistance

Resistant or very resistant	Moderately resistant	Slightly or nonresistant
Domestic		
Baldcypress, old growth	Baldcypress, young growth	Alder, red
Catalpa	Douglas-fir	Ashes
Cedar	Larch, western	Aspens
Atlantic white	Pine, longleaf, old growth	Beech
Eastern redcedar	Pine, slash, old growth	Birches
Incense	Redwood, young growth	Buckeye
Northern white	Tamarack	Butternut
Port-Orford		Cottonwood
Western redcedar		Elms
Yellow	Pine, eastern white, old growth	Basswood
Cherry, black		Firs, true
Chestnut		Hackberry
Cypress, Arizona		Hemlocks
Junipers		Hickories
Locust,		Magnolia
Black[a]		Maples
Honeylocust		Pines (other than those listed)[b]
Mesquite		Spruces
Mulberry, red[a]		Sweetgum
Oaks, white[b]		Sycamore
Osage orange[a]		Tanoak
Redwood, old growth		Willows
Sassafras		Yellow-poplar
Walnut, black		
Yew, Pacific[a]		
Imported		
Aftotmosia (Kokrodua)	Andiroba	Balsa
Angelique[a]	Avodire	Banak
Apamate (Roble)	Benge	Cativo
Azobe[a]	Bubinga	Ceiba
Balata[a]	Ehie	Hura
Balau[b]	Ekop	Jelutong
Courbaril	Keruing[b]	Limba
Determa	Mahogany, African	Meranti, light red[b]
Goncalo alves[a]	Meranti, dark red[b]	Meranti, yellow[b]
Greenheart[a]	Mersawa[b]	Meranti, white[b]
Ipe (lapacho)[a]	Sapele	Obeche
Iroko	Teak , young growth	Okoume
Jarrah[a]	Tornillo	Parana pine
Kapur		Ramin
Karri		Sande
Kempas		Sepitir
Lignumvitae[a]		Seraya, white
Mahogany, American		
Manni		
Purpleheart[a]		
Spanish-cedar		
Sucupira		
Teak, old growth[a]		
Wallaba		

[a]Exceptionally high decay resistance.
[b]More than one species included, some of which may vary in resistance from that indicated.

Table 3–11. Thermal conductivity of selected hardwoods and softwoods[a]

Species	Specific gravity	Conductivity (W/m·K (Btu·in/h·ft^2·°F))		Resistivity (K·m/W (h·ft^2·°F/Btu·in))	
		Ovendry	12% MC	Ovendry	12% MC
Hardwoods					
Ash					
Black	0.53	0.12 (0.84)	0.15 (1.0)	8.2 (1.2)	6.8 (0.98)
White	0.63	0.14 (0.98)	0.17 (1.2)	7.1 (1.0)	5.8 (0.84)
Aspen					
Big tooth	0.41	0.10 (0.68)	0.12 (0.82)	10 (1.5)	8.5 (1.2)
Quaking	0.40	0.10 (0.67)	0.12 (0.80)	10 (1.5)	8.6 (1.2)
Basswood, American	0.38	0.092 (0.64)	0.11 (0.77)	11 (1.6)	9.0 (1.3)
Beech, American	0.68	0.15 (1.0)	0.18 (1.3)	6.6 (0.96)	5.4 (0.78)
Birch					
Sweet	0.71	0.16 (1.1)	0.19 (1.3)	6.4 (0.92)	5.2 (0.76)
Yellow	0.66	0.15 (1.0)	0.18 (1.2)	6.8 (0.98)	5.6 (0.81)
Cherry, black	0.53	0.12 (0.84)	0.15 (1.0)	8.2 (1.2)	6.8 (0.98)
Chestnut, American	0.45	0.11 (0.73)	0.13 (0.89)	9.4 (1.4)	7.8 (1.1)
Cottonwood					
Black	0.35	0.087 (0.60)	0.10 (0.72)	12 (1.7)	9.6 (1.4)
Eastern	0.43	0.10 (0.71)	0.12 (0.85)	9.8 (1.4)	8.1 (1.2)
Elm					
American	0.54	0.12 (0.86)	0.15 (1.0)	8.1 (1.2)	6.7 (0.96)
Rock	0.67	0.15 (1.0)	0.18 (1.3)	6.7 (0.97)	5.5 (0.80)
Slippery	0.56	0.13 (0.88)	0.15 (1.1)	7.9 (1.1)	6.5 (0.93)
Hackberry	0.57	0.13 (0.90)	0.16 (1.1)	7.7 (1.1)	6.4 (0.92)
Hickory, pecan	0.69	0.15 (1.1)	0.19 (1.3)	6.6 (0.95)	5.4 (0.77)
Hickory, true					
Mockernut	0.78	0.17 (1.2)	0.21 (1.4)	5.9 (0.85)	4.8 (0.69)
Shagbark	0.77	0.17 (1.2)	0.21 (1.4)	5.9 (0.86)	4.9 (0.70)
Magnolia, southern	0.52	0.12 (0.83)	0.14 (1.0)	8.4 (1.2)	6.9 (1.0)
Maple					
Black	0.60	0.14 (0.94)	0.16 (1.1)	7.4 (1.1)	6.1 (0.88)
Red	0.56	0.13 (0.88)	0.15 (1.1)	7.9 (1.1)	6.5 (0.93)
Silver	0.50	0.12 (0.80)	0.14 (0.97)	8.6 (1.2)	7.1 (1.0)
Sugar	0.66	0.15 (1.0)	0.18 (1.2)	6.8 (0.98)	5.6 (0.81)
Oak, red					
Black	0.66	0.15 (1.0)	0.18 (1.2)	6.8 (0.98)	5.6 (0.81)
Northern red	0.65	0.14 (1.0)	0.18 (1.2)	6.9 (1.0)	5.7 (0.82)
Southern red	0.62	0.14 (0.96)	0.17 (1.2)	7.2 (1.0)	5.9 (0.85)
Oak, white					
Bur	0.66	0.15 (1.0)	0.18 (1.2)	6.8 (0.98)	5.6 (0.81)
White	0.72	0.16 (1.1)	0.19 (1.3)	6.3 (0.91)	5.2 (0.75)
Sweetgum	0.55	0.13 (0.87	0.15 (1.1)	8.0 (1.2)	6.6 (0.95)
Sycamore, American	0.54	0.12 (0.86)	0.15 (1.0)	8.1 (1.2)	6.7 (0.96)
Tupelo					
Black	0.54	0.12 (0.86)	0.15 (1.0)	8.1 (1.2)	6.7 (0.96)
Water	0.53	0.12 (0.84)	0.15 (1.0)	8.2 (1.2)	6.8 (0.98)
Yellow-poplar	0.46	0.11 (0.75)	0.13 (0.90)	9.3 (1.3)	7.7 (1.1)

Table 3–11. Thermal conductivity of selected hardwoods and softwoods[a]—con.

Species	Specific gravity	Conductivity (W/m·K (Btu·in/h·ft^2·°F))		Resistivity (W/m·K (h·ft^2·°F/Btu·in))	
		Ovendry	12% MC	Ovendry	12% MC
Softwoods					
Baldcypress	0.47	0.11 (0.76)	0.13 (0.92)	9.1 (1.3)	7.5 (1.1)
Cedar					
Atlantic white	0.34	0.085 (0.59)	0.10 (0.70)	12 (1.7)	9.9 (1.4)
Eastern red	0.48	0.11 (0.77)	0.14 (0.94)	8.9 (1.3)	7.4 (1.1)
Northern white	0.31	0.079 (0.55)	0.094 (0.65)	13 (1.8)	11 (1.5)
Port-Orford	0.43	0.10 (0.71)	0.12 (0.85)	9.8 (1.4)	8.1 (1.2)
Western red	0.33	0.083 (0.57)	0.10 (0.68)	12 (1.7)	10 (1.5)
Yellow	0.46	0.11 (0.75)	0.13 (0.90)	9.3 (1.3)	7.7 (1.1)
Douglas-fir					
Coast	0.51	0.12 (0.82)	0.14 (0.99)	8.5 (1.2)	7.0 (1.0)
Interior north	0.50	0.12 (0.80)	0.14 (0.97)	8.6 (1.2)	7.1 (1.0)
Interior west	0.52	0.12 (0.83)	0.14 (1.0)	8.4 (1.2)	6.9 1.0)
Fir					
Balsam	0.37	0.090 (0.63)	0.11 (0.75)	11 (1.6)	9.2 (1.3)
White	0.41	0.10 (0.68)	0.12 (0.82)	10 (1.5)	8.5 (1.2)
Hemlock					
Eastern	0.42	0.10 (0.69)	0.12 (0.84)	10 (1.4)	8.3 (1.2)
Western	0.48	0.11 (0.77)	0.14 (0.94)	8.9 (1.3)	7.4 (1.1)
Larch, western	0.56	0.13 (0.88)	0.15 (1.1)	7.9 (1.1)	6.5 (0.93)
Pine					
Eastern white	0.37	0.090 (0.63)	0.11 (0.75)	11 (1.6)	9.2 (1.3)
Jack	0.45	0.11 (0.73)	0.13 (0.89)	9.4 (1.4)	7.8 (1.1)
Loblolly	0.54	0.12 (0.86)	0.15 (1.0)	8.1 (1.2)	6.7 (0.96)
Lodgepole	0.43	0.10 (0.71)	0.12 (0.85)	9.8 (1.4)	8.1 (1.2)
Longleaf	0.62	0.14 (0.96)	0.17 (1.2)	7.2 (1.0)	5.9 (0.85)
Pitch	0.53	0.12 (0.84)	0.15 (1.0)	8.2 (1.2)	6.8 (0.98)
Ponderosa	0.42	0.10 (0.69)	0.12 (0.84)	10 (1.4)	8.3 (1.2)
Red	0.46	0.11 (0.75)	0.13 (0.90)	9.3 (1.3)	7.7 (1.1)
Shortleaf	0.54	0.12 (0.86)	0.15 (1.0)	8.1 (1.2)	6.7 (0.96)
Slash	0.61	0.14 (0.95)	0.17 (1.2)	7.3 (1.1)	6.0 (0.86)
Sugar	0.37	0.090 (0.63)	0.11 (0.75)	11 (1.6)	9.2 (1.3)
Western white	0.40	0.10 (0.67)	0.12 (0.80)	10 (1.5)	8.6 (1.2)
Redwood					
Old growth	0.41	0.10 (0.68)	0.12 (0.82)	10 (1.5)	8.5 (1.2)
Young growth	0.37	0.090 (0.63)	0.11 (0.75)	11 (1.6)	9.2 (1.3)
Spruce					
Black	0.43	0.10 (0.71)	0.12 (0.85)	9.8 (1.4)	8.1 (1.2)
Engelmann	0.37	0.090 (0.63)	0.11 (0.75)	11 (1.6)	9.2 (1.3)
Red	0.42	0.10 (0.69)	0.12 (0.84)	10 (1.4)	8.3 (1.2)
Sitka	0.42	0.10 (0.69)	0.12 (0.84)	10 (1.4)	8.3 (1.2)
White	0.37	0.090 (0.63)	0.11 (0.75)	11 (1.6)	9.2 (1.3)

[a]Values in this table are approximate and should be used with caution; actual conductivities may vary by as much as 20%. The specific gravities also do not represent species averages.

Table 3–12. Heat capacity of solid wood at selected temperatures and moisture contents

Temperature			Specific heat (kJ/kg·K (Btu/lb·°F))			
(K)	(°C	(°F))	Ovendry	5% MC	12% MC	20% MC
280	7	(45)	1.2 (0.28)	1.3 (0.32)	1.5 (0.37)	1.7 (0.41)
290	17	(75)	1.2 (0.29)	1.4 (0.33)	1.6 (0.38)	1.8 (0.43)
300	27	(80)	1.3 (0.30)	1.4 (0.34)	1.7 (0.40)	1.9 (0.45)
320	47	(116)	1.3 (0.32)	1.5 (0.37)	1.8 (0.43)	2.0 (0.49)
340	67	(152)	1.4 (0.34)	1.6 (0.39)	1.9 (0.46)	2.2 (0.52)
360	87	(188)	1.5 (0.36)	1.7 (0.41)	2.0 (0.49)	2.3 (0.56)

Thermal Expansion Coefficient

The coefficient of thermal expansion is a measure of the change of dimension caused by temperature change. The thermal expansion coefficients of completely dry wood are positive in all directions; that is, wood expands on heating and contracts on cooling. Limited research has been carried out to explore the influence of wood property variability on thermal expansion. The thermal 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-grain values have ranged from about 0.000031 to 0.0000045 per K (0.0000017 to 0.0000025 per °F).

The thermal expansion coefficients across the grain (radial and tangential) are proportional to wood specific gravity. These coefficients range from about 5 to more than 10 times greater than the parallel-to-grain coefficients and 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:

$$\alpha_r = (32.4G + 9.9)10^{-6} \text{ per K} \quad (3\text{–}11a)$$

$$\alpha_r = (18G + 5.5)10^{-6} \text{ per °F} \quad (3\text{–}11b)$$

$$\alpha_t = (32.4G + 18.4)10^{-6} \text{ per K} \quad (3\text{–}12a)$$

$$\alpha_t = (18G + 10.2)10^{-6} \text{ per °F} \quad (3\text{–}12b)$$

Thermal expansion coefficients can be considered independent of temperature over the temperature range of −51.1°C to 54.4°C (−60°F to 130°F).

Wood that contains moisture reacts differently to varying temperature 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% moisture content or less), shrinkage caused by moisture loss on heating will be greater than thermal expansion, so the net dimensional change on heating will be negative. Wood at intermediate moisture levels (about 8% to 20%) 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 caused by moisture change is very small, such changes will still predominate over corresponding dimensional changes as a result of 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 conductivity, dielectric constant, and dielectric power factor. The conductivity of a material determines the electric 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 potential electric 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, utility worker's tools, and the heat-curing of adhesives in wood products by high frequency electric fields. Moisture meters for wood utilize the relationship between electrical properties and moisture content to estimate the moisture content.

Conductivity

The electrical conductivity of wood varies slightly with applied voltage and approximately doubles for each temperature increase of 10°C (18°F). 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, electrical conductivity increases (resistivity decreases) by 10^{10} to 10^{13} times. Resistivity is about 10^{14} to 10^{16} Ω·m for ovendry wood and 10^3 to 10^4 Ω·m for wood at fiber saturation. As the moisture content increases from fiber saturation to complete saturation of the wood structure, the

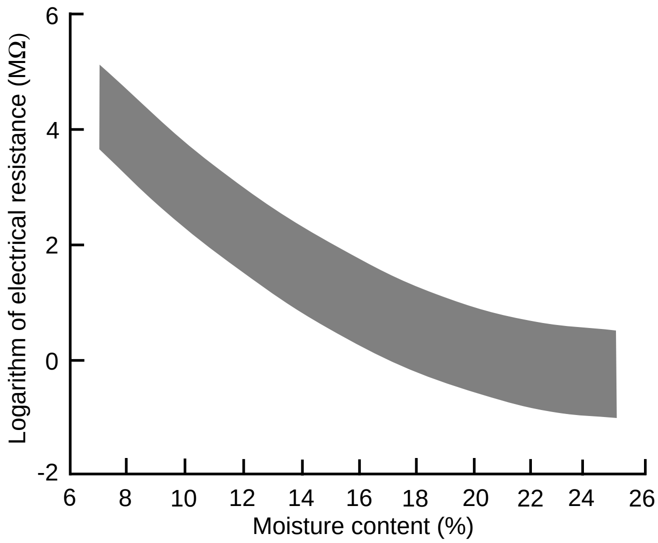

Figure 3–7. Change in electrical resistance of wood with varying moisture content levels for many U.S. species; 90% of test values are represented by the shaded area.

further increase in conductivity is smaller and erratic, generally amounting to less than a hundredfold.

Figure 3–7 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. The resistance values were obtained using a standard moisture meter electrode at 27°C (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 conductivity values in the longitudinal, radial, and tangential directions are related by 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 preservative or fire-retardant treatment, or is in prolonged contact with seawater, electrical conductivity can be substantially increased. The increase is small when the moisture content of the wood is less than about 8% but quickly increases as the moisture content exceeds 10% to 12%.

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 increases, 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 about 4 for dry wood to near 1,000,000 for wet wood; at 1 kHz, from about 4 when dry to about 5,000 when wet; and at 1 MHz, from about 3 when dry to about 100 when wet. The dielectric constant is larger for polarization parallel to the grain than 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 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 with that of inert plastic insulating materials, but 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. The power factor is usually, but not always, greater for electric fields 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 the roughness of the surface. It varies little with species except for those species, such as lignumvitae, that contain abundant oily or waxy extractives.

On most materials, the coefficients of friction for wood increase continuously as the moisture content of the wood increases from ovendry to fiber saturation, then remain about constant as the moisture content increases further until considerable free water is present. When the surface is flooded with water, the coefficient of friction decreases.

Static coefficients of friction are generally greater than sliding coefficients, and the latter depend somewhat on the speed of sliding. Sliding coefficients of friction vary only slightly with speed when the wood moisture content is less than about 20%; at high moisture content, the coefficient of friction decreases substantially as the speed increases.

Coefficients of sliding friction for smooth, dry wood against hard, smooth surfaces commonly range from 0.3 to 0.5; at intermediate moisture content, 0.5 to 0.7; and near fiber saturation, 0.7 to 0.9.

Nuclear Radiation

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

$$I = I_0 \exp(-\mu x) \quad (3\text{–}13)$$

where I is the reduced intensity of the beam at depth 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. When 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 the type and energy of radiation.

The linear absorption coefficient of wood for γ radiation is known to vary directly with moisture content and density and inversely with the γ ray energy. As an example, the irradiation of ovendry yellow-poplar with 0.047-MeV γ rays yields linear absorption coefficients ranging from about 0.065 to about 0.11 cm^{-1} over the ovendry specific gravity range of about 0.33 to 0.62. An increase in the linear absorption coefficient of about 0.01 cm^{-1} 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 measuring the density of wood.

The interaction of wood with 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 cm^{-1}. 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. Higher energy neutrons lose energy much more quickly through interaction with hydrogen than with other elements found in wood. Lower energy neutrons that result from this interaction are thus 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 the amount of isotope present. This procedure, called neutron activation analysis, provides a sensitive nondestructive method of analysis for trace elements.

In the previous discussions, 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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Chapter 4

Mechanical Properties of Wood

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Contents

The mechanical properties presented in this chapter were 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 did have anatomical characteristics such as growth rings that occurred in consistent patterns within each 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 are represented as the average mechanical properties of the species. Some properties, such as tension parallel to the grain, and all properties for some imported species are based on a more limited number of specimens that were not subjected to the same sampling and analysis procedures. The appropriateness of these latter properties to represent the average properties of a species is uncertain; nevertheless, the properties represent the best information available.

Variability, or variation in properties, is common to all materials. Because wood is a natural material and the tree is subject to many 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 variability in properties.

This chapter also includes a discussion of the effect of growth features, such as knots and slope of grain, on clear wood properties. The effects of manufacturing and service environments on mechanical properties are discussed, and their effects on clear wood and material containing growth features are compared. Chapter 6 discusses how these research results have been implemented in engineering standards.

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

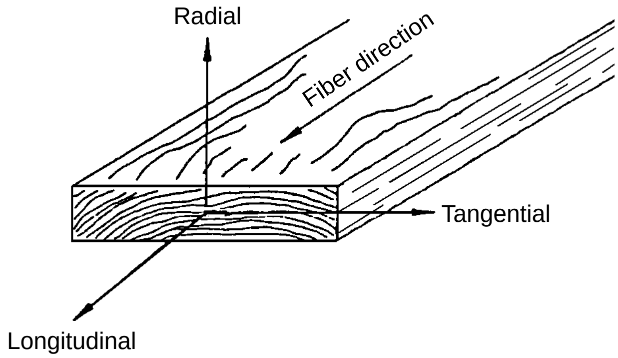

Figure 4–1. Three principal axes of wood with respect to grain direction and growth rings.

the tangential axis T is perpendicular to the grain but tangent to the growth rings. These axes are shown in Figure 4–1.

Elastic Properties

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

$$\frac{\mu_{ij}}{E_i} = \frac{\mu_{ji}}{E_j}, \quad i \neq j \quad i,j = L,R,T \tag{4–1}$$

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

Modulus of Elasticity

Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs. The three moduli of elasticity, which are denoted by E_L, E_R, and E_T, respectively, are the elastic moduli along the 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. Average values of E_R and E_T for samples from a few species are presented in Table 4–1 as ratios with E_L; the Poisson's ratios are shown in Table 4–2. The elastic ratios, as well as the elastic constants themselves, vary within and between species and with moisture content and specific gravity.

The modulus of elasticity determined from bending, E_L, rather than from an axial test, may be the only modulus of elasticity available for a species. Average E_L values obtained from bending tests are given in Tables 4–3 to 4–5. Representative coefficients of variation of E_L determined with bending tests for clear wood are reported in Table 4–6. As tabulated, E_L includes an effect of shear deflection; E_L from bending can be increased by 10% to remove this effect approximately.

Table 4–1. Elastic ratios for various species at approximately 12% moisture content[a]

Species	E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
Hardwoods					
Ash, white	0.080	0.125	0.109	0.077	—
Balsa	0.015	0.046	0.054	0.037	0.005
Basswood	0.027	0.066	0.056	0.046	—
Birch, yellow	0.050	0.078	0.074	0.068	0.017
Cherry, black	0.086	0.197	0.147	0.097	—
Cottonwood, eastern	0.047	0.083	0.076	0.052	—
Mahogany, African	0.050	0.111	0.088	0.059	0.021
Mahogany, Honduras	0.064	0.107	0.066	0.086	0.028
Maple, sugar	0.065	0.132	0.111	0.063	—
Maple, red	0.067	0.140	0.133	0.074	—
Oak, red	0.082	0.154	0.089	0.081	—
Oak, white	0.072	0.163	0.086	—	—
Sweet gum	0.050	0.115	0.089	0.061	0.021
Walnut, black	0.056	0.106	0.085	0.062	0.021
Yellow-poplar	0.043	0.092	0.075	0.069	0.011
Softwoods					
Baldcypress	0.039	0.084	0.063	0.054	0.007
Cedar, northern white	0.081	0.183	0.210	0.187	0.015
Cedar, western red	0.055	0.081	0.087	0.086	0.005
Douglas-fir	0.050	0.068	0.064	0.078	0.007
Fir, subalpine	0.039	0.102	0.070	0.058	0.006
Hemlock, western	0.031	0.058	0.038	0.032	0.003
Larch, western	0.065	0.079	0.063	0.069	0.007
Pine					
Loblolly	0.078	0.113	0.082	0.081	0.013
Lodgepole	0.068	0.102	0.049	0.046	0.005
Longleaf	0.055	0.102	0.071	0.060	0.012
Pond	0.041	0.071	0.050	0.045	0.009
Ponderosa	0.083	0.122	0.138	0.115	0.017
Red	0.044	0.088	0.096	0.081	0.011
Slash	0.045	0.074	0.055	0.053	0.010
Sugar	0.087	0.131	0.124	0.113	0.019
Western white	0.038	0.078	0.052	0.048	0.005
Redwood	0.089	0.087	0.066	0.077	0.011
Spruce, Sitka	0.043	0.078	0.064	0.061	0.003
Spruce, Engelmann	0.059	0.128	0.124	0.120	0.010

[a] E_L may be approximated by increasing modulus of elasticity values in Table 4–3 by 10%.

This adjusted bending E_L can be used to determine E_R and E_T based on the ratios in Table 4–1.

Poisson's Ratio

When a member is loaded axially, the deformation perpendicular to the direction of the load is proportional to the deformation parallel to the direction of the load. The ratio of the transverse to axial strain is called Poisson's ratio. The Poisson's ratios are denoted by μ_{LR}, μ_{RL}, μ_{LT}, μ_{TL}, μ_{RT}, and μ_{TR}. The first letter of the subscript refers to direction of applied stress and the second letter 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. Average values of Poisson's ratios for samples of a few species are given in Table 4–2. Values for μ_{RL} and μ_{TL} are less precisely determined than are those for the other Poisson's ratios. Poisson's ratios vary within and between species and are affected by moisture content and specific gravity.

Table 4–2. Poisson's ratios for various species at approximately 12% moisture content

Species	μ_{LR}	μ_{LT}	μ_{RT}	μ_{TR}	μ_{RL}	μ_{TL}
Hardwoods						
Ash, white	0.371	0.440	0.684	0.360	0.059	0.051
Aspen, quaking	0.489	0.374	—	0.496	0.054	0.022
Balsa	0.229	0.488	0.665	0.231	0.018	0.009
Basswood	0.364	0.406	0.912	0.346	0.034	0.022
Birch, yellow	0.426	0.451	0.697	0.426	0.043	0.024
Cherry, black	0.392	0.428	0.695	0.282	0.086	0.048
Cottonwood, eastern	0.344	0.420	0.875	0.292	0.043	0.018
Mahogany, African	0.297	0.641	0.604	0.264	0.033	0.032
Mahogany, Honduras	0.314	0.533	0.600	0.326	0.033	0.034
Maple, sugar	0.424	0.476	0.774	0.349	0.065	0.037
Maple, red	0.434	0.509	0.762	0.354	0.063	0.044
Oak, red	0.350	0.448	0.560	0.292	0.064	0.033
Oak, white	0.369	0.428	0.618	0.300	0.074	0.036
Sweet gum	0.325	0.403	0.682	0.309	0.044	0.023
Walnut, black	0.495	0.632	0.718	0.378	0.052	0.035
Yellow-poplar	0.318	0.392	0.703	0.329	0.030	0.019
Softwoods						
Baldcypress	0.338	0.326	0.411	0.356	—	—
Cedar, northern white	0.337	0.340	0.458	0.345	—	—
Cedar, western red	0.378	0.296	0.484	0.403	—	—
Douglas-fir	0.292	0.449	0.390	0.374	0.036	0.029
Fir, subalpine	0.341	0.332	0.437	0.336	—	—
Hemlock, western	0.485	0.423	0.442	0.382	—	—
Larch, western	0.355	0.276	0.389	0.352	—	—
Pine						
Loblolly	0.328	0.292	0.382	0.362	—	—
Lodgepole	0.316	0.347	0.469	0.381	—	—
Longleaf	0.332	0.365	0.384	0.342	—	—
Pond	0.280	0.364	0.389	0.320	—	—
Ponderosa	0.337	0.400	0.426	0.359	—	—
Red	0.347	0.315	0.408	0.308	—	—
Slash	0.392	0.444	0.447	0.387	—	—
Sugar	0.356	0.349	0.428	0.358	—	—
Western white	0.329	0.344	0.410	0.334	—	—
Redwood	0.360	0.346	0.373	0.400	—	—
Spruce, Sitka	0.372	0.467	0.435	0.245	0.040	0.025
Spruce, Engelmann	0.422	0.462	0.530	0.255	0.083	0.058

Modulus of Rigidity

The modulus of rigidity, also called shear modulus, indicates the resistance to deflection of a member caused by shear stresses. The three moduli of rigidity denoted by G_{LR}, G_{LT}, and 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. Average 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.

Strength Properties

Common Properties

Mechanical properties most commonly measured and represented as "strength properties" for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain, and shear strength parallel to grain. Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to 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 4–3 to 4–5 for many of the commercially important species. Average coefficients of variation for these properties from a limited sampling of specimens are reported in Table 4–6.

Modulus of rupture—Reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. Modulus of rupture is an accepted criterion of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit.

Work to maximum load in bending—Ability to absorb shock with some permanent deformation and more or less injury to a specimen. Work to maximum load is a measure of the combined strength and toughness of wood under bending stresses.

Compressive strength parallel to grain—Maximum stress sustained by a compression parallel-to-grain specimen having a ratio of length to least dimension of less than 11.

Compressive stress perpendicular to grain—Reported as stress at proportional limit. There is no clearly defined ultimate stress for this property.

Shear strength parallel to grain—Ability to resist internal slipping of one part upon another along the grain. Values presented are average strength in radial and tangential shear planes.

Impact bending—In the impact bending test, a hammer of given weight is dropped upon a beam from successively increased heights until rupture occurs or the beam deflects 152 mm (6 in.) or more. The height of the maximum drop, or the drop that causes failure, is a comparative value that represents the ability of wood to absorb shocks that cause stresses beyond the proportional limit.

Tensile strength perpendicular to grain—Resistance of wood to forces acting across the grain that tend to split a member. Values presented are the average of radial and tangential observations.

Hardness—Generally defined as resistance to indentation using a modified Janka hardness test, measured by the load required to embed a 11.28-mm (0.444-in.) ball to one-half its diameter. Values presented are the average of radial and tangential penetrations.

Tensile strength parallel to grain—Maximum tensile stress sustained in direction parallel to grain. Relatively few data are available on the tensile strength of various species of clear wood parallel to grain. Table 4–7 lists average tensile strength values for a limited number of specimens of a few species. In the absence of sufficient tension test data, 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 clear specimens (this is not true for lumber).

Table 4–3a. Strength properties of some commercially important woods grown in the United States (metric)[a]

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity[c] (MPa)	Static bending: Work to maximum load (kJ/m^3)	Impact bending (mm)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)	Side hardness (N)
Hardwoods											
Alder, red	Green	0.37	45,000	8,100	55	560	20,400	1,700	5,300	2,700	2,000
	12%	0.41	68,000	9,500	58	510	40,100	3,000	7,400	2,900	2,600
Ash											
Black	Green	0.45	41,000	7,200	83	840	15,900	2,400	5,900	3,400	2,300
	12%	0.49	87,000	11,000	103	890	41,200	5,200	10,800	4,800	3,800
Blue	Green	0.53	66,000	8,500	101	—	24,800	5,600	10,600	—	—
	12%	0.58	95,000	9,700	99	—	48,100	9,800	14,000	—	—
Green	Green	0.53	66,000	9,700	81	890	29,000	5,000	8,700	4,100	3,900
	12%	0.56	97,000	11,400	92	810	48,800	9,000	13,200	4,800	5,300
Oregon	Green	0.50	52,000	7,800	84	990	24,200	3,700	8,200	4,100	3,500
	12%	0.55	88,000	9,400	99	840	41,600	8,600	12,300	5,000	5,200
White	Green	0.55	66,000	9,900	108	970	27,500	4,600	9,300	4,100	4,300
	12%	0.60	103,000	12,000	115	1,090	51,100	8,000	13,200	6,500	5,900
Aspen											
Bigtooth	Green	0.36	37,000	7,700	39	—	17,200	1,400	5,000	—	—
	12%	0.39	63,000	9,900	53	—	36,500	3,100	7,400	—	—
Quaking	Green	0.35	35,000	5,900	44	560	14,800	1,200	4,600	1,600	1,300
	12%	0.38	58,000	8,100	52	530	29,300	2,600	5,900	1,800	1,600
Basswood, American	Green	0.32	34,000	7,200	37	410	15,300	1,200	4,100	1,900	1,100
	12%	0.37	60,000	10,100	50	410	32,600	2,600	6,800	2,400	1,800
Beech, American	Green	0.56	59,000	9,500	82	1,090	24,500	3,700	8,900	5,000	3,800
	12%	0.64	103,000	11,900	104	1,040	50,300	7,000	13,900	7,000	5,800
Birch											
Paper	Green	0.48	44,000	8,100	112	1,240	16,300	1,900	5,800	2,600	2,500
	12%	0.55	85,000	11,000	110	860	39,200	4,100	8,300	—	4,000
Sweet	Green	0.60	65,000	11,400	108	1,220	25,800	3,200	8,500	3,000	4,300
	12%	0.65	117,000	15,000	124	1,190	58,900	7,400	15,400	6,600	6,500
Yellow	Green	0.55	57,000	10,300	111	1,220	23,300	3,000	7,700	3,000	3,600
	12%	0.62	114,000	13,900	143	1,400	56,300	6,700	13,000	6,300	5,600
Butternut	Green	0.36	37,000	6,700	57	610	16,700	1,500	5,200	3,000	1,700
	12%	0.38	56,000	8,100	57	610	36,200	3,200	8,100	3,000	2,200
Cherry, black	Green	0.47	55,000	9,000	88	840	24,400	2,500	7,800	3,900	2,900
	12%	0.50	85,000	10,300	79	740	49,000	4,800	11,700	3,900	4,200
Chestnut, American	Green	0.40	39,000	6,400	48	610	17,000	2,100	5,500	3,000	1,900
	12%	0.43	59,000	8,500	45	480	36,700	4,300	7,400	3,200	2,400
Cottonwood											
Balsam poplar	Green	0.31	27,000	5,200	29	—	11,700	1,000	3,400	—	—
	12%	0.34	47,000	7,600	34	—	27,700	2,100	5,400	—	—
Black	Green	0.31	34,000	7,400	34	510	15,200	1,100	4,200	1,900	1,100
	12%	0.35	59,000	8,800	46	560	31,000	2,100	7,200	2,300	1,600
Eastern	Green	0.37	37,000	7,000	50	530	15,700	1,400	4,700	2,800	1,500
	12%	0.40	59,000	9,400	51	510	33,900	2,600	6,400	4,000	1,900
Elm											
American	Green	0.46	50,000	7,700	81	970	20,100	2,500	6,900	4,100	2,800
	12%	0.50	81,000	9,200	90	990	38,100	4,800	10,400	4,600	3,700
Rock	Green	0.57	66,000	8,200	137	1,370	26,100	4,200	8,800	—	—
	12%	0.63	102,000	10,600	132	1,420	48,600	8,500	13,200	—	—
Slippery	Green	0.48	55,000	8,500	106	1,190	22,900	2,900	7,700	4,400	2,900
	12%	0.53	90,000	10,300	117	1,140	43,900	5,700	11,200	3,700	3,800
Hackberry	Green	0.49	45,000	6,600	100	1,220	18,300	2,800	7,400	4,300	3,100
	12%	0.53	76,000	8,200	88	1,090	37,500	6,100	11,000	4,000	3,900

Table 4–3a. Strength properties of some commercially important woods grown in the United States (metric)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity[c] (MPa)	Static bending: Work to maximum load (kJ/m³)	Impact bending (mm)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)	Side hardness (N)
Hickory, pecan											
Bitternut	Green	0.60	71,000	9,700	138	1,680	31,500	5,500	8,500	—	—
	12%	0.66	118,000	12,300	125	1,680	62,300	11,600	—	—	—
Nutmeg	Green	0.56	63,000	8,900	157	1,370	27,400	5,200	7,100	—	—
	12%	0.60	114,000	11,700	173	—	47,600	10,800	—	—	—
Pecan	Green	0.60	68,000	9,400	101	1,350	27,500	5,400	10,200	4,700	5,800
	12%	0.66	94,000	11,900	95	1,120	54,100	11,900	14,300	—	8,100
Water	Green	0.61	74,000	10,800	130	1,420	32,100	6,100	9,900	—	—
	12%	0.62	123,000	13,900	133	1,350	59,300	10,700	—	—	—
Hickory, true											
Mockernut	Green	0.64	77,000	10,800	180	2,240	30,900	5,600	8,800	—	—
	12%	0.72	132,000	15,300	156	1,960	61,600	11,900	12,000	—	—
Pignut	Green	0.66	81,000	11,400	219	2,260	33,200	6,300	9,400	—	—
	12%	0.75	139,000	15,600	210	1,880	63,400	13,700	14,800	—	—
Shagbark	Green	0.64	76,000	10,800	163	1,880	31,600	5,800	10,500	—	—
	12%	0.72	139,000	14,900	178	1,700	63,500	12,100	16,800	—	—
Shellbark	Green	0.62	72,000	9,200	206	2,640	27,000	5,600	8,200	—	—
	12%	0.69	125,000	13,000	163	2,240	55,200	12,400	14,500	—	—
Honeylocust	Green	0.60	70,000	8,900	87	1,190	30,500	7,900	11,400	6,400	6,200
	12%	—	101,000	11,200	92	1,190	51,700	12,700	15,500	6,200	7,000
Locust, black	Green	0.66	95,000	12,800	106	1,120	46,900	8,000	12,100	5,300	7,000
	12%	0.69	134,000	14,100	127	1,450	70,200	12,600	17,100	4,400	7,600
Magnolia											
Cucumber tree	Green	0.44	51,000	10,800	69	760	21,600	2,300	6,800	3,000	2,300
	12%	0.48	85,000	12,500	84	890	43,500	3,900	9,200	4,600	3,100
Southern	Green	0.46	47,000	7,700	106	1,370	18,600	3,200	7,200	4,200	3,300
	12%	0.50	77,000	9,700	88	740	37,600	5,900	10,500	5,100	4,500
Maple											
Bigleaf	Green	0.44	51,000	7,600	60	580	22,300	3,100	7,700	4,100	2,800
	12%	0.48	74,000	10,000	54	710	41,000	5,200	11,900	3,700	3,800
Black	Green	0.52	54,000	9,200	88	1,220	22,500	4,100	7,800	5,000	3,700
	12%	0.57	92,000	11,200	86	1,020	46,100	7,000	12,500	4,600	5,200
Red	Green	0.49	53,000	9,600	79	810	22,600	2,800	7,900	—	3,100
	12%	0.54	92,000	11,300	86	810	45,100	6,900	12,800	—	4,200
Silver	Green	0.44	40,000	6,500	76	740	17,200	2,600	7,200	3,900	2,600
	12%	0.47	61,000	7,900	57	640	36,000	5,100	10,200	3,400	3,100
Sugar	Green	0.56	65,000	10,700	92	1,020	27,700	4,400	10,100	—	4,300
	12%	0.63	109,000	12,600	114	990	54,000	10,100	16,100	—	6,400
Oak, red											
Black	Green	0.56	57,000	8,100	84	1,020	23,900	4,900	8,400	—	4,700
	12%	0.61	96,000	11,300	94	1,040	45,000	6,400	13,200	—	5,400
Cherrybark	Green	0.61	74,000	12,300	101	1,370	31,900	5,200	9,100	5,500	5,500
	12%	0.68	125,000	15,700	126	1,240	60,300	8,600	13,800	5,800	6,600
Laurel	Green	0.56	54,000	9,600	77	990	21,900	3,900	8,100	5,300	4,400
	12%	0.63	87,000	11,700	81	990	48,100	7,300	12,600	5,400	5,400
Northern red	Green	0.56	57,000	9,300	91	1,120	23,700	4,200	8,300	5,200	4,400
	12%	0.63	99,000	12,500	100	1,090	46,600	7,000	12,300	5,500	5,700
Pin	Green	0.58	57,000	9,100	97	1,220	25,400	5,000	8,900	5,500	4,800
	12%	0.63	97,000	11,900	102	1,140	47,000	7,000	14,300	7,200	6,700
Scarlet	Green	0.60	72,000	10,200	103	1,370	28,200	5,700	9,700	4,800	5,300
	12%	0.67	120,000	13,200	141	1,350	57,400	7,700	13,000	6,000	6,200
Southern red	Green	0.52	48,000	7,900	55	740	20,900	3,800	6,400	3,300	3,800
	12%	0.59	75,000	10,300	65	660	42,000	6,000	9,600	3,500	4,700
Water	Green	0.56	61,000	10,700	77	990	25,800	4,300	8,500	5,700	4,500
	12%	0.63	106,000	13,900	148	1,120	46,700	7,000	13,900	6,300	5,300

Table 4–3a. Strength properties of some commercially important woods grown in the United States (metric)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity[c] (MPa)	Static bending: Work to maximum load (kJ/m³)	Impact bending (mm)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)	Side hardness (N)
Oak, red—con.											
Willow	Green	0.56	51,000	8,900	61	890	20,700	4,200	8,100	5,200	4,400
	12%	0.69	100,000	13,100	101	1,070	48,500	7,800	11,400	—	6,500
Oak, white											
Bur	Green	0.58	50,000	6,100	74	1,120	22,700	4,700	9,300	5,500	4,900
	12%	0.64	71,000	7,100	68	740	41,800	8,300	12,500	4,700	6,100
Chestnut	Green	0.57	55,000	9,400	65	890	24,300	3,700	8,300	4,800	4,000
	12%	0.66	92,000	11,000	76	1,020	47,100	5,800	10,300	—	5,000
Live	Green	0.80	82,000	10,900	85	—	37,400	14,100	15,200	—	—
	12%	0.88	127,000	13,700	130	—	61,400	19,600	18,300	—	—
Overcup	Green	0.57	55,000	7,900	87	1,120	23,200	3,700	9,100	5,000	4,300
	12%	0.63	87,000	9,800	108	970	42,700	5,600	13,800	6,500	5,300
Post	Green	0.60	56,000	7,500	76	1,120	24,000	5,900	8,800	5,400	5,000
	12%	0.67	91,000	10,400	91	1,170	45,300	9,900	12,700	5,400	6,000
Swamp chestnut	Green	0.60	59,000	9,300	88	1,140	24,400	3,900	8,700	4,600	4,900
	12%	0.67	96,000	12,200	83	1,040	50,100	7,700	13,700	4,800	5,500
Swamp white	Green	0.64	68,000	11,000	100	1,270	30,100	5,200	9,000	5,900	5,200
	12%	0.72	122,000	14,100	132	1,240	59,300	8,200	13,800	5,700	7,200
White	Green	0.60	57,000	8,600	80	1,070	24,500	4,600	8,600	5,300	4,700
	12%	0.68	105,000	12,300	102	940	51,300	7,400	13,800	5,500	6,000
Sassafras	Green	0.42	41,000	6,300	49	—	18,800	2,600	6,600	—	—
	12%	0.46	62,000	7,700	60	—	32,800	5,900	8,500	—	—
Sweetgum	Green	0.46	49,000	8,300	70	910	21,000	2,600	6,800	3,700	2,700
	12%	0.52	86,000	11,300	82	810	43,600	4,300	11,000	5,200	3,800
Sycamore, American	Green	0.46	45,000	7,300	52	660	20,100	2,500	6,900	4,300	2,700
	12%	0.49	69,000	9,800	59	660	37,100	4,800	10,100	5,000	3,400
Tanoak	Green	0.58	72,000	10,700	92	—	32,100	—	—	—	—
	12%	—	—	—	—	—	—	—	—	—	—
Tupelo											
Black	Green	0.46	48,000	7,100	55	760	21,000	3,300	7,600	3,900	2,800
	12%	0.50	66,000	8,300	43	560	38,100	6,400	9,200	3,400	3,600
Water	Green	0.46	50,000	7,200	57	760	23,200	3,300	8,200	4,100	3,200
	12%	0.50	66,000	8,700	48	580	40,800	6,000	11,000	4,800	3,900
Walnut, black	Green	0.51	66,000	9,800	101	940	29,600	3,400	8,400	3,900	4,000
	12%	0.55	101,000	11,600	74	860	52,300	7,000	9,400	4,800	4,500
Willow, black	Green	0.36	33,000	5,400	76	—	14,100	1,200	4,700	—	—
	12%	0.39	54,000	7,000	61	—	28,300	3,000	8,600	—	—
Yellow-poplar	Green	0.40	41,000	8,400	52	660	18,300	1,900	5,400	3,500	2,000
	12%	0.42	70,000	10,900	61	610	38,200	3,400	8,200	3,700	2,400
Softwoods											
Baldcypress	Green	0.42	46,000	8,100	46	640	24,700	2,800	5,600	2,100	1,700
	12%	0.46	73,000	9,900	57	610	43,900	5,000	6,900	1,900	2,300
Cedar											
Atlantic white	Green	0.31	32,000	5,200	41	460	16,500	1,700	4,800	1,200	1,300
	12%	0.32	47,000	6,400	28	330	32,400	2,800	5,500	1,500	1,600
Eastern redcedar	Green	0.44	48,000	4,500	103	890	24,600	4,800	7,000	2,300	2,900
	12%	0.47	61,000	6,100	57	560	41,500	6,300	—	—	4,000
Incense	Green	0.35	43,000	5,800	44	430	21,700	2,600	5,700	1,900	1,700
	12%	0.37	55,000	7,200	37	430	35,900	4,100	6,100	1,900	2,100
Northern white	Green	0.29	29,000	4,400	39	380	13,700	1,600	4,300	1,700	1,000
	12%	0.31	45,000	5,500	33	300	27,300	2,100	5,900	1,700	1,400

Table 4–3a. Strength properties of some commercially important woods grown in the United States (metric)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity[c] (MPa)	Static bending: Work to maximum load (kJ/m³)	Impact bending (mm)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)	Side hardness (N)
Cedar—con.											
Port-Orford	Green	0.39	45,000	9,000	51	530	21,600	2,100	5,800	1,200	1,700
	12%	0.43	88,000	11,700	63	710	43,100	5,000	9,400	2,800	2,800
Western redcedar	Green	0.31	35,900	6,500	34	430	19,100	1,700	5,300	1,600	1,200
	12%	0.32	51,700	7,700	40	430	31,400	3,200	6,800	1,500	1,600
Yellow	Green	0.42	44,000	7,900	63	690	21,000	2,400	5,800	2,300	2,000
	12%	0.44	77,000	9,800	72	740	43,500	4,300	7,800	2,500	2,600
Douglas-fir[d]											
Coast	Green	0.45	53,000	10,800	52	660	26,100	2,600	6,200	2,100	2,200
	12%	0.48	85,000	13,400	68	790	49,900	5,500	7,800	2,300	3,200
Interior West	Green	0.46	53,000	10,400	50	660	26,700	2,900	6,500	2,000	2,300
	12%	0.50	87,000	12,600	73	810	51,200	5,200	8,900	2,400	2,900
Interior North	Green	0.45	51,000	9,700	56	560	23,900	2,500	6,600	2,300	1,900
	12%	0.48	90,000	12,300	72	660	47,600	5,300	9,700	2,700	2,700
Interior South	Green	0.43	47,000	8,000	55	380	21,400	2,300	6,600	1,700	1,600
	12%	0.46	82,000	10,300	62	510	43,000	5,100	10,400	2,300	2,300
Fir											
Balsam	Green	0.33	38,000	8,600	32	410	18,100	1,300	4,600	1,200	1,300
	12%	0.35	63,000	10,000	35	510	36,400	2,800	6,500	1,200	1,800
California red	Green	0.36	40,000	8,100	44	530	19,000	2,300	5,300	2,600	1,600
	12%	0.38	72,400	10,300	61	610	37,600	4,200	7,200	2,700	2,200
Grand	Green	0.35	40,000	8,600	39	560	20,300	1,900	5,100	1,700	1,600
	12%	0.37	61,400	10,800	52	710	36,500	3,400	6,200	1,700	2,200
Noble	Green	0.37	43,000	9,500	41	480	20,800	1,900	5,500	1,600	1,300
	12%	0.39	74,000	11,900	61	580	42,100	3,600	7,200	1,500	1,800
Pacific silver	Green	0.40	44,000	9,800	41	530	21,600	1,500	5,200	1,700	1,400
	12%	0.43	75,800	12,100	64	610	44,200	3,100	8,400	—	1,900
Subalpine	Green	0.31	34,000	7,200	—	—	15,900	1,300	4,800	—	1,200
	12%	0.32	59,000	8,900	—	—	33,500	2,700	7,400	—	1,600
White	Green	0.37	41,000	8,000	39	560	20,000	1,900	5,200	2,100	1,500
	12%	0.39	68,000	10,300	50	510	40,000	3,700	7,600	2,100	2,100
Hemlock											
Eastern	Green	0.38	44,000	7,400	46	530	21,200	2,500	5,900	1,600	1,800
	12%	0.40	61,000	8,300	47	530	37,300	4,500	7,300	—	2,200
Mountain	Green	0.42	43,000	7,200	76	810	19,900	2,600	6,400	2,300	2,100
	12%	0.45	79,000	9,200	72	810	44,400	5,900	10,600	—	3,000
Western	Green	0.42	46,000	9,000	48	560	23,200	1,900	5,900	2,000	1,800
	12%	0.45	78,000	11,300	57	580	49,000	3,800	8,600	2,300	2,400
Larch, western	Green	0.48	53,000	10,100	71	740	25,900	2,800	6,000	2,300	2,300
	12%	0.52	90,000	12,900	87	890	52,500	6,400	9,400	3,000	3,700
Pine											
Eastern white	Green	0.34	34,000	6,800	36	430	16,800	1,500	4,700	1,700	1,300
	12%	0.35	59,000	8,500	47	460	33,100	3,000	6,200	2,100	1,700
Jack	Green	0.40	41,000	7,400	50	660	20,300	2,100	5,200	2,500	1,800
	12%	0.43	68,000	9,300	57	690	39,000	4,000	8,100	2,900	2,500
Loblolly	Green	0.47	50,000	9,700	57	760	24,200	2,700	5,900	1,800	2,000
	12%	0.51	88,000	12,300	72	760	49,200	5,400	9,600	3,200	3,100
Lodgepole	Green	0.38	38,000	7,400	39	510	18,000	1,700	4,700	1,500	1,500
	12%	0.41	65,000	9,200	47	510	37,000	4,200	6,100	2,000	2,100
Longleaf	Green	0.54	59,000	11,000	61	890	29,800	3,300	7,200	2,300	2,600
	12%	0.59	100,000	13,700	81	860	58,400	6,600	10,400	3,200	3,900
Pitch	Green	0.47	47,000	8,300	63	—	20,300	2,500	5,900	—	—
	12%	0.52	74,000	9,900	63	—	41,000	5,600	9,400	—	—

Table 4–3a. Strength properties of some commercially important woods grown in the United States (metric)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity[c] (MPa)	Static bending: Work to maximum load (kJ/m³)	Impact bending (mm)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)	Tension perpendicular to grain (kPa)	Side hardness (N)
Pine—con.											
Pond	Green	0.51	51,000	8,800	52	—	25,200	3,000	6,500	—	—
	12%	0.56	80,000	12,100	59	—	52,000	6,300	9,500	—	—
Ponderosa	Green	0.38	35,000	6,900	36	530	16,900	1,900	4,800	2,100	1,400
	12%	0.40	65,000	8,900	49	480	36,700	4,000	7,800	2,900	2,000
Red	Green	0.41	40,000	8,800	42	660	18,800	1,800	4,800	2,100	1,500
	12%	0.46	76,000	11,200	68	660	41,900	4,100	8,400	3,200	2,500
Sand	Green	0.46	52,000	7,000	66	—	23,700	3,100	7,900	—	—
	12%	0.48	80,000	9,700	66	—	47,700	5,800	—	—	—
Shortleaf	Green	0.47	51,000	9,600	57	760	24,300	2,400	6,300	2,200	2,000
	12%	0.51	90,000	12,100	76	840	50,100	5,700	9,600	3,200	3,100
Slash	Green	0.54	60,000	10,500	66	—	26,300	3,700	6,600	—	—
	12%	0.59	112,000	13,700	91	—	56,100	7,000	11,600	—	—
Spruce	Green	0.41	41,000	6,900	—	—	19,600	1,900	6,200	—	2,000
	12%	0.44	72,000	8,500	—	—	39,000	5,000	10,300	—	2,900
Sugar	Green	0.34	34,000	7,100	37	430	17,000	1,400	5,000	1,900	1,200
	12%	0.36	57,000	8,200	38	460	30,800	3,400	7,800	2,400	1,700
Virginia	Green	0.45	50,000	8,400	75	860	23,600	2,700	6,100	2,800	2,400
	12%	0.48	90,000	10,500	94	810	46,300	6,300	9,300	2,600	3,300
Western white	Green	0.36	32,000	8,200	34	480	16,800	1,300	4,700	1,800	1,200
	12%	0.38	67,000	10,100	61	580	34,700	3,200	7,200	—	1,900
Redwood											
Old-growth	Green	0.38	52,000	8,100	51	530	29,000	2,900	5,500	1,800	1,800
	12%	0.40	69,000	9,200	48	480	42,400	4,800	6,500	1,700	2,100
Young-growth	Green	0.34	41,000	6,600	39	410	21,400	1,900	6,100	2,100	1,600
	12%	0.35	54,000	7,600	36	380	36,000	3,600	7,600	1,700	1,900
Spruce											
Black	Green	0.38	42,000	9,500	51	610	19,600	1,700	5,100	700	1,600
	12%	0.46	74,000	11,100	72	580	41,100	3,800	8,500	—	2,300
Engelmann	Green	0.33	32,000	7,100	35	410	15,000	1,400	4,400	1,700	1,150
	12%	0.35	64,000	8,900	44	460	30,900	2,800	8,300	2,400	1,750
Red	Green	0.37	41,000	9,200	48	460	18,800	1,800	5,200	1,500	1,600
	12%	0.40	74,000	11,100	58	640	38,200	3,800	8,900	2,400	2,200
Sitka	Green	0.33	34,000	7,900	43	610	16,200	1,400	4,400	1,700	1,600
	12%	0.36	65,000	9,900	65	640	35,700	3,000	6,700	2,600	2,300
White	Green	0.37	39,000	7,400	41	560	17,700	1,700	4,800	1,500	1,400
	12%	0.40	68,000	9,200	53	510	37,700	3,200	7,400	2,500	2,100
Tamarack	Green	0.49	50,000	8,500	50	710	24,000	2,700	5,900	1,800	1,700
	12%	0.53	80,000	11,300	49	580	49,400	5,500	8,800	2,800	2,600

[a]Results of tests on small clear specimens in the green and air-dried conditions, converted to metric units directly from Table 4–3b. Definition of properties: impact bending is height of drop that causes complete failure, using 0.71-kg (50-lb) hammer; compression parallel to grain is also called maximum crushing strength; compression perpendicular to grain is fiber stress at proportional limit; shear is maximum shearing strength; tension is maximum tensile strength; and side hardness is hardness measured when load is perpendicular to grain.
[b]Specific gravity is based on weight when ovendry and volume when green or at 12% moisture content.
[c]Modulus of elasticity measured from a simply supported, center-loaded beam, on a span depth ratio of 14/1. To correct for shear deflection, the modulus can be increased by 10%.
[d]Coast Douglas-fir is defined as Douglas-fir growing in Oregon and Washington State west of the Cascade Mountains summit. Interior West includes California and all counties in Oregon and Washington east of, but adjacent to, the Cascade summit; Interior North, the remainder of Oregon and Washington plus Idaho, Montana, and Wyoming; and Interior South, Utah, Colorado, Arizona, and New Mexico.

Table 4–3b. Strength properties of some commercially important woods grown in the United States (inch–pound)[a]

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity[c] (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Impact bending (in.)	Compression parallel to grain (lbf/in²)	Compression perpendicular to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Tension perpendicular to grain (lbf/in²)	Side hardness (lbf)
					Hardwoods						
Alder, red	Green	0.37	6,500	1.17	8.0	22	2,960	250	770	390	440
	12%	0.41	9,800	1.38	8.4	20	5,820	440	1,080	420	590
Ash											
Black	Green	0.45	6,000	1.04	12.1	33	2,300	350	860	490	520
	12%	0.49	12,600	1.60	14.9	35	5,970	760	1,570	700	850
Blue	Green	0.53	9,600	1.24	14.7	—	4,180	810	1,540	—	—
	12%	0.58	13,800	1.40	14.4	—	6,980	1,420	2,030	—	—
Green	Green	0.53	9,500	1.40	11.8	35	4,200	730	1,260	590	870
	12%	0.56	14,100	1.66	13.4	32	7,080	1,310	1,910	700	1,200
Oregon	Green	0.50	7,600	1.13	12.2	39	3,510	530	1,190	590	790
	12%	0.55	12,700	1.36	14.4	33	6,040	1,250	1,790	720	1,160
White	Green	0.55	9,500	1.44	15.7	38	3,990	670	1,350	590	960
	12%	0.60	15,000	1.74	16.6	43	7,410	1,160	1,910	940	1,320
Aspen											
Bigtooth	Green	0.36	5,400	1.12	5.7	—	2,500	210	730	—	—
	12%	0.39	9,100	1.43	7.7	—	5,300	450	1,080	—	—
Quaking	Green	0.35	5,100	0.86	6.4	22	2,140	180	660	230	300
	12%	0.38	8,400	1.18	7.6	21	4,250	370	850	260	350
Basswood, American	Green	0.32	5,000	1.04	5.3	16	2,220	170	600	280	250
	12%	0.37	8,700	1.46	7.2	16	4,730	370	990	350	410
Beech, American	Green	0.56	8,600	1.38	11.9	43	3,550	540	1,290	720	850
	12%	0.64	14,900	1.72	15.1	41	7,300	1,010	2,010	1,010	1,300
Birch											
Paper	Green	0.48	6,400	1.17	16.2	49	2,360	270	840	380	560
	12%	0.55	12,300	1.59	16.0	34	5,690	600	1,210	—	910
Sweet	Green	0.60	9,400	1.65	15.7	48	3,740	470	1,240	430	970
	12%	0.65	16,900	2.17	18.0	47	8,540	1,080	2,240	950	1,470
Yellow	Green	0.55	8,300	1.50	16.1	48	3,380	430	1,110	430	780
	12%	0.62	16,600	2.01	20.8	55	8,170	970	1,880	920	1,260
Butternut	Green	0.36	5,400	0.97	8.2	24	2,420	220	760	430	390
	12%	0.38	8,100	1.18	8.2	24	5,110	460	1,170	440	490
Cherry, black	Green	0.47	8,000	1.31	12.8	33	3,540	360	1,130	570	660
	12%	0.50	12,300	1.49	11.4	29	7,110	690	1,700	560	950
Chestnut, American	Green	0.40	5,600	0.93	7.0	24	2,470	310	800	440	420
	12%	0.43	8,600	1.23	6.5	19	5,320	620	1,080	460	540
Cottonwood											
Balsam, poplar	Green	0.31	3,900	0.75	4.2	—	1,690	140	500	—	—
	12%	0.34	6,800	1.10	5.0	—	4,020	300	790	—	—
Black	Green	0.31	4,900	1.08	5.0	20	2,200	160	610	270	250
	12%	0.35	8,500	1.27	6.7	22	4,500	300	1,040	330	350
Eastern	Green	0.37	5,300	1.01	7.3	21	2,280	200	680	410	340
	12%	0.40	8,500	1.37	7.4	20	4,910	380	930	580	430
Elm											
American	Green	0.46	7,200	1.11	11.8	38	2,910	360	1,000	590	620
	12%	0.50	11,800	1.34	13.0	39	5,520	690	1,510	660	830
Rock	Green	0.57	9,500	1.19	19.8	54	3,780	610	1,270	—	940
	12%	0.63	14,800	1.54	19.2	56	7,050	1,230	1,920	—	1,320
Slippery	Green	0.48	8,000	1.23	15.4	47	3,320	420	1,110	640	660
	12%	0.53	13,000	1.49	16.9	45	6,360	820	1,630	530	860
Hackberry	Green	0.49	6,500	0.95	14.5	48	2,650	400	1,070	630	700
	12%	0.53	11,000	1.19	12.8	43	5,440	890	1,590	580	880

Table 4–3b. Strength properties of some commercially important woods grown in the United States (inch–pound)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity[c] (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Impact bending (in.)	Compression parallel to grain (lbf/in²)	Compression perpendicular to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Tension perpendicular to grain (lbf/in²)	Side hardness (lbf)
Hickory, pecan											
Bitternut	Green	0.60	10,300	1.40	20.0	66	4,570	800	1,240	—	—
	12%	0.66	17,100	1.79	18.2	66	9,040	1,680	—	—	—
Nutmeg	Green	0.56	9,100	1.29	22.8	54	3,980	760	1,030	—	—
	12%	0.60	16,600	1.70	25.1	—	6,910	1,570	—	—	—
Pecan	Green	0.60	9,800	1.37	14.6	53	3,990	780	1,480	680	1,310
	12%	0.66	13,700	1.73	13.8	44	7,850	1,720	2,080	—	1,820
Water	Green	0.61	10,700	1.56	18.8	56	4,660	880	1,440	—	—
	12%	0.62	17,800	2.02	19.3	53	8,600	1,550	—	—	—
Hickory, true											
Mockernut	Green	0.64	11,100	1.57	26.1	88	4,480	810	1,280	—	—
	12%	0.72	19,200	2.22	22.6	77	8,940	1,730	1,740	—	—
Pignut	Green	0.66	11,700	1.65	31.7	89	4,810	920	1,370	—	—
	12%	0.75	20,100	2.26	30.4	74	9,190	1,980	2,150	—	—
Shagbark	Green	0.64	11,000	1.57	23.7	74	4,580	840	1,520	—	—
	12%	0.72	20,200	2.16	25.8	67	9,210	1,760	2,430	—	—
Shellbark	Green	0.62	10,500	1.34	29.9	104	3,920	810	1,190	—	—
	12%	0.69	18,100	1.89	23.6	88	8,000	1,800	2,110	—	—
Honeylocust	Green	0.60	10,200	1.29	12.6	47	4,420	1,150	1,660	930	1,390
	12%	—	14,700	1.63	13.3	47	7,500	1,840	2,250	900	1,580
Locust, black	Green	0.66	13,800	1.85	15.4	44	6,800	1,160	1,760	770	1,570
	12%	0.69	19,400	2.05	18.4	57	10,180	1,830	2,480	640	1,700
Magnolia											
Cucumbertree	Green	0.44	7,400	1.56	10.0	30	3,140	330	990	440	520
	12%	0.48	12,300	1.82	12.2	35	6,310	570	1,340	660	700
Southern	Green	0.46	6,800	1.11	15.4	54	2,700	460	1,040	610	740
	12%	0.50	11,200	1.40	12.8	29	5,460	860	1,530	740	1,020
Maple											
Bigleaf	Green	0.44	7,400	1.10	8.7	23	3,240	450	1,110	600	620
	12%	0.48	10,700	1.45	7.8	28	5,950	750	1,730	540	850
Black	Green	0.52	7,900	1.33	12.8	48	3,270	600	1,130	720	840
	12%	0.57	13,300	1.62	12.5	40	6,680	1,020	1,820	670	1,180
Red	Green	0.49	7,700	1.39	11.4	32	3,280	400	1,150	—	700
	12%	0.54	13,400	1.64	12.5	32	6,540	1,000	1,850	—	950
Silver	Green	0.44	5,800	0.94	11.0	29	2,490	370	1,050	560	590
	12%	0.47	8,900	1.14	8.3	25	5,220	740	1,480	500	700
Sugar	Green	0.56	9,400	1.55	13.3	40	4,020	640	1,460	—	970
	12%	0.63	15,800	1.83	16.5	39	7,830	1,470	2,330	—	1,450
Oak, red											
Black	Green	0.56	8,200	1.18	12.2	40	3,470	710	1,220	—	1,060
	12%	0.61	13,900	1.64	13.7	41	6,520	930	1,910	—	1,210
Cherrybark	Green	0.61	10,800	1.79	14.7	54	4,620	760	1,320	800	1,240
	12%	0.68	18,100	2.28	18.3	49	8,740	1,250	2,000	840	1,480
Laurel	Green	0.56	7900	1.39	11.2	39	3,170	570	1,180	770	1,000
	12%	0.63	12,600	1.69	11.8	39	6,980	1,060	1,830	790	1,210
Northern red	Green	0.56	8300	1.35	13.2	44	3,440	610	1,210	750	1,000
	12%	0.63	14,300	1.82	14.5	43	6,760	1,010	1,780	800	1,290
Pin	Green	0.58	8300	1.32	14.0	48	3,680	720	1,290	800	1,070
	12%	0.63	14000	1.73	14.8	45	6,820	1,020	2,080	1,050	1,510
Scarlet	Green	0.60	10,400	1.48	15.0	54	4,090	830	1,410	700	1,200
	12%	0.67	17400	1.91	20.5	53	8,330	1,120	1,890	870	1,400
Southern red	Green	0.52	6,900	1.14	8.0	29	3,030	550	930	480	860
	12%	0.59	10,900	1.49	9.4	26	6,090	870	1,390	510	1,060

Table 4–3b. Strength properties of some commercially important woods grown in the United States (inch–pound)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity[c] (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Impact bending (in.)	Compression parallel to grain (lbf/in²)	Compression perpendicular to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Tension perpendicular to grain (lbf/in²)	Side hardness (lbf)
Oak, red—con.											
Water	Green	0.56	8,900	1.55	11.1	39	3,740	620	1,240	820	1,010
	12%	0.63	15,400	2.02	21.5	44	6,770	1,020	2,020	920	1,190
Willow	Green	0.56	7400	1.29	8.8	35	3,000	610	1,180	760	980
	12%	0.69	14,500	1.90	14.6	42	7,040	1,130	1,650	—	1,460
Oak, white											
Bur	Green	0.58	7,200	0.88	10.7	44	3,290	680	1,350	800	1,110
	12%	0.64	10,300	1.03	9.8	29	6,060	1,200	1,820	680	1,370
Chestnut	Green	0.57	8,000	1.37	9.4	35	3,520	530	1,210	690	890
	12%	0.66	13,300	1.59	11.0	40	6,830	840	1,490	—	1,130
Live	Green	0.80	11,900	1.58	12.3	—	5,430	2,040	2,210	—	—
	12%	0.88	18,400	1.98	18.9	—	8,900	2,840	2,660	—	—
Overcup	Green	0.57	8,000	1.15	12.6	44	3,370	540	1,320	730	960
	12%	0.63	12,600	1.42	15.7	38	6,200	810	2,000	940	1,190
Post	Green	0.60	8,100	1.09	11.0	44	3,480	860	1,280	790	1,130
	12%	0.67	13,200	1.51	13.2	46	6,600	1,430	1,840	780	1,360
Swamp chestnut	Green	0.60	8,500	1.35	12.8	45	3,540	570	1,260	670	1,110
	12%	0.67	13,900	1.77	12.0	41	7,270	1,110	1,990	690	1,240
Swamp white	Green	0.64	9,900	1.59	14.5	50	4,360	760	1,300	860	1,160
	12%	0.72	17,700	2.05	19.2	49	8,600	1,190	2,000	830	1,620
White	Green	0.60	8,300	1.25	11.6	42	3,560	670	1,250	770	1,060
	12%	0.68	15,200	1.78	14.8	37	7,440	1,070	2,000	800	1,360
Sassafras	Green	0.42	6,000	0.91	7.1	—	2,730	370	950	—	—
	12%	0.46	9,000	1.12	8.7	—	4,760	850	1,240	—	—
Sweetgum	Green	0.46	7,100	1.20	10.1	36	3,040	370	990	540	600
	12%	0.52	12,500	1.64	11.9	32	6,320	620	1,600	760	850
Sycamore, American	Green	0.46	6,500	1.06	7.5	26	2,920	360	1,000	630	610
	12%	0.49	10,000	1.42	8.5	26	5,380	700	1,470	720	770
Tanoak	Green	0.58	10,500	1.55	13.4	—	4,650	—	—	—	—
	12%	—	—	—	—	—	—	—	—	—	—
Tupelo											
Black	Green	0.46	7,000	1.03	8.0	30	3,040	480	1,100	570	640
	12%	0.50	9,600	1.20	6.2	22	5,520	930	1,340	500	810
Water	Green	0.46	7,300	1.05	8.3	30	3,370	480	1,190	600	710
	12%	0.50	9,600	1.26	6.9	23	5,920	870	1,590	700	880
Walnut, Black	Green	0.51	9,500	1.42	14.6	37	4,300	490	1,220	570	900
	12%	0.55	14,600	1.68	10.7	34	7,580	1,010	1,370	690	1,010
Willow, Black	Green	0.36	4,800	0.79	11.0	—	2,040	180	680	—	—
	12%	0.39	7,800	1.01	8.8	—	4,100	430	1,250	—	—
Yellow-poplar	Green	0.40	6,000	1.22	7.5	26	2,660	270	790	510	440
	12%	0.42	10,100	1.58	8.8	24	5,540	500	1,190	540	540
Softwoods											
Baldcypress	Green	0.42	6,600	1.18	6.6	25	3,580	400	810	300	390
	12%	0.46	10,600	1.44	8.2	24	6,360	730	1,000	270	510
Cedar											
Atlantic white	Green	0.31	4,700	0.75	5.9	18	2,390	240	690	180	290
	12%	0.32	6,800	0.93	4.1	13	4,700	410	800	220	350
Eastern redcedar	Green	0.44	7,000	0.65	15.0	35	3,570	700	1,010	330	650
	12%	0.47	8,800	0.88	8.3	22	6,020	920	—	—	—
Incense	Green	0.35	6,200	0.84	6.4	17	3,150	370	830	280	390
	12%	0.37	8,000	1.04	5.4	17	5,200	590	880	270	470
Northern White	Green	0.29	4,200	0.64	5.7	15	1,990	230	620	240	230
	12%	0.31	6,500	0.80	4.8	12	3,960	310	850	240	320

Table 4–3b. Strength properties of some commercially important woods grown in the United States (inch–pound)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity[c] (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Impact bending (in.)	Com-pression parallel to grain (lbf/in²)	Com-pression perpen-dicular to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Tension perpen-dicular to grain (lbf/in²)	Side hard-ness (lbf)
Cedar—con.											
Port-Orford	Green	0.39	6,600	1.30	7.4	21	3,140	300	840	180	380
	12%	0.43	12,700	1.70	9.1	28	6,250	720	1,370	400	630
Western redcedar	Green	0.31	5,200	0.94	5.0	17	2,770	240	770	230	260
	12%	0.32	7,500	1.11	5.8	17	4,560	460	990	220	350
Yellow	Green	0.42	6,400	1.14	9.2	27	3,050	350	840	330	440
	12%	0.44	11,100	1.42	10.4	29	6,310	620	1,130	360	580
Douglas-fir[d]											
Coast	Green	0.45	7,700	1.56	7.6	26	3,780	380	900	300	500
	12%	0.48	12,400	1.95	9.9	31	7,230	800	1,130	340	710
Interior West	Green	0.46	7,700	1.51	7.2	26	3,870	420	940	290	510
	12%	0.50	12,600	1.83	10.6	32	7,430	760	1,290	350	660
Interior North	Green	0.45	7,400	1.41	8.1	22	3,470	360	950	340	420
	12%	0.48	13,100	1.79	10.5	26	6,900	770	1,400	390	600
Interior South	Green	0.43	6,800	1.16	8.0	15	3,110	340	950	250	360
	12%	0.46	11,900	1.49	9.0	20	6,230	740	1,510	330	510
Fir											
Balsam	Green	0.33	5,500	1.25	4.7	16	2,630	190	662	180	290
	12%	0.35	9,200	1.45	5.1	20	5,280	404	944	180	400
California red	Green	0.36	5,800	1.17	6.4	21	2,760	330	770	380	360
	12%	0.38	10,500	1.50	8.9	24	5,460	610	1,040	390	500
Grand	Green	0.35	5,800	1.25	5.6	22	2,940	270	740	240	360
	12%	0.37	8,900	1.57	7.5	28	5,290	500	900	240	490
Noble	Green	0.37	6,200	1.38	6.0	19	3,010	270	800	230	290
	12%	0.39	10,700	1.72	8.8	23	6,100	520	1,050	220	410
Pacific silver	Green	0.40	6,400	1.42	6.0	21	3,140	220	750	240	310
	12%	0.43	11,000	1.76	9.3	24	6,410	450	1,220	—	430
Subalpine	Green	0.31	4,900	1.05	—	—	2,300	190	700	—	260
	12%	0.32	8,600	1.29	—	—	4,860	390	1,070	—	350
White	Green	0.37	5,900	1.16	5.6	22	2,900	280	760	300	340
	12%	0.39	9,800	1.50	7.2	20	5,800	530	1,100	300	480
Hemlock											
Eastern	Green	0.38	6,400	1.07	6.7	21	3,080	360	850	230	400
	12%	0.40	8,900	1.20	6.8	21	5,410	650	1,060	—	500
Mountain	Green	0.42	6,300	1.04	11.0	32	2,880	370	930	330	470
	12%	0.45	11,500	1.33	10.4	32	6,440	860	1,540	—	680
Western	Green	0.42	6,600	1.31	6.9	22	3,360	280	860	290	410
	12%	0.45	11,300	1.63	8.3	23	7,200	550	1,290	340	540
Larch, western	Green	0.48	7,700	1.46	10.3	29	3,760	400	870	330	510
	12%	0.52	13,000	1.87	12.6	35	7,620	930	1,360	430	830
Pine											
Eastern white	Green	0.34	4,900	0.99	5.2	17	2,440	220	680	250	290
	12%	0.35	8,600	1.24	6.8	18	4,800	440	900	310	380
Jack	Green	0.40	6,000	1.07	7.2	26	2,950	300	750	360	400
	12%	0.43	9,900	1.35	8.3	27	5,660	580	1,170	420	570
Loblolly	Green	0.47	7,300	1.40	8.2	30	3,510	390	860	260	450
	12%	0.51	12,800	1.79	10.4	30	7,130	790	1,390	470	690
Lodgepole	Green	0.38	5,500	1.08	5.6	20	2,610	250	680	220	330
	12%	0.41	9,400	1.34	6.8	20	5,370	610	880	290	480
Longleaf	Green	0.554	8,500	1.59	8.9	35	4,320	480	1,040	330	590
	12%	0.59	14,500	1.98	11.8	34	8,470	960	1,510	470	870
Pitch	Green	0.47	6,800	1.20	9.2	—	2,950	360	860	—	—
	12%	0.52	10,800	1.43	9.2	—	5,940	820	1,360	—	—

Table 4–3b. Strength properties of some commercially important woods grown in the United States (inch–pound)[a]—con.

Common species names	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity[c] (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Impact bending (in.)	Compression parallel to grain (lbf/in²)	Compression perpendicular to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Tension perpendicular to grain (lbf/in²)	Side hardness (lbf)
Pine—con.											
Pond	Green	0.51	7,400	1.28	7.5	—	3,660	440	940	—	—
	12%	0.56	11,600	1.75	8.6	—	7,540	910	1,380	—	—
Ponderosa	Green	0.38	5,100	1.00	5.2	21	2,450	280	700	310	320
	12%	0.40	9,400	1.29	7.1	19	5,320	580	1,130	420	460
Red	Green	0.41	5,800	1.28	6.1	26	2,730	260	690	300	340
	12%	0.46	11,000	1.63	9.9	26	6,070	600	1,210	460	560
Sand	Green	0.46	7,500	1.02	9.6	—	3,440	450	1,140	—	—
	12%	0.48	11,600	1.41	9.6	—	6,920	836	—	—	—
Shortleaf	Green	0.47	7,400	1.39	8.2	30	3,530	350	910	320	440
	12%	0.51	13,100	1.75	11.0	33	7,270	820	1,390	470	690
Slash	Green	0.54	8,700	1.53	9.6	—	3,820	530	960	—	—
	12%	0.59	16,300	1.98	13.2	—	8,140	1020	1,680	—	—
Spruce	Green	0.41	6,000	1.00	—	—	2,840	280	900	—	450
	12%	0.44	10,400	1.23	—	—	5,650	730	1,490	—	660
Sugar	Green	0.34	4,900	1.03	5.4	17	2,460	210	720	270	270
	12%	0.36	8,200	1.19	5.5	18	4,460	500	1,130	350	380
Virginia	Green	0.45	7,300	1.22	10.9	34	3,420	390	890	400	540
	12%	0.48	13,000	1.52	13.7	32	6,710	910	1,350	380	740
Western white	Green	0.35	4,700	1.19	5.0	19	2,430	190	680	260	260
	12%	0.38	9,700	1.46	8.8	23	5,040	470	1,040	—	420
Redwood											
Old-growth	Green	0.38	7,500	1.18	7.4	21	4,200	420	800	260	410
	12%	0.40	10,000	1.34	6.9	19	6,150	700	940	240	480
Young-growth	Green	0.34	5,900	0.96	5.7	16	3,110	270	890	300	350
	12%	0.35	7,900	1.10	5.2	15	5,220	520	1,110	250	420
Spruce											
Black	Green	0.38	6,100	1.38	7.4	24	2,840	240	739	100	370
	12%	0.42	10,800	1.61	10.5	23	5,960	550	1,230	—	520
Engelmann	Green	0.33	4,700	1.03	5.1	16	2,180	200	640	240	260
	12%	0.35	9,300	1.30	6.4	18	4,480	410	1,200	350	390
Red	Green	0.37	6,000	1.33	6.9	18	2,720	260	750	220	350
	12%	0.40	10,800	1.61	8.4	25	5,540	550	1,290	350	490
Sitka	Green	0.37	5,700	1.23	6.3	24	2,670	280	760	250	350
	12%	0.40	10,200	1.57	9.4	25	5,610	580	1,150	370	510
White	Green	0.33	5,000	1.14	6.0	22	2,350	210	640	220	320
	12%	0.36	9,400	1.43	7.7	20	5,180	430	970	360	480
Tamarack	Green	0.49	7,200	1.24	7.2	28	3,480	390	860	260	380
	12%	0.53	11,600	1.64	7.1	23	7,160	800	1,280	400	590

[a]Results of tests on small clear specimens in the green and air-dried conditions. Definition of properties: impact bending is height of drop that causes complete failure, using 0.71-kg (50-lb) hammer; compression parallel to grain is also called maximum crushing strength; compression perpendicular to grain is fiber stress at proportional limit; shear is maximum shearing strength; tension is maximum tensile strength; and side hardness is hardness measured when load is perpendicular to grain.

[b]Specific gravity is based on weight when ovendry and volume when green or at 12% moisture content.

[c]Modulus of elasticity measured from a simply supported, center-loaded beam, on a span depth ratio of 14/1. To correct for shear deflection, the modulus can be increased by 10%.

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

Table 4–4a. Mechanical properties of some commercially important woods grown in Canada and imported into the United States (metric)[a]

Common species names	Moisture content	Specific gravity	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity (MPa)	Compression parallel to grain (kPa)	Compression perpendicular to grain (kPa)	Shear parallel to grain (kPa)
Hardwoods							
Aspen							
Quaking	Green	0.37	38,000	9,000	16,200	1,400	5,000
	12%		68,000	11,200	36,300	3,500	6,800
Big-toothed	Green	0.39	36,000	7,400	16,500	1,400	5,400
	12%		66,000	8,700	32,800	3,200	7,600
Cottonwood							
Black	Green	0.30	28,000	6,700	12,800	700	3,900
	12%		49,000	8,800	27,700	1,800	5,900
Eastern	Green	0.35	32,000	6,000	13,600	1,400	5,300
	12%		52,000	7,800	26,500	3,200	8,000
Balsam, poplar	Green	0.37	34,000	7,900	14,600	1,200	4,600
	12%		70,000	11,500	34,600	2,900	6,100
Softwoods							
Cedar							
Northern white	Green	0.30	27,000	3,600	13,000	1,400	4,600
	12%		42,000	4,300	24,800	2,700	6,900
Western redcedar	Green	0.31	36,000	7,200	19,200	1,900	4,800
	12%		54,000	8,200	29,600	3,400	5,600
Yellow	Green	0.42	46,000	9,200	22,300	2,400	6,100
	12%		80,000	11,000	45,800	4,800	9,200
Douglas-fir	Green	0.45	52,000	11,100	24,900	3,200	6,300
	12%		88,000	13,600	50,000	6,000	9,500
Fir							
Subalpine	Green	0.33	36,000	8,700	17,200	1,800	4,700
	12%		56,000	10,200	36,400	3,700	6,800
Pacific silver	Green	0.36	38,000	9,300	19,100	1,600	4,900
	12%		69,000	11,300	40,900	3,600	7,500
Balsam	Green	0.34	36,000	7,800	16,800	1,600	4,700
	12%		59,000	9,600	34,300	3,200	6,300
Hemlock							
Eastern	Green	0.40	47,000	8,800	23,600	2,800	6,300
	12%		67,000	9,700	41,200	4,300	8,700
Western	Green	0.41	48,000	10,200	24,700	2,600	5,200
	12%		81,000	12,300	46,700	4,600	6,500
Larch, western	Green	0.55	60,000	11,400	30,500	3,600	6,300
	12%		107,000	14,300	61,000	7,300	9,200
Pine							
Eastern white	Green	0.36	35,000	8,100	17,900	1,600	4,400
	12%		66,000	9,400	36,000	3,400	6,100
Jack	Green	0.42	43,000	8,100	20,300	2,300	5,600
	12%		78,000	10,200	40,500	5,700	8,200
Lodgepole	Green	0.40	39,000	8,800	19,700	1,900	5,000
	12%		76,000	10,900	43,200	3,600	8,500
Ponderosa	Green	0.44	39,000	7,800	19,600	2,400	5,000
	12%		73,000	9,500	42,300	5,200	7,000
Red	Green	0.39	34,000	7,400	16,300	1,900	4,900
	12%		70,000	9,500	37,900	5,200	7,500
Western white	Green	0.36	33,000	8,200	17,400	1,600	4,500
	12%		64,100	10,100	36,100	3,200	6,300
Spruce							
Black	Green	0.41	41,000	9,100	19,000	2,100	5,500
	12%		79,000	10,500	41,600	4,300	8,600
Engelmann	Green	0.38	39,000	8,600	19,400	1,900	4,800
	12%		70,000	10,700	42,400	3,700	7,600
Red	Green	0.38	41,000	9,100	19,400	1,900	5,600
	12%		71,000	11,000	38,500	3,800	9,200
Sitka	Green	0.35	37,000	9,400	17,600	2,000	4,300
	12%		70,000	11,200	37,800	4,100	6,800
White	Green	0.35	35,000	7,900	17,000	1,600	4,600
	12%		63,000	10,000	37,000	3,400	6,800
Tamarack	Green	0.48	47,000	8,600	21,600	2,800	6,300
	12%		76,000	9,400	44,900	6,200	9,000

[a]Results of tests on small, clear, straight-grained specimens. Property values based on ASTM Standard D2555–88. Information on additional properties can be obtained from Department of Forestry, Canada, Publication No. 1104. For each species, values in the first line are from tests of green material; those in the second line are adjusted from the green condition to 12% moisture content using dry to green clear wood property ratios as reported in ASTM D2555–88. Specific gravity is based on weight when ovendry and volume when green.

Table 4–4b. Mechanical properties of some commercially important woods grown in Canada and imported into the United States (inch–pound)[a]

Common species names	Moisture content	Specific gravity	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity (×10⁶ lbf/in²)	Compression parallel to grain (lbf/in²)	Compression perpendicular to grain (lbf/in²)	Shear parallel to grain (lbf/in²)
Hardwoods							
Aspen							
Quaking	Green	0.37	5,500	1.31	2,350	200	720
	12%		9,800	1.63	5,260	510	980
Bigtooth	Green	0.39	5,300	1.08	2,390	210	790
	12%		9,500	1.26	4,760	470	1,100
Cottonwood							
Balsam, poplar	Green	0.37	5,000	1.15	2,110	180	670
	12%		10,100	1.67	5,020	420	890
Black	Green	0.30	4,100	0.97	1,860	100	560
	12%		7,100	1.28	4,020	260	860
Eastern	Green	0.35	4,700	0.87	1,970	210	770
	12%		7,500	1.13	3,840	470	1,160
Softwoods							
Cedar							
Northern white	Green	0.30	3,900	0.52	1,890	200	660
	12%		6,100	0.63	3,590	390	1,000
Western redcedar	Green	0.31	5,300	1.05	2,780	280	700
	12%		7,800	1.19	4,290	500	810
Yellow	Green	0.42	6,600	1.34	3,240	350	880
	12%		11,600	1.59	6,640	690	1,340
Douglas-fir	Green	0.45	7,500	1.61	3,610	460	920
	12%		12,800	1.97	7,260	870	1,380
Fir							
Balsam	Green	0.34	5,300	1.13	2,440	240	680
	12%		8,500	1.40	4,980	460	910
Pacific silver	Green	0.36	5,500	1.35	2,770	230	710
	12%		10,000	1.64	5,930	520	1,190
Subalpine	Green	0.33	5,200	1.26	2,500	260	680
	12%		8,200	1.48	5,280	540	980
Hemlock							
Eastern	Green	0.40	6,800	1.27	3,430	400	910
	12%		9,700	1.41	5,970	630	1,260
Western	Green	0.41	7,000	1.48	3,580	370	750
	12%		11,800	1.79	6,770	660	940
Larch, western	Green	0.55	8,700	1.65	4,420	520	920
	12%		15,500	2.08	8,840	1,060	1,340
Pine							
Eastern white	Green	0.36	5,100	1.18	2,590	240	640
	12%		9,500	1.36	5,230	490	880
Jack	Green	0.42	6,300	1.17	2,950	340	820
	12%		11,300	1.48	5,870	830	1,190
Lodgepole	Green	0.40	5,600	1.27	2,860	280	720
	12%		11,000	1.58	6,260	530	1,240
Ponderosa	Green	0.44	5,700	1.13	2,840	350	720
	12%		10,600	1.38	6,130	760	1,020
Red	Green	0.39	5,000	1.07	2,370	280	710
	12%		10,100	1.38	5,500	720	1,090
Western white	Green	0.36	4,800	1.19	2,520	240	650
	12%		9,300	1.46	5,240	470	920
Spruce							
Black	Green	0.41	5,900	1.32	2,760	300	800
	12%		11,400	1.52	6,040	620	1,250
Engelmann	Green	0.38	5,700	1.25	2,810	270	700
	12%		10,100	1.55	6,150	540	1,100
Red	Green	0.38	5,900	1.32	2,810	270	810
	12%		10,300	1.60	5,590	550	1,330
Sitka	Green	0.35	5,400	1.37	2,560	290	630
	12%		10,100	1.63	5,480	590	980
White	Green	0.35	5,100	1.15	2,470	240	670
	12%		9,100	1.45	5,360	500	980
Tamarack	Green	0.48	6,800	1.24	3,130	410	920
	12%		11,000	1.36	6,510	900	1,300

[a]Results of tests on small, clear, straight-grained specimens. Property values based on ASTM Standard D2555–88. Information on additional properties can be obtained from Department of Forestry, Canada, Publication No. 1104. For each species, values in the first line are from tests of green material; those in the second line are adjusted from the green condition to 12% moisture content using dry to green clear wood property ratios as reported in ASTM D2555–88. Specific gravity is based on weight when ovendry and volume when green.

Table 4–5a. Mechanical properties of some woods imported into the United States other than Canadian imports (metric)[a]

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity (MPa)	Static bending: Work to maximum load (kJ/m^3)	Compression parallel to grain (kPa)	Shear parallel to grain (kPa)	Side hardness (N)	Sample origin[b]
Afrormosia (*Pericopsis elata*)	Green	0.61	102,000	12,200	135	51,600	11,500	7,100	AF
	12%		126,900	13,400	127	68,500	14,400	6,900	
Albarco (*Cariniana* spp.)	Green	0.48	—	—	—	—	—	—	AM
	12%		100,000	10,300	95	47,000	15,900	4,500	
Andiroba (*Carapa guianensis*)	Green	0.54	71,000	11,700	68	33,000	8,400	3,900	AM
	12%	—	106,900	13,800	97	56,000	10,400	5,000	
Angelin (*Andira inermis*)	Green	0.65	—	—	—	—	—	—	AF
	12%		124,100	17,200	—	63,400	12,700	7,800	
Angelique (*Dicorynia guianensis*)	Green	0.6	78,600	12,700	83	38,500	9,200	4,900	AM
	12%	—	120,000	15,100	105	60,500	11,400	5,700	
Avodire (*Turraeanthus africanus*)	Green	0.48	—	—	—	—	—	—	AF
	12%		87,600	10,300	65	49,300	14,000	4,800	
Azobe (*Lophira alata*)	Green	0.87	116,500	14,900	83	65,600	14,100	12,900	AF
	12%		168,900	17,000	—	86,900	20,400	14,900	
Balsa (*Ochroma pyramidale*)	Green	0.16	—	—	—	—	—	—	AM
	12%		21,600	3,400	14	14,900	2,100	—	
Banak (*Virola* spp.)	Green	0.42	38,600	11,300	28	16,500	5,000	1,400	AM
	12%	—	75,200	14,100	69	35,400	6,800	2,300	
Benge (*Guibourtia arnoldiana*)	Green	0.65	—	—	—	—	—	—	AF
	12%		147,500	14,100	—	78,600	14,400	7,800	
Bubinga (*Guibourtia* spp.)	Green	0.71	—	—	—	—	—	—	AF
	12%		155,800	17,100	—	72,400	21,400	12,000	
Bulletwood (*Manilkara bidentata*)	Green	0.85	119,300	18,600	94	59,900	13,100	9,900	AM
	12%		188,200	23,800	197	80,300	17,200	14,200	
Cativo (*Prioria copaifera*)	Green	0.4	40,700	6,500	37	17,000	5,900	2,000	AM
	12%	—	59,300	7,700	50	29,600	7,300	2,800	
Ceiba (*Ceiba pentandra*)	Green	0.25	15,200	2,800	8	7,300	2,400	1,000	AM
	12%		29,600	3,700	19	16,400	3,800	1,100	
Courbaril (*Hymenaea courbaril*)	Green	0.71	88,900	12,700	101	40,000	12,200	8,800	AM
	12%	—	133,800	14,900	121	65,600	17,000	10,500	
Cuangare (*Dialyanthera* spp.)	Green	0.31	27,600	7,000	—	14,300	4,100	1,000	AM
	12%		50,300	10,500	—	32,800	5,700	1,700	
Cypress, Mexican (*Cupressus lustianica*)	Green	0.93	42,700	6,300	—	19,900	6,600	1,500	AF
	12%		71,000	7,000	—	37,100	10,900	2,000	
Degame (*Calycophyllum candidissimum*)	Green	0.67	98,600	13,300	128	42,700	11,400	7,300	AM
	12%		153,800	15,700	186	66,700	14,600	8,600	
Determa (*Ocotea rubra*)	Green	0.52	53,800	10,100	33	25,900	5,900	2,300	AM
	12%		72,400	12,500	44	40,000	6,800	2,900	
Ekop (*Tetraberlinia tubmaniana*)	Green	0.6	—	—	—	—	—	—	AF
	12%		115,100	15,200	—	62,100	—	—	
Goncalo alves (*Astronium graveolens*)	Green	0.84	83,400	13,400	46	45,400	12,100	8,500	AM
	12%	—	114,500	15,400	72	71,200	13,500	9,600	
Greenheart (*Chlorocardium rodiei*)	Green	0.8	133,100	17,000	72	64,700	13,300	8,400	AM
	12%		171,700	22,400	175	86,300	18,100	10,500	
Hura (*Hura crepitans*)	Green	0.38	43,400	7,200	41	19,200	5,700	2,000	AM
	12%		60,000	8,100	46	33,100	7,400	2,400	

Table 4–5a. Mechanical properties of some woods imported into the United States other than Canadian imports (metric)[a]—con.

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity (MPa)	Static bending: Work to maximum load (kJ/m^3)	Compression parallel to grain (kPa)	Shear parallel to grain (kPa)	Side hardness (N)	Sample origin[b]
Ilomba (*Pycnanthus*	Geen	0.4	37,900	7,900	—	20,000	5,800	2,100	AF
angolensis)	12%		68,300	11,000	—	38,300	8,900	2,700	
Ipe (*Tabebuia* spp.,	Green	0.92	155,800	20,100	190	71,400	14,600	13,600	AM
lapacho group)	12%		175,100	21,600	152	89,700	14,200	16,400	
Iroko (*Chlorophora* spp.)	Green	0.54	70,300	8,900	72	33,900	9,000	4,800	AF
	12%		85,500	10,100	62	52,300	12,400	5,600	
Jarrah (*Eucalyptus marginata*)	Green	0.67	68,300	10,200	—	35,800	9,100	5,700	AS
	12%	—	111,700	13,000	—	61,200	14,700	8,500	
Jelutong (*Dyera costulata*)	Green	0.36	38,600	8,000	39	21,000	5,200	1,500	AS
	15%		50,300	8,100	44	27,000	5,800	1,700	
Kaneelhart (*Licaria* spp.)	Green	0.96	153,800	26,300	94	92,300	11,600	9,800	AM
	12%		206,200	28,000	121	120,000	13,600	12,900	
Kapur (*Dryobalanops* spp.)	Green	0.64	88,300	11,000	108	42,900	8,100	4,400	AS
	12%		126,200	13,000	130	69,600	13,700	5,500	
Karri (*Eucalyptus diversicolor*)	Green	0.82	77,200	13,400	80	37,600	10,400	6,000	AS
	12%		139,000	17,900	175	74,500	16,700	9,100	
Kempas (*Koompassia*	Green	0.71	100,000	16,600	84	54,700	10,100	6,600	AS
malaccensis)	12%		122,000	18,500	106	65,600	12,300	7,600	
Keruing (*Dipterocarpus* spp.)	Green	0.69	82,000	11,800	96	39,200	8,100	4,700	AS
	12%		137,200	14,300	162	72,400	14,300	5,600	
Lignumvitae (*Guaiacum* spp.)	Green	1.05	—	—	—	—	—	—	AM
	12%	—	—	—	—	78,600	—	20,000	
Limba (*Terminalia superba*)	Green	0.38	41,400	5,300	53	19,200	600	1,800	AF
	12%		60,700	7,000	61	32,600	9,700	2,200	
Macawood (*Platymiscium* spp.)	Green	0.94	153,800	20,800	—	72,700	12,700	14,800	AM
	12%		190,300	22,100	—	111,000	17,500	14000	
Mahogany, African	Green	0.42	51,000	7,900	49	25,700	6,400	2,800	AF
(*Khaya* spp.)	12%		73,800	9,700	57	44,500	10,300	3,700	
Mahogany, true	Green	0.45	62,100	9,200	63	29,900	8,500	3,300	AM
(*Swietenia macrophylla*)	12%	—	79,300	10,300	52	46,700	8,500	3,600	
Manbarklak (*Eschweilera* spp.)	Green	0.87	117,900	18,600	120	50,600	11,200	10,100	AM
	12%		182,700	21,600	230	77,300	14,300	15,500	
Manni (*Symphonia globulifera*)	Green	0.58	77,200	13,500	77	35,600	7,900	4,200	AM
	12%		116,500	17,000	114	60,800	9,800	5,000	
Marishballi (*Lincania* spp.)	Green	0.88	117,900	20,200	92	52,300	11,200	10,000	AM
	12%		191,000	23,000	98	92,300	12,100	15,900	
Merbau (*Intsia* spp.)	Green	0.64	88,900	13,900	88	46,700	10,800	6,100	AS
	15%	—	115,800	15,400	102	58,200	12,500	6,700	
Mersawa (*Anisoptera* spp.)	Green	0.52	55,200	12,200	—	27,300	5,100	3,900	AS
	12%		95,100	15,700	—	50,800	6,100	5,700	
Mora (*Mora* spp.)	Green	0.78	86,900	16,100	93	44,100	9,700	6,400	AM
	12%		152,400	20,400	128	81,600	13,100	10,200	
Oak (*Quercus* spp.)	Green	0.76	—	—	—	—	—	—	AM
	12%		158,600	20,800	114	—	—	11,100	
Obeche (*Triplochiton*	Green	0.3	35,200	5,000	43	17,700	4,600	1,900	AF
scleroxylon)	12%		51,000	5,900	48	27,100	6,800	1,900	

Table 4–5a. Mechanical properties of some woods imported into the United States other than Canadian imports (metric)[a]—con.

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity (MPa)	Static bending: Work to maximum load (kJ/m³)	Compression parallel to grain (kPa)	Shear parallel to grain (kPa)	Side hardness (N)	Sample origin[b]
Okoume (*Aucoumea klaineana*)	Green	0.33	—	—	—	—	—	—	AF
	12%		51,000	7,900	—	27,400	6,700	1,700	
Opepe (*Nauclea diderrichii*)	Green	0.63	93,800	11,900	84	51,600	13,100	6,800	AF
	12%		120,000	13,400	99	71,700	17,100	7,300	
Ovangkol (*Guibourtia ehie*)	Green	0.67	—	—	—	—	—	—	AF
	12%		116,500	17,700	—	57,200	—	—	
Para-angelim (*Hymenolobium excelsum*)	Green	0.63	100,700	13,400	88	51,400	11,000	7,700	AM
	12%		121,300	14,100	110	62,000	13,900	7,700	
Parana-pine (*Araucaria augustifolia*)	Green	0.46	49,600	9,300	67	27,600	6,700	2,500	AM
	12%	—	93,100	11,100	84	52,800	11,900	3,500	
Pau marfim (*Balfourodendron riedelianum*)	Green	0.73	99,300	11,400	—	41,900	—	—	AM
	15%		130,300	—	—	56,500	—	—	
Peroba de campos (*Paratecoma peroba*)	Green	0.62	—	—	—	—	—	—	AM
	12%		106,200	12,200	70	61,200	14,700	7,100	
Peroba rosa (*Aspidosperma* spp., peroba group)	Green	0.66	75,200	8,900	72	38,200	13,000	7,000	AM
	12%		83,400	10,500	63	54,600	17,200	7,700	
Pilon (*Hyeronima* spp.)	Green	0.65	73,800	13,000	57	34,200	8,300	5,400	AM
	12%		125,500	15,700	83	66,300	11,900	7,600	
Pine, Caribbean (*Pinus caribaea*)	Green	0.68	77,200	13,000	74	33,800	8,100	4,400	AM
	12%	—	115,100	15,400	119	58,900	14,400	5,500	
Pine, ocote (*Pinus oocarpa*)	Green	0.55	55,200	12,000	48	25,400	7,200	2,600	AM
	12%	—	102,700	15,500	75	53,000	11,900	4,000	
Pine, radiata (*Pinus radiata*)	Green	0.42	42,100	8,100	—	19,200	5,200	2,100	AS
	12%	—	80,700	10,200	—	41,900	11,000	3,300	
Piquia (*Caryocar* spp.)	Green	0.72	85,500	12,500	58	43,400	11,300	7,700	AM
	12%		117,200	14,900	109	58,000	13,700	7,700	
Primavera (*Tabebuia donnell–smithii*)	Green	0.4	49,600	6,800	50	24,200	7,100	3,100	AM
	12%		65,500	7,200	44	38,600	9,600	2,900	
Purpleheart (*Peltogyne* spp.)	Green	0.67	9,400	13,800	102	48,400	11,300	8,100	AM
	12%		132,400	15,700	121	71,200	15,300	8,300	
Ramin (*Gonystylus bancanus*)	Green	0.52	67,600	10,800	62	37,200	6,800	2,800	AS
	12%	—	127,600	15,000	117	69,500	10,500	5,800	
Robe (*Tabebuia* spp., roble group)	Green	0.52	74,500	10,000	81	33,900	8,600	4,000	AM
	12%		95,100	11,000	86	50,600	10,000	4,300	
Rosewood, Brazilian (*Dalbergia nigra*)	Green	0.8	97,200	12,700	91	38,000	16,300	10,900	AM
	12%	—	131,000	13,000	—	66,200	14,500	12,100	
Rosewood, Indian (*Dalbergia latifolia*)	Green	0.75	63,400	8,200	80	31,200	9,700	6,900	AS
	12%		116,500	12,300	90	63,600	14,400	14,100	
Sande (*Brosimum* spp., utile group)	Green	0.49	58,600	13,400	—	31,000	7,200	2,700	AM
	12%		98,600	16,500	—	56,700	8,900	4,000	
Santa Maria (*Calophyllum brasiliense*)	Green	0.52	72,400	11,000	88	31,400	8,700	4,000	AM
	12%	—	100,700	12,600	111	47,600	14,300	5,100	
Sapele (*Entandrophragma cylindricum*)	Green	0.55	70,300	10,300	72	34,500	8,600	4,500	AF
	12%	—	105,500	12,500	108	56,300	15,600	6,700	
Sepetir (*Pseudosindora palustris*)	Green	0.56	77,200	10,800	92	37,600	9,000	4,200	AS
	12%		118,600	13,600	92	61,200	14,000	6,300	

Table 4–5a. Mechanical properties of some woods imported into the United States other than Canadian imports (metric)[a]—con.

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (kPa)	Static bending: Modulus of elasticity (MPa)	Static bending: Work to maximum load (kJ/m³)	Compression parallel to grain (kPa)	Shear parallel to grain (kPa)	Side hardness (N)	Sample origin[b]
Shorea (*Shorea* spp.,	Green	0.68	80,700	14,500	—	37,100	9,900	6,000	AS
baulau group)	12%		129,600	18,000	—	70,200	15,100	7,900	
Shorea, lauan–meranti group									
Dark red meranti	Green	0.46	64,800	10,300	59	32,500	7,700	3,100	AS
	12%		87,600	12,200	95	50,700	10,000	3,500	
Light red meranti	Green	0.34	45,500	7,200	43	23,000	4,900	2,000	AS
	12%		65,500	8,500	59	40,800	6,700	2,000	
White meranti	Green	0.55	67,600	9,000	57	37,900	9,100	4,400	AS
	15%		85,500	10,300	79	43,800	10,600	5,100	
Yellow meranti	Green	0.46	55,200	9,000	56	26,800	7,100	3,300	AS
	12%		78,600	10,700	70	40,700	10,500	3,400	
Spanish-cedar (*Cedrela* spp.)	Green	0.41	51,700	9,000	49	23,200	6,800	2,400	AM
	12%	—	79,300	9,900	65	42,800	7,600	2,700	
Sucupira (*Bowdichia* spp.)	Green	0.74	118,600	15,700	—	67,100	—	—	AM
	15%		133,800	—	—	76,500	—	—	
Sucupira (*Diplotropis purpurea*)	Green	0.78	120,000	18,500	90	55,300	12,400	8,800	AM
	12%		142,000	19,800	102	83,700	13,500	9,500	
Teak (*Tectona grandis*)	Green	0.55	80,000	9,400	92	41,100	8,900	4,100	AS
	12%		100,700	10,700	83	58,000	13,000	4,400	
Tornillo (*Cedrelinga*	Green	0.45	57,900	—	—	28,300	8,100	3,900	AM
cateniformis)	12%	—	—	—	—	—	—	—	
Wallaba (*Eperua* spp.)	Green	0.78	98,600	16,100	—	55,400	—	6,900	AM
	12%	—	131,700	15,700	—	74,200	—	9,100	

[a]Results of tests on small, clear, straight-grained specimens. Property values were taken from world literature (not obtained from experiments conducted at the Forest Products Laboratory). Other species may be reported in the world literature, as well as additional data on many of these species. Some property values have been adjusted to 12% moisture content.
[b]AF is Africa; AM, America; AS, Asia.

Table 4–5b. Mechanical properties of some woods imported into the United States other than Canadian imports (inch–pound)[a]

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Compression parallel to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Side hardness (lbf)	Sample origin[b]
Afrormosia (*Pericopsis elata*)	Green	0.61	14,800	1.77	19.5	7,490	1,670	1,600	AF
	12%		18,400	1.94	18.4	9,940	2,090	1,560	
Albarco (*Cariniana* spp.)	Green	0.48	—	—	—	—	—	—	AM
	12%		14,500	1.5	13.8	6,820	2,310	1,020	
Andiroba (*Carapa guianensis*)	Green	0.54	10,300	1.69	9.8	4,780	1,220	880	AM
	12%	—	15,500	2	14	8,120	1,510	1,130	
Angelin (*Andira inermis*)	Green	0.65	—	—	—	—	—	—	AF
	12%		18,000	2.49	—	9,200	1,840	1,750	
Angelique (*Dicorynia guianensis*)	Green	0.6	11,400	1.84	12	5,590	1,340	1,100	AM
	12%	—	17,400	2.19	15.2	8,770	1,660	1,290	
Avodire (*Turraeanthus africanus*)	Green	0.48	—	—	—	—	—	—	AF
	12%		12,700	1.49	9.4	7,150	2,030	1,080	
Azobe (*Lophira alata*)	Green	0.87	16,900	2.16	12	9,520	2,040	2,890	AF
	12%		24,500	2.47	—	12,600	2,960	3,350	
Balsa (*Ochroma pyramidale*)	Green	0.16	—	—	—	—	—	—	AM
	12%		3,140	0.49	2.1	2,160	300	—	
Banak (*Virola* spp.)	Green	0.42	5,600	1.64	4.1	2,390	720	320	AM
	12%	—	10,900	2.04	10	5,140	980	510	
Benge (*Guibourtia arnoldiana*)	Green	0.65	—	—	—	—	—	—	AF
	12%		21,400	2.04	—	11,400	2,090	1,750	
Bubinga (*Guibourtia* spp.)	Green	0.71	—	—	—	—	—	—	AF
	12%		22,600	2.48	—	10,500	3,110	2,690	
Bulletwood (*Manilkara bidentata*)	Green	0.85	17,300	2.7	13.6	8,690	1,900	2,230	AM
	12%		27,300	3.45	28.5	11,640	2,500	3,190	
Cativo (*Prioria copaifera*)	Green	0.4	5,900	0.94	5.4	2,460	860	440	AM
	12%	—	8,600	1.11	7.2	4,290	1,060	630	
Ceiba (*Ceiba pentandra*)	Green	0.25	2,200	0.41	1.2	1,060	350	220	AM
	12%		4,300	0.54	2.8	2,380	550	240	
Courbaril (*Hymenaea courbaril*)	Green	0.71	12,900	1.84	14.6	5,800	1,770	1,970	AM
	12%	—	19,400	2.16	17.6	9,510	2,470	2,350	
Cuangare (*Dialyanthera* spp.)	Green	0.31	4,000	1.01	—	2,080	590	230	AM
	12%		7,300	1.52	—	4,760	830	380	
Cypress, Mexican (*Cupressus lustianica*)	Green	0.93	6,200	0.92	—	2,880	950	340	AF
	12%		10,300	1.02	—	5,380	1,580	460	
Degame (*Calycophyllum candidissimum*)	Green	0.67	14,300	1.93	18.6	6,200	1,660	1,630	AM
	12%		22,300	2.27	27	9,670	2,120	1,940	
Determa (*Ocotea rubra*)	Green	0.52	7,800	1.46	4.8	3,760	860	520	AM
	12%		10,500	1.82	6.4	5,800	980	660	
Ekop (*Tetraberlinia tubmaniana*)	Green	0.6	—	—	—	—	—	—	AF
	12%		16,700	2.21	—	9,010	—	—	
Goncalo alves (*Astronium graveolens*)	Green	0.84	12,100	1.94	6.7	6,580	1,760	1,910	AM
	12%	—	16,600	2.23	10.4	10,320	1,960	2,160	
Greenheart (*Chlorocardium rodiei*)	Green	0.8	19,300	2.47	10.5	9,380	1,930	1,880	AM
	12%		24,900	3.25	25.3	12,510	2,620	2,350	
Hura (*Hura crepitans*)	Green	0.38	6,300	1.04	5.9	2,790	830	440	AM
	12%		8,700	1.17	6.7	4,800	1,080	550	

Table 4–5b. Mechanical properties of some woods imported into the United States other than Canadian imports (inch–pound)[a]—con.

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Compression parallel to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Side hardness (lbf)	Sample origin[b]
Ilomba (*Pycnanthus angolensis*)	Geen	0.4	5,500	1.14	—	2,900	840	470	AF
	12%		9,900	1.59	—	5,550	1,290	610	
Ipe (*Tabebuia* spp., lapacho group)	Green	0.92	22,600	2.92	27.6	10,350	2,120	3,060	AM
	12%		25,400	3.14	22	13,010	2,060	3,680	
Iroko (*Chlorophora* spp.)	Green	0.54	10,200	1.29	10.5	4,910	1,310	1,080	AF
	12%		12,400	1.46	9	7,590	1,800	1,260	
Jarrah (*Eucalyptus marginata*)	Green	0.67	9,900	1.48	—	5,190	1,320	1,290	AS
	12%	—	16,200	1.88	—	8,870	2,130	1,910	
Jelutong (*Dyera costulata*)	Green	0.36	5,600	1.16	5.6	3,050	760	330	AS
	15%		7,300	1.18	6.4	3,920	840	390	
Kaneelhart (*Licaria* spp.)	Green	0.96	22,300	3.82	13.6	13,390	1,680	2,210	AM
	12%		29,900	4.06	17.5	17,400	1,970	2,900	
Kapur (*Dryobalanops* spp.)	Green	0.64	12,800	1.6	15.7	6,220	1,170	980	AS
	12%		18,300	1.88	18.8	10,090	1,990	1,230	
Karri (*Eucalyptus diversicolor*)	Green	0.82	11,200	1.94	11.6	5,450	1,510	1,360	AS
	12%		20,160	2.6	25.4	10,800	2,420	2,040	
Kempas (*Koompassia malaccensis*)	Green	0.71	14,500	2.41	12.2	7,930	1,460	1,480	AS
	12%		17,700	2.69	15.3	9,520	1,790	1,710	
Keruing (*Dipterocarpus* spp.)	Green	0.69	11,900	1.71	13.9	5,680	1,170	1,060	AS
	12%		19,900	2.07	23.5	10,500	2,070	1,270	
Lignumvitae (*Guaiacum* spp.)	Green	1.05	—	—	—	—	—	—	AM
	12%	—	—	—	—	11,400	—	4,500	
Limba (*Terminalia superba*)	Green	0.38	6,000	0.77	7.7	2,780	88	400	AF
	12%		8,800	1.01	8.9	4,730	1,410	490	
Macawood (*Platymiscium* spp.)	Green	0.94	22,300	3.02	—	10,540	1,840	3,320	AM
	12%		27,600	3.2	—	16,100	2,540	3,150	
Mahogany, African (*Khaya* spp.)	Green	0.42	7,400	1.15	7.1	3,730	931	640	AF
	12%		10,700	1.4	8.3	6,460	1,500	830	
Mahogany, true (*Swietenia macrophylla*)	Green	0.45	9,000	1.34	9.1	4,340	1,240	740	AM
	12%	—	11,500	1.5	7.5	6,780	1,230	800	
Manbarklak (*Eschweilera* spp.)	Green	0.87	17,100	2.7	17.4	7,340	1,630	2,280	AM
	12%		26,500	3.14	33.3	11,210	2,070	3,480	
Manni (*Symphonia globulifera*)	Green	0.58	11,200	1.96	11.2	5,160	1,140	940	AM
	12%		16,900	2.46	16.5	8,820	1,420	1,120	
Marishballi (*Lincania* spp.)	Green	0.88	17,100	2.93	13.4	7,580	1,620	2,250	AM
	12%		27,700	3.34	14.2	13,390	1,750	3,570	
Merbau (*Intsia* spp.)	Green	0.64	12,900	2.02	12.8	6,770	1,560	1,380	AS
	15%	—	16,800	2.23	14.8	8,440	1,810	1,500	
Mersawa (*Anisoptera* spp.)	Green	0.52	8,000	1.77	—	3,960	740	880	AS
	12%		13,800	2.28	—	7,370	890	1,290	
Mora (*Mora* spp.)	Green	0.78	12,600	2.33	13.5	6,400	1,400	1,450	AM
	12%		22,100	2.96	18.5	11,840	1,900	2,300	
Oak (*Quercus* spp.)	Green	0.76	—	—	—	—	—	—	AM
	12%		23,000	3.02	16.5	—	—	2,500	
Obeche (*Triplochiton scleroxylon*)	Green	0.3	5,100	0.72	6.2	2,570	660	420	AF
	12%		7,400	0.86	6.9	3,930	990	430	

Table 4–5b. Mechanical properties of some woods imported into the United States other than Canadian imports (inch–pound)[a]—con.

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Compression parallel to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Side hardness (lbf)	Sample origin[b]
Okoume (*Aucoumea*	Green	0.33	—	—	—	—	—	—	AF
klaineana)	12%		7,400	1.14	—	3,970	970	380	
Opepe (*Nauclea diderrichii*)	Green	0.63	13,600	1.73	12.2	7,480	1,900	1,520	AF
	12%		17,400	1.94	14.4	10,400	2,480	1,630	
Ovangkol (*Guibourtia ehie*)	Green	0.67	—	—	—	—	—	—	AF
	12%		16,900	2.56	—	8,300	—	—	
Para-angelim (*Hymenolobium*	Green	0.63	14,600	1.95	12.8	7,460	1,600	1,720	AM
excelsum)	12%		17,600	2.05	15.9	8,990	2,010	1,720	
Parana-pine (*Araucaria*	Green	0.46	7,200	1.35	9.7	4,010	970	560	AM
augustifolia)	12%	—	13,500	1.61	12.2	7,660	1,730	780	
Pau marfim (*Balfourodendron*	Green	0.73	14,400	1.66	—	6,070	—	—	AM
riedelianum)	15%		18,900	—	—	8,190	—	—	
Peroba de campos	Green	0.62	—	—	—	—	—	—	AM
(*Paratecoma peroba*)	12%		15,400	1.77	10.1	8,880	2,130	1,600	
Peroba rosa (*Aspidosperma*	Green	0.66	10,900	1.29	10.5	5,540	1,880	1,580	AM
spp., peroba group)	12%		12,100	1.53	9.2	7,920	2,490	1,730	
Pilon (*Hyeronima* spp.)	Green	0.65	10,700	1.88	8.3	4,960	1,200	1,220	AM
	12%		18,200	2.27	12.1	9,620	1,720	1,700	
Pine, Caribbean (*Pinus caribaea*)	Green	0.68	11,200	1.88	10.7	4,900	1,170	980	AM
	12%	—	16,700	2.24	17.3	8,540	2,090	1,240	
Pine, ocote (*Pinus oocarpa*)	Green	0.55	8,000	1.74	6.9	3,690	1,040	580	AM
	12%	—	14,900	2.25	10.9	7,680	1,720	910	
Pine, radiata (*Pinus radiata*)	Green	0.42	6,100	1.18	—	2,790	750	480	AS
	12%	—	11,700	1.48	—	6,080	1,600	750	
Piquia (*Caryocar* spp.)	Green	0.72	12,400	1.82	8.4	6,290	1,640	1,720	AM
	12%		17,000	2.16	15.8	8,410	1,990	1,720	
Primavera (*Tabebuia*	Green	0.4	7,200	0.99	7.2	3,510	1,030	700	AM
donnell–smithii)	12%		9,500	1.04	6.4	5,600	1,390	660	
Purpleheart (*Peltogyne* spp.)	Green	0.67	1,370	2	14.8	7,020	1,640	1,810	AM
	12%		19,200	2.27	17.6	10,320	2,220	1,860	
Ramin (*Gonystylus bancanus*)	Green	0.52	9,800	1.57	9	5,390	990	640	AS
	12%	—	18,500	2.17	17	10,080	1,520	1,300	
Robe (*Tabebuia* spp.,	Green	0.52	10,800	1.45	11.7	4,910	1,250	910	AM
roble group)	12%		13,800	1.6	12.5	7,340	1,450	960	
Rosewood, Brazilian	Green	0.8	14,100	1.84	13.2	5,510	2,360	2,440	AM
(*Dalbergia nigra*)	12%	—	19,000	1.88	—	9,600	2,110	2,720	
Rosewood, Indian (*Dalbergia*	Green	0.75	9,200	1.19	11.6	4,530	1,400	1,560	AS
latifolia)	12%		16,900	1.78	13.1	9,220	2,090	3,170	
Sande (*Brosimum* spp.,	Green	0.49	8,500	1.94	—	4,490	1,040	600	AM
utile group)	12%		14,300	2.39	—	8,220	1,290	900	
Santa Maria (*Calophyllum*	Green	0.52	10,500	1.59	12.7	4,560	1,260	890	AM
brasiliense)	12%	—	14,600	1.83	16.1	6,910	2,080	1,150	
Sapele (*Entandrophragma*	Green	0.55	10,200	1.49	10.5	5,010	1,250	1,020	AF
cylindricum)	12%	—	15,300	1.82	15.7	8,160	2,260	1,510	
Sepetir (*Pseudosindora palustris*)	Green	0.56	11,200	1.57	13.3	5,460	1,310	950	AS
	12%		17,200	1.97	13.3	8,880	2,030	1,410	

Table 4–5b. Mechanical properties of some woods imported into the United States other than Canadian imports (inch–pound)[a]—con.

Common and botanical names of species	Moisture content	Specific gravity	Static bending: Modulus of rupture (lbf/in²)	Static bending: Modulus of elasticity (×10⁶ lbf/in²)	Static bending: Work to maximum load (in-lbf/in³)	Compression parallel to grain (lbf/in²)	Shear parallel to grain (lbf/in²)	Side hardness (lbf)	Sample origin[b]
Shorea (*Shorea* spp.,	Green	0.68	11,700	2.1	—	5,380	1,440	1,350	AS
bullau group)	12%		18,800	2.61	—	10,180	2,190	1,780	
Shorea, lauan–meranti group									
Dark red meranti	Green	0.46	9,400	1.5	8.6	4,720	1,110	700	AS
	12%		12,700	1.77	13.8	7,360	1,450	780	
Light red meranti	Green	0.34	6,600	1.04	6.2	3,330	710	440	AS
	12%		9,500	1.23	8.6	5,920	970	460	
White meranti	Green	0.55	9,800	1.3	8.3	5,490	1,320	1,000	AS
	15%		12,400	1.49	11.4	6,350	1,540	1,140	
Yellow meranti	Green	0.46	8,000	1.3	8.1	3,880	1,030	750	AS
	12%		11,400	1.55	10.1	5,900	1,520	770	
Spanish-cedar (*Cedrela* spp.)	Green	0.41	7,500	1.31	7.1	3,370	990	550	AM
	12%	—	11,500	1.44	9.4	6,210	1,100	600	
Sucupira (*Bowdichia* spp.)	Green	0.74	17,200	2.27	—	9,730	—	—	AM
	15%		19,400	—	—	11,100	—	—	
Sucupira (*Diplotropis purpurea*)	Green	0.78	17,400	2.68	13	8,020	1,800	1,980	AM
	12%		20,600	2.87	14.8	12,140	1,960	2,140	
Teak (*Tectona grandis*)	Green	0.55	11,600	1.37	13.4	5,960	1,290	930	AS
	12%		14,600	1.55	12	8,410	1,890	1,000	
Tornillo (*Cedrelinga*	Green	0.45	8,400	—	—	4,100	1,170	870	AM
cateniformis)	12%	—	—	—	—	—	—	—	
Wallaba (*Eperua* spp.)	Green	0.78	14,300	2.33	—	8,040	—	1,540	AM
	12%	—	19,100	2.28	—	10,760	—	2,040	

[a]Results of tests on small, clear, straight-grained specimens. Property values were taken from world literature (not obtained from experiments conducted at the Forest Products Laboratory). Other species may be reported in the world literature, as well as additional data on many of these species. Some property values have been adjusted to 12% moisture content.
[b]AF is Africa; AM, America; AS, Asia.

Table 4–6. Average coefficients of variation for some mechanical properties of clear wood

Property	Coefficient of variation[a] (%)
Static bending	
Modulus of rupture	16
Modulus of elasticity	22
Work to maximum load	34
Impact bending	25
Compression parallel to grain	18
Compression perpendicular to grain	28
Shear parallel to grain, maximum shearing strength	14
Tension parallel to grain	25
Side hardness	20
Toughness	34
Specific gravity	10

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

Table 4–7. Average parallel-to-grain tensile strength of some wood species[a]

Species	Tensile strength (kPa (lb/in^2))	
Hardwoods		
Beech, American	86,200	(12,500)
Elm, cedar	120,700	(17,500)
Maple, sugar	108,200	(15,700)
Oak		
Overcup	77,900	(11,300)
Pin	112,400	(16,300)
Poplar, balsam	51,000	(7,400)
Sweetgum	93,800	(13,600)
Willow, black	73,100	(10,600)
Yellow-poplar	109,600	(15,900)
Softwoods		
Baldcypress	58,600	(8,500)
Cedar		
Port-Orford	78,600	(11,400)
Western redcedar	45,500	(6,600)
Douglas-fir, interior north	107,600	(15,600)
Fir		
California red	77,900	(11,300)
Pacific silver	95,100	(13,800)
Hemlock, western	89,600	(13,000)
Larch, western	111,700	(16,200)
Pine		
Eastern white	73,100	(10,600)
Loblolly	80,000	(11,600)
Ponderosa	57,900	(8,400)
Virginia	94,500	(13,700)
Redwood		
Virgin	64,800	(9,400)
Young growth	62,700	(9,100)
Spruce		
Engelmann	84,800	(12,300)
Sitka	59,300	(8,600)

[a]Results of tests on small, clear, straight-grained specimens tested green. For hardwood species, strength of specimens tested at 12% moisture content averages about 32% higher; for softwoods, about 13% higher.

Table 4–8. Average toughness values for a few hardwood species[a]

Species	Moisture content	Specific gravity	Toughness: Radial (J (in-lbf))		Toughness: Tangential (J (in-lbf))	
Birch, yellow	12%	0.65	8,100	(500)	10,100	(620)
Hickory (mocker-nut, pignut, sand)	Green	0.64	11,400	(700)	11,700	(720)
	12%	0.71	10,100	(620)	10,700	(660)
Maple, sugar	14%	0.64	6,000	(370)	5,900	(360)
Oak, red						
Pin	12%	0.64	7,000	(430)	7,000	(430)
Scarlet	11%	0.66	8,300	(510)	7,200	(440)
Oak, white						
Overcup	Green	0.56	11,900	(730)	11,100	(680)
	13%	0.62	5,500	(340)	5,000	(310)
Sweetgum	Green	0.48	5,500	(340)	5,400	(330)
	13%	0.51	4,200	(260)	4,200	(260)
Willow, black	Green	0.38	5,000	(310)	5,900	(360)
	11%	0.4	3,400	(210)	3,700	(230)
Yellow-poplar	Green	0.43	5,200	(320)	4,900	(300)
	12%	0.45	3,600	(220)	3,400	(210)

Less Common Properties

Strength properties less commonly measured in clear wood include torsion, toughness, rolling shear, and fracture toughness. Other properties involving time under load include creep, creep rupture or duration of load, and fatigue strength.

Torsion strength—Resistance to twisting about a longitudinal axis. For solid wood members, torsional shear strength may be taken as shear strength parallel to grain. Two-thirds of the value for torsional shear strength may be used as an estimate of the torsional shear stress at the proportional limit.

Toughness—Energy required to cause rapid complete failure in a centrally loaded bending specimen. Tables 4–8 and 4–9 give average toughness values for samples of a few hardwood and softwood species. Average coefficients of variation for toughness as determined from approximately 50 species are shown in Table 4–6.

Creep and duration of load—Time-dependent deformation of wood under load. If the load is sufficiently high and the duration of load is long, failure (creep–rupture) will eventually occur. The time required to reach rupture is commonly called duration of load. Duration of load is an important factor in setting design values for wood. Creep and duration of load are described in later sections of this chapter.

Fatigue—Resistance to failure under specific combinations of cyclic loading conditions: frequency and number of cycles, maximum stress, ratio of maximum to minimum stress, and other less-important factors. The main factors affecting fatigue in wood are discussed later in this chapter. The discussion also includes interpretation of fatigue data and information on fatigue as a function of the service environment.

Rolling shear strength—Shear strength of wood where shearing force is in a longitudinal plane and is acting perpendicular to the grain. Few test values of rolling shear in solid wood have been reported. In limited tests, rolling shear strength averaged 18% to 28% of parallel-to-grain shear values. Rolling shear strength is about the same in the longitudinal–radial and longitudinal–tangential planes.

Fracture toughness—Ability of wood to withstand flaws that initiate failure. Measurement of fracture toughness helps identify the length of critical flaws that initiate failure in materials.

To date there is no standard test method for determining fracture toughness in wood. Three types of stress fields, and associated stress intensity factors, can be defined at a crack tip: opening mode (I), forward shear mode (II), and transverse shear mode (III) (Fig. 4–2a). A crack may lie in one of these

Table 4–9. Average toughness values for a few softwood species[a]

Species	Moisture content	Specific gravity	Toughness: Radial (J (in-lbf))		Toughness: Tangential (J (in-lbf))	
Cedar						
Western red	9%	0.33	1,500	(90)	2,100	(130)
Yellow	10%	0.48	3,400	(210)	3,700	(230)
Douglas-fir						
Coast	Green	0.44	3,400	(210)	5,900	(360)
	12%	0.47	3,300	(200)	5,900	(360)
Interior west	Green	0.48	3,300	(200)	4,900	(300)
	13%	0.51	3,400	(210)	5,500	(340)
Interior north	Green	0.43	2,800	(170)	3,900	(240)
	14%	0.46	2,600	(160)	4,100	(250)
Interior south	Green	0.38	2,100	(130)	2,900	(180)
	14%	0.4	2,000	(120)	2,900	(180)
Fir						
California red	Green	0.36	2,100	(130)	2,900	(180)
	12%	0.39	2,000	(120)	2,800	(170)
Noble	Green	0.36	—	—	3,900	(240)
	12%	0.39	—	—	3,600	(220)
Pacific silver	Green	0.37	2,400	(150)	3,700	(230)
	13%	0.4	2,800	(170)	4,200	(260)
White	Green	0.36	2,300	(140)	3,600	(220)
	13%	0.38	2,100	(130)	3,300	(200)
Hemlock						
Mountain	Green	0.41	4,100	(250)	4,600	(280)
	14%	0.44	2,300	(140)	2,800	(170)
Western	Green	0.38	2,400	(150)	2,800	(170)
	12%	0.41	2,300	(140)	3,400	(210)
Larch, western	Green	0.51	4,400	(270)	6,500	(400)
	12%	0.55	3,400	(210)	5,500	(340)
Pine						
Eastern white	Green	0.33	2,000	(120)	2,600	(160)
	12%	0.34	1,800	(110)	2,000	(120)
Jack	Green	0.41	3,300	(200)	6,200	(380)
	12%	0.42	2,300	(140)	3,900	(240)
Loblolly	Green	0.48	5,000	(310)	6,200	(380)
	12%	0.51	2,600	(160)	4,200	(260)
Lodgepole	Green	0.38	2,600	(160)	3,400	(210)
Ponderosa	Green	0.38	3,100	(190)	4,400	(270)
	11%	0.43	2,400	(150)	3,100	(190)
Red	Green	0.4	3,400	(210)	5,700	(350)
	12%	0.43	2,600	(160)	4,700	(290)
Shortleaf	Green	0.47	4,700	(290)	6,500	(400)
	13%	0.5	2,400	(150)	3,700	(230)
Slash	Green	0.55	5,700	(350)	7,300	(450)
	12%	0.59	3,400	(210)	5,200	(320)
Virginia	Green	0.45	5,500	(340)	7,600	(470)
	12%	0.49	2,800	(170)	4,100	(250)
Redwood						
Old-growth	Green	0.39	1,800	(110)	3,300	(200)
	11%	0.39	1,500	(90)	2,300	(140)
Young-growth	Green	0.33	1,800	(110)	2,300	(140)
	12%	0.34	1,500	(90)	1,800	(110)
Spruce, Engelmann	Green	0.34	2,400	(150)	3,100	(190)
	12%	0.35	1,800	(110)	2,900	(180)

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

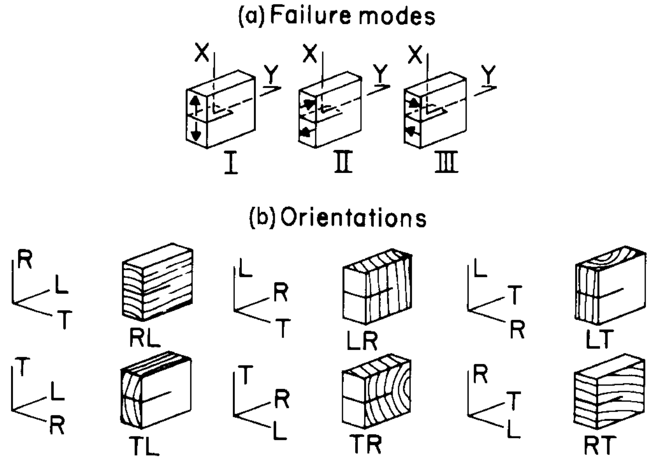

Figure 4–2. Possible crack propagation systems for wood.

three planes and may propagate in one of two directions in each plane. This gives rise to six crack-propagation systems (*RL*, *TL*, *LR*, *TR*, *LT*, and *RT*) (Fig. 4–2b). Of these crack-propagation systems, four systems are of practical importance: *RL*, *TL*, *TR*, and *RT*. Each of these four systems allow for propagation of a crack along the lower strength path parallel to the grain. The *RL* and *TL* orientations in wood (where *R* or *T* is perpendicular to the crack plane and *L* is the direction in which the crack propagates) will predominate as a result of the low strength and stiffness of wood perpendicular to the grain. It is therefore one of these two orientations that is most often tested. Values for Mode I fracture toughness range from 220 to 550 $\text{kPa}\sqrt{\text{m}}$ (200 to 500 $\text{lbf}/\text{in}^2\sqrt{\text{in.}}$) and for Mode II range from 1,650 to 2,400 $\text{kPa}\sqrt{\text{m}}$ (1,500 to 2,200 $\text{lbf}/\text{in}^2\sqrt{\text{in.}}$). Table 4–10 summarizes selected mode I and mode II test results at 10% to 12% moisture content available in the literature. The limited information available on moisture content effects on fracture toughness suggests that fracture toughness is either insensitive to moisture content or increases as the material dries, reaching a maximum between 6% and 15% moisture content; fracture toughness then decreases with further drying.

Vibration Properties

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

Speed of Sound

The speed of sound in a structural material is a function of the modulus of elasticity and density. In wood, the speed of sound also varies with grain direction because the transverse modulus of elasticity is much less than the longitudinal value (as little as 1/20); the speed of sound across the grain is about one-fifth to one-third of the longitudinal value. For example, a piece of wood with a longitudinal modulus of elasticity of 12.4 GPa (1.8×10^6 lbf/in^2) and density of

Table 4–10. Summary of selected fracture toughness results

	Fracture toughness ($kPa\sqrt{m}$ ($lbf/in^2\sqrt{in.}$))			
	Mode I		Mode II	
Species	*TL*	*RL*	*TL*	*RL*
Douglas-fir	320 (290)	360 (330)		2,230 (2,030)
Western hemlock	375 (340)		2,240 (2,040)	
Pine				
Western white	250 (225)	260 (240)		
Scots	440 (400)	500 (455)	2,050 (1,860)	
Southern	375 (340)		2,070 (1,880)	
Ponderosa	290 (265)			
Red spruce	420 (380)		2,190 (1,990)	1,665 (1,510)
Northern red oak	410 (370)			
Sugar maple	480 (430)			
Yellow-poplar	517 (470)			

480 kg/m^3 (30 lb/ft^3) would have a speed of sound in the longitudinal direction of about 3,800 m/s (12,500 ft/s). In the transverse direction, modulus of elasticity would be about 690 MPa (100 × 10^3 lbf/in^2) and the speed of sound approximately 890 m/s (2,900 ft/s).

The speed of sound decreases with increasing temperature or moisture content in proportion to the influence of these variables on 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. In general, there is a value of moisture content at which internal friction is minimum. On either side of this minimum, internal friction increases as moisture content varies down to zero or up to the fiber saturation point. The moisture content at which minimum internal friction occurs varies with temperature. At room temperature (23ºC (73ºF)), the minimum occurs at about 6% moisture content; at −20ºC (−4ºF), it occurs at about 14% moisture content, and at 70ºC (158ºF), at about 4%. At 90ºC (194ºF), the minimum is not well defined and occurs near zero moisture content.

Similarly, there are temperatures at which internal friction is minimum, and the temperatures of minimum internal friction vary with moisture content. The temperatures of minimum internal friction are higher as the moisture content is decreased. For temperatures above 0ºC (32ºF) and moisture content greater than about 10%, internal friction increases strongly as temperature increases, with a strong positive interaction with moisture content. For very dry wood, there is a general tendency for internal friction to decrease as the temperature increases.

The value of internal friction, expressed by logarithmic decrement, ranges from about 0.1 for hot, moist wood to less than 0.02 for hot, dry wood. Cool wood, regardless of moisture content, would have an intermediate value.

Mechanical Properties of Clear Straight-Grained Wood

The mechanical properties listed in Table 4–1 through Table 4–9 are based on a variety of sampling methods. Generally, the most extensive sampling is represented in Tables 4–3 and 4–4. The values in Table 4–3 are averages derived for a number of species grown in the United States. The tabulated value is an estimate of the average clear wood property of the species. Many values were obtained from test specimens taken at a height of 2.4 to 5 m (8 to 16 ft) above the stump of the tree. Values reported in Table 4–4 represent estimates of the average clear wood properties of species grown in Canada and commonly imported into the United States.

Methods of data collection and analysis changed over the years during which the data in Tables 4–3 and 4–4 were collected. In addition, the character of some forests has changed with time. Because not all the species were reevaluated to reflect these changes, the appropriateness of the data should be reviewed when used for critical applications such as stress grades of lumber.

Values reported in Table 4–5 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, 4–2, 4–5, 4–7, 4–8, 4–9 and 4–10 may not necessarily represent average species characteristics because of inadequate sampling; however, they do 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. The fact that a piece may be stronger, harder, or stiffer than the average is often of less concern to the user than if the piece is weaker; however, this may not be true if lightweight material is selected for a specific purpose or if harder or tougher material is difficult to work. Some indication of the spread of property values is therefore desirable. Average coefficients of variation for many mechanical properties are presented in Table 4–6.

The mechanical properties reported in the tables are significantly affected by specimen moisture content at time of test. Some tables include properties that were evaluated at differing moisture levels; these moisture levels are reported. As indicated in the tables, many of the dry test data were adjusted to a common moisture content base of 12%.

Specific gravity is reported in many tables because this property is used as an index of clear wood mechanical properties. The specific gravity values given in Tables 4–3 and 4–4 represent the estimated average clear wood specific gravity of the species. In the other tables, the specific gravity values represent 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 4–6.

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 the test specimen and the test mode. The test methods used to establish properties in Tables 4–3, 4–4, 4–7, 4–8 and 4–9 are based on standard procedures (ASTM D143). The test methods for properties presented in other tables are referenced in the selected bibliography at the end of this chapter.

Common names of species listed in the tables conform to standard nomenclature of the U.S. Department of Agriculture, Forest Service. Other names may be used locally for a species. Also, one common name may be applied to groups of species for marketing.

Natural Characteristics Affecting Mechanical Properties

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 may have knots and localized slope of grain. Natural defects such as pitch pockets may occur as a result of biological or climatic elements influencing the living tree. These wood characteristics must be taken into account in assessing actual properties or estimating the actual performance of wood products.

Specific Gravity

The substance of which wood is composed is actually heavier than water; its specific gravity is about 1.5 regardless of wood species. In spite of this, 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 other species and therefore higher specific gravity. Thus, specific gravity is an excellent index of the amount of wood substance contained in a piece of wood; it is a good index of mechanical properties as long as the wood is clear, straight grained, and free from defects. However, specific gravity values also reflect the presence of gums, resins, and extractives, which contribute little to mechanical properties.

Approximate relationships between various mechanical properties and specific gravity for clear straight-grained wood of hardwoods and softwoods are given in Table 4–11 as power functions. Those relationships are based on average values for the 43 softwood and 66 hardwood species presented in Table 4–3. The average data vary around the relationships, so that the relationships do not accurately predict individual average species values or an individual specimen value. In fact, mechanical properties within a species tend to be linearly, rather than curvilinearly, related to specific gravity; where data are available for individual species, linear analysis is suggested.

Knots

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

The shape (form) of a knot on a sawn surface depends upon the direction of the exposing cut. A nearly round knot is produced when lumber is sawn from a log and a branch is sawn through at right angles to its length (as in a flatsawn board). An oval knot is produced if the saw cut is diagonal to the branch length (as in a bastard-sawn board) and a "spiked" knot when the cut is lengthwise to the branch (as in a quartersawn board).

Knots are further classified as intergrown or encased (Fig. 4–3). As long as a limb remains alive, there is continuous growth at the junction of the limb and the bole of the tree, and the resulting knot is called intergrown. After the branch has died, additional growth on the trunk encloses the dead limb, resulting in an encased knot; bole fibers are not continuous with the fibers of the encased knot. Encased knots and knotholes tend to be accompanied by less cross-grain than are intergrown knots and are therefore generally less problematic with regard to most mechanical properties.

Most mechanical properties are lower in sections containing knots than in clear straight-grained wood because (a) the clear wood is displaced by the knot, (b) the fibers around the knot are distorted, resulting in cross grain, (c) the discontinuity of wood fiber leads to stress concentrations, and (d) checking often occurs around the knots during drying. Hardness and strength in compression perpendicular to the grain are exceptions, where knots may be objectionable only in that they cause nonuniform wear or nonuniform stress distributions at contact surfaces.

Knots have a much greater effect on strength in axial tension than in axial short-column compression, and the effects on bending are somewhat less than those in axial tension.

Table 4–11a. Functions relating mechanical properties to specific gravity of clear, straight-grained wood (metric)

	Specific gravity–strength relationship			
	Green wood		Wood at 12% moisture content	
Property[a]	Softwoods	Hardwoods	Softwoods	Hardwoods
Static bending				
MOR (kPa)	109,600 $G^{1.01}$	118,700 $G^{1.16}$	170,700 $G^{1.01}$	171,300 $G^{1.13}$
MOE (MPa)	16,100 $G^{0.76}$	13,900 $G^{0.72}$	20,500 $G^{0.84}$	16,500 $G^{0.7}$
WML (kJ/m^3)	147 $G^{1.21}$	229 $G^{1.52}$	179 $G^{1.34}$	219 $G^{1.54}$
Impact bending (N)	353 $G^{1.35}$	422 $G^{1.39}$	346 $G^{1.39}$	423 $G^{1.65}$
Compression parallel (kPa)	49,700 $G^{0.94}$	49,000 $G^{1.11}$	93,700 $G^{0.97}$	76,000 $G^{0.89}$
Compression perpendicular (kPa)	8,800 $G^{1.53}$	18,500 $G^{2.48}$	16,500 $G^{1.57}$	21,600 $G^{2.09}$
Shear parallel (kPa)	11,000 $G^{0.73}$	17,800 $G^{1.24}$	16,600 $G^{0.85}$	21,900 $G^{1.13}$
Tension perpendicular (kPa)	3,800 $G^{0.78}$	10,500 $G^{1.37}$	6,000 $G^{1.11}$	10,100 $G^{1.3}$
Side hardness (N)	6,230 $G^{1.41}$	16,550 $G^{2.31}$	85,900 $G^{1.5}$	15,300 $G^{2.09}$

[a]Compression parallel to grain is maximum crushing strength; compression perpendicular to grain is fiber stress at proportional limit. MOR is modulus of rupture; MOE, modulus of elasticity; and WML, work to maximum load. For green wood, use specific gravity based on ovendry weight and green volume; for dry wood, use specific gravity based on ovendry weight and volume at 12% moisture content.

Table 4–11b. Functions relating mechanical properties to specific gravity of clear, straight-grained wood (inch–pound)

	Specific gravity–strength relationship			
	Green wood		Wood at 12% moisture content	
Property[a]	Softwoods	Hardwoods	Softwoods	Hardwoods
Static bending				
MOR (lb/in^2)	15,890 $G^{1.01}$	17,210 $G^{1.16}$	24,760 $G^{1.01}$	24,850 $G^{1.13}$
MOE ($\times 10^6$ lb/in^2)	2.33 $G^{0.76}$	2.02 $G^{0.72}$	2.97 $G^{0.84}$	2.39 $G^{0.7}$
WML (in-lbf/in^3)	21.33 $G^{1.21}$	33.2 $G^{1.52}$	25.9 $G^{1.34}$	31.8 $G^{1.54}$
Impact bending (lbf)	79.28 $G^{1.35}$	94.9 $G^{1.39}$	77.7 $G^{1.39}$	95.1 $G^{1.65}$
Compression parallel (lb/in^2)	7,210 $G^{0.94}$	7,110 $G^{1.11}$	13,590 $G^{0.97}$	11,030 $G^{0.89}$
Compression perpendicular (lb/in^2)	1,270 $G^{1.53}$	2,680 $G^{2.48}$	2,390 $G^{1.57}$	3,130 $G^{2.09}$
Shear parallel (lb/in^2)	1,590 $G^{0.73}$	2,580 $G^{1.24}$	2,410 $G^{0.85}$	3,170 $G^{1.13}$
Tension perpendicular (lb/in^2)	550 $G^{0.78}$	1,520 $G^{1.37}$	870 $G^{1.11}$	1,460 $G^{1.3}$
Side hardness (lbf)	1,400 $G^{1.41}$	3,720 $G^{2.31}$	1,930 $G^{1.5}$	3,440 $G^{2.09}$

[a]Compression parallel to grain is maximum crushing strength; compression perpendicular to grain is fiber stress at proportional limit. MOR is modulus of rupture; MOE, modulus of elasticity; and WML, work to maximum load. For green wood, use specific gravity based on ovendry weight and green volume; for dry wood, use specific gravity based on ovendry weight and volume at 12% moisture content.

For this reason, in a simply supported beam, a knot on the lower side (subjected to tensile stresses) has a greater effect on the load the beam will support than does a knot on the upper side (subjected to compressive stresses).

In long columns, knots are important because they affect stiffness. In short or intermediate columns, the reduction in strength caused by knots is approximately proportional to their size; 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 do knots in sawn timbers. Although the grain is irregular around knots in both forms of timber, the angle of the grain to the surface is smaller in naturally round timber than in sawn timber. Furthermore, in round timbers there is no discontinuity in wood fibers, which results from sawing through both local and general slope of grain.

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

Slope of Grain

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, from the way the wood was removed from the log, or because of grain irregularities that occurred while the tree was growing.

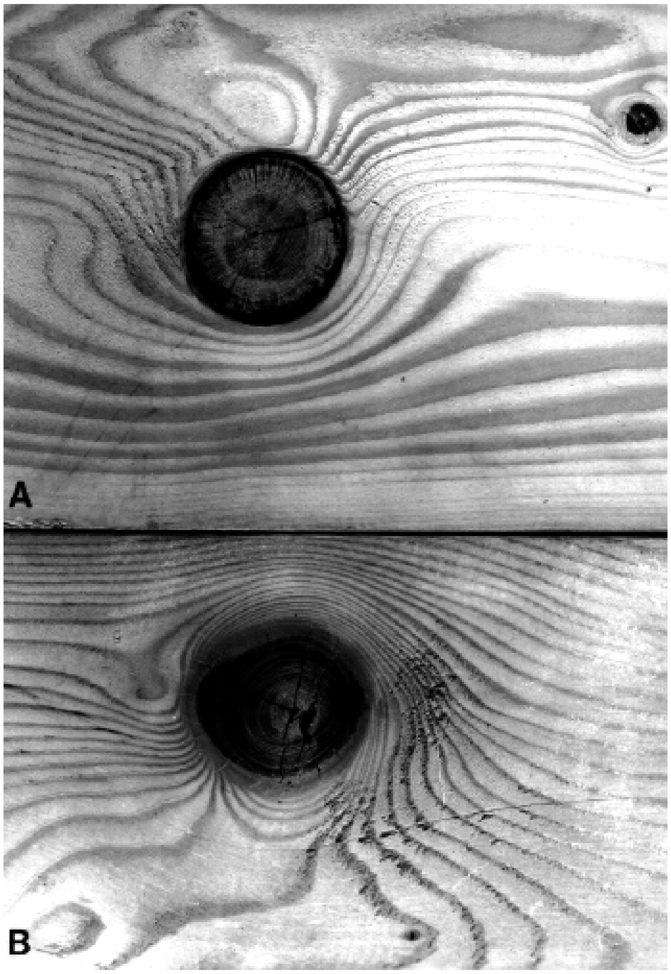

Figure 4–3. Types of knots. A, encased knot; B, intergrown.

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 (Bodig and Jayne 1982):

$$N = \frac{PQ}{P\sin^n \theta + Q\cos^n \theta} \tag{4–2}$$

where N is strength at angle θ from fiber direction, Q strength perpendicular to grain, P strength parallel to grain, and n an empirically determined constant.

This formula has been used for modulus of elasticity as well as strength properties. Values of n and associated ratios of Q/P tabulated from available literature are as follows:

Property	*n*	*Q/P*
Tensile strength	1.5–2	0.04–0.07
Compression strength	2–2.5	0.03–0.40
Bending strength	1.5–2	0.04–0.10
Modulus of elasticity	2	0.04–0.12
Toughness	1.5–2	0.06–0.10

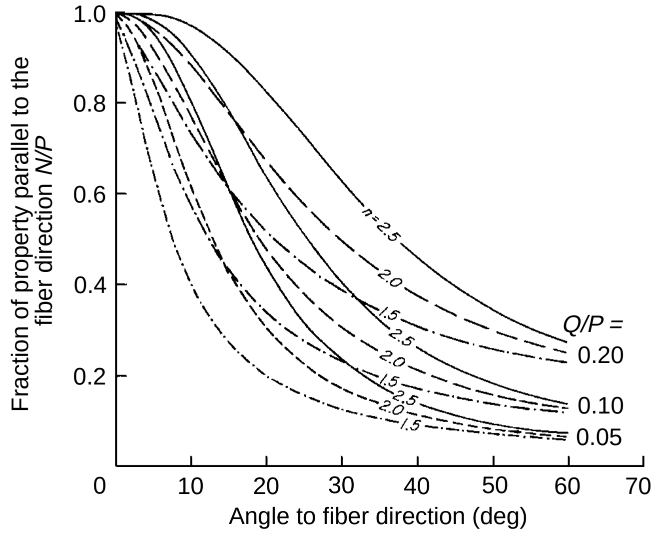

Figure 4–4. Effect of grain angle on mechanical property of clear wood according to Hankinson-type formula. *Q/P* is ratio of mechanical property across the grain (*Q*) to that parallel to the grain (*P*); *n* is an empirically determined constant.

The Hankinson-type formula can be graphically depicted as a function of Q/P and n. Figure 4–4 shows the strength in any direction expressed as a fraction of the strength parallel to 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 25 mm (1 in.) of the grain from the edge or long axis of the piece and the distance in millimeters (inches) within which this deviation occurs (tan θ). The effect of grain slope on some properties of wood, as determined from tests, is shown in Table 4–12. The values for modulus of rupture fall very close to the curve in Figure 4–4 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 the compression values for the curve for $Q/P = 0.1$, $n = 2.5$.

The term cross grain indicates the condition measured by slope of grain. Two important forms of cross grain are spiral and diagonal (Fig. 4–5). Other types are wavy, dipped, interlocked, and curly.

Spiral grain is caused by winding or spiral growth of wood fibers about the bole of the tree instead of vertical growth. In sawn products, spiral grain can be defined as fibers lying in the tangential plane of the growth rings, rather than parallel to the longitudinal axis of the product (see Fig. 4–5 for a simple case). Spiral grain in sawn products often goes undetected by ordinary visual inspection. The best test for spiral grain is to split a sample section from the piece in the radial direction. A visual method of determining the presence of spiral grain is to note the alignment of pores, rays, and resin ducts on a flatsawn face. Drying checks on a flatsawn surface follow the fibers and indicate the slope of the fiber. Relative

Table 4–12. Strength of wood members with various grain slopes compared with strength of a straight-grained member[a]

Maximum slope of grain in member	Modulus of rupture (%)	Impact bending (%)	Compression parallel to grain (%)
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

[a]Impact bending is height of drop causing complete failure (0.71-kg (50-lb) hammer); compression parallel to grain is maximum crushing strength.

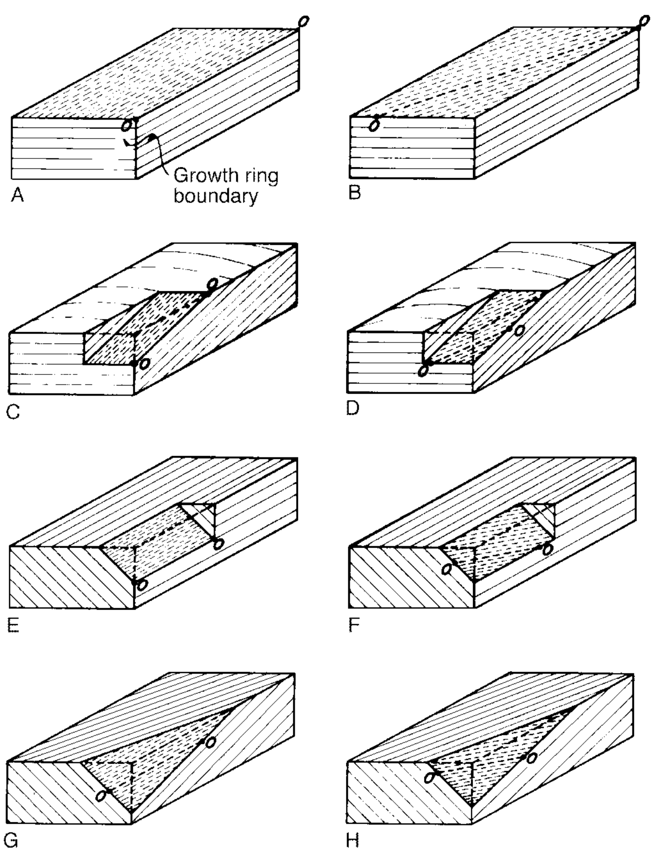

Figure 4–5. Relationship of fiber orientation (O-O) to axes, as shown by schematic of wood specimens containing straight grain and cross grain. Specimens A through D have radial and tangential surfaces; E through H do not. Specimens A and E contain no cross grain; B, D, F, and H have spiral grain; C, D, G, and H have diagonal grain.

change in electrical capacitance is an effective technique for measuring slope of grain.

Diagonal grain is cross grain caused by growth rings that are not parallel to one or both surfaces of the sawn piece. Diagonal grain is produced by sawing a log with pronounced taper parallel to the axis (pith) of the tree. Diagonal grain also occurs in lumber sawn from crooked logs or logs with butt swell.

Cross grain can be quite localized as a result of the disturbance of a growth pattern by a branch. This condition, termed local slope of grain, may be present even though the branch (knot) may have been removed by sawing. The degree of local cross grain may often be difficult to determine. Any form of cross grain can have a deleterious effect on mechanical properties or machining characteristics.

Spiral and diagonal grain can combine to produce a more complex cross grain. To determine net cross grain, regardless of origin, fiber slopes on the contiguous surface 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 that the spiral grain slope on the flat-grained surface of Figure 4–5D is 1 in 12 and the diagonal-grain slope is 1 in 18. The combined slope is

$$\sqrt{(1/18)^2 + (1/12)^2} = 1/10$$

or a slope of 1 in 10.

A regular reversal of right and left spiraling of grain in a tree stem produces the condition known as interlocked grain. Interlocked grain occurs in some hardwood species (Ch. 3, Table 3–9) and markedly increases resistance to splitting in the radial plane. Interlocked grain decreases both the static bending strength and stiffness of clear wood specimens. The data from tests of domestic hardwoods shown in Table 4–3 do not include pieces that exhibited interlocked grain. Some mechanical property values in Table 4–5 are based on specimens with interlocked grain because that is a characteristic of some species. The presence of interlocked grain alters the relationship between bending strength and compressive strength of lumber cut from tropical hardwoods.

Annual Ring Orientation

Stresses perpendicular to the fiber (grain) direction may be at any angle from 0° (T) to 90° (R) to the growth rings (Fig. 4–6). Perpendicular-to-grain properties depend somewhat upon orientation of annual rings with respect to the direction of stress. The compression perpendicular-to-grain values in Table 4–3 were derived from tests in which the load was applied parallel to the growth rings (T direction); shear parallel-to-grain and tension perpendicular-to-grain values are averages of equal numbers of specimens with 0° and 90° growth ring orientations. In some species, there is no difference in 0° and 90° orientation properties. Other species exhibit slightly higher shear parallel or tension perpendicular-to-grain properties for the 0° orientation than for

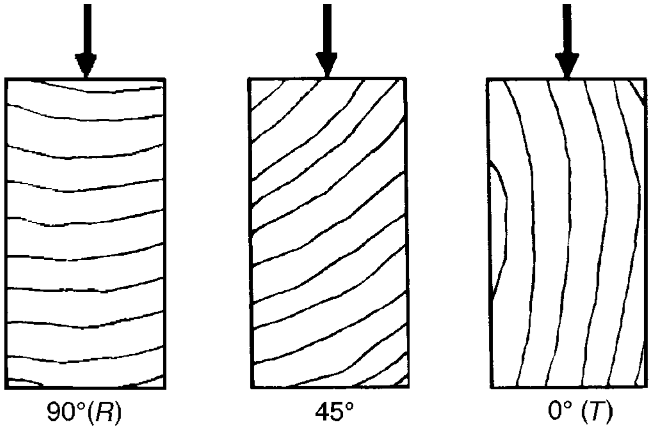

Figure 4–6. Direction of load in relation to direction of annual growth rings: 90° or perpendicular (*R*), 45°, 0° or parallel (*T*).

the 90° orientation; the converse is true for about an equal number of species.

The effects of intermediate annual ring orientations have been studied in a limited way. Modulus of elasticity, compressive perpendicular-to-grain stress at the proportional limit, and tensile strength perpendicular to the grain tend to be about the same at 45° and 0°, but for some species these values are 40% to 60% lower at the 45° orientation. For those species with lower properties at 45° ring orientation, properties tend to be about equal at 0° and 90° orientations. For species with about equal properties at 0° and 45° orientations, properties tend to be higher at the 90° orientation.

Reaction Wood

Abnormal woody tissue is frequently associated with leaning boles and crooked limbs of both conifers and hardwoods. It is generally believed that such wood 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 density compared with that of normal wood. The specific gravity of compression wood is commonly 30% to 40% greater than that of normal wood; the specific gravity of tension wood commonly ranges between 5% and 10% greater than that of normal wood, but it may be as much as 30% greater.

Compression wood is usually somewhat darker than normal wood because of the greater proportion of latewood, and it frequently has a relatively lifeless appearance, especially in woods in which the transition from earlywood to latewood is abrupt. Because compression wood is more opaque than normal wood, intermediate stages of compression wood can be detected by transmitting light through thin cross sections; however, borderline forms of compression wood that merge with normal wood can commonly be detected only by microscopic examination.

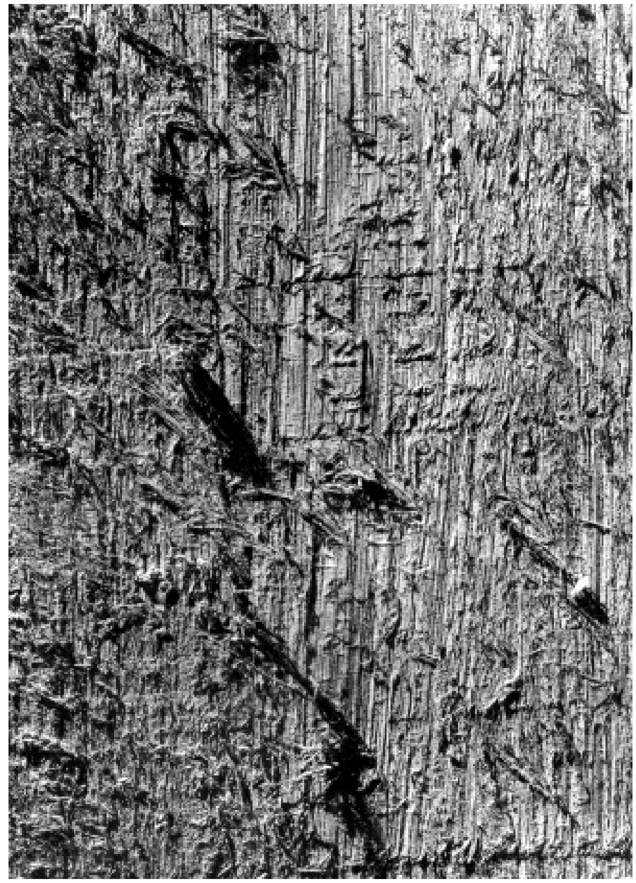

Figure 4–7. Projecting tension wood fibers on sawn surface of mahogany board.

Tension wood is more difficult to detect than is compression wood. However, eccentric growth as seen on the transverse section suggests its presence. Also, because it is difficult to cleanly cut the tough tension wood fibers, the surfaces of sawn boards are "woolly," especially when the boards are sawn in the green condition (Fig. 4–7). In some species, tension wood may be evident 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.

Reaction wood, particularly compression wood in the green condition, may be stronger than normal wood. However, compared with normal wood with similar specific gravity, 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.

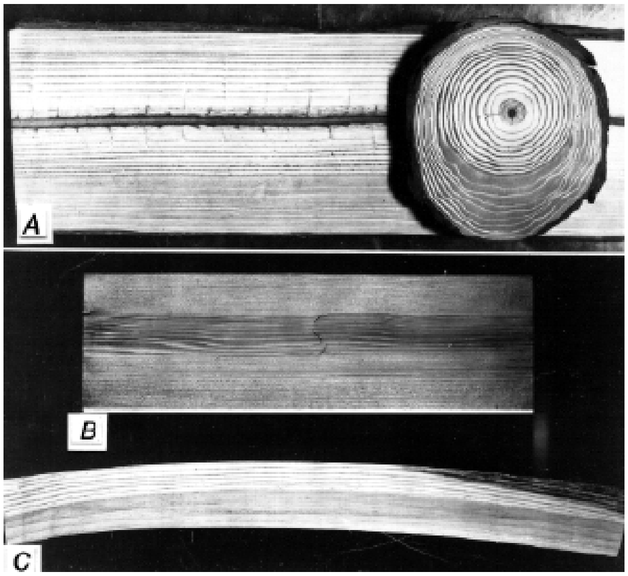

Figure 4–8. Effects of compression wood. A, eccentric growth about pith in cross section containing compression wood—dark area in lower third of cross section is compression wood; B, axial tension break caused by excessive longitudinal shrinkage of compression wood; C, warp caused by excessive longitudinal shrinkage.

Because of the abnormal properties of reaction wood, it may be desirable to eliminate this wood from raw material. In logs, compression wood is characterized by eccentric growth about the pith and the large proportion of latewood at the point of greatest eccentricity (Fig. 4–8A). Fortunately, pronounced compression wood in lumber can generally be detected by ordinary visual examination.

Compression and tension wood undergo extensive longitudinal shrinkage when subjected to moisture loss below the fiber saturation point. Longitudinal shrinkage in compression wood may be up to 10 times that in normal wood and in tension wood, perhaps up to 5 times that in normal wood. When reaction wood and normal wood are present in the same board, unequal longitudinal shrinkage causes internal stresses that result in warping. In extreme cases, unequal longitudinal shrinkage results in axial tension failure over a portion of the cross section of the lumber (Fig. 4–8B). Warp sometimes occurs in rough lumber but more often in planed, ripped, or resawn lumber (Fig. 4–8C).

Juvenile Wood

Juvenile wood is the wood produced near the pith of the tree; for softwoods, it is usually defined as the material 5 to 20 rings from the pith depending on species. Juvenile wood has considerably different physical and anatomical properties than that of mature wood (Fig. 4–9). In clear wood, the properties that have been found to influence mechanical behavior include fibril angle, cell length, and specific gravity, the latter a composite of percentage of latewood, cell wall thickness, and lumen diameter. Juvenile wood has a high fibril angle (angle between longitudinal axis of wood cell

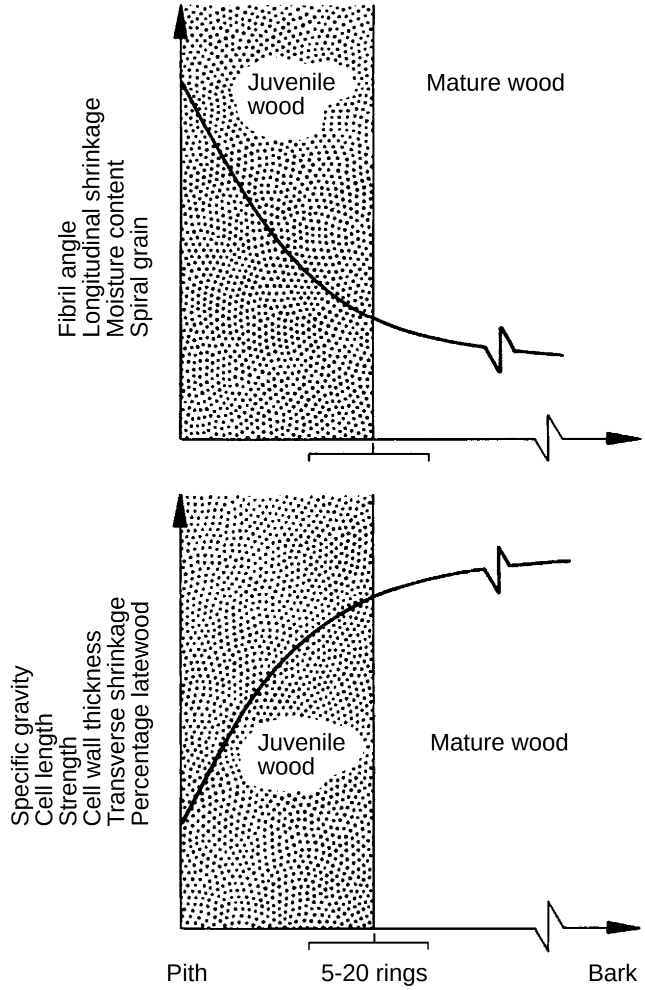

Figure 4–9. Properties of juvenile wood.

and cellulose fibrils), which causes longitudinal shrinkage that may be more than 10 times that of mature wood. Compression wood and spiral grain are also more prevalent in juvenile wood than in mature wood and contribute to longitudinal shrinkage. In structural lumber, the ratio of modulus of rupture, ultimate tensile stress, and modulus of elasticity for juvenile to mature wood ranges from 0.5 to 0.9, 0.5 to 0.95, and 0.45 to 0.75, respectively. Changes in shear strength resulting from increases in juvenile wood content can be adequately predicted by monitoring changes in density alone for all annual ring orientations. The same is true for perpendicular-to-grain compressive strength when the load is applied in the tangential direction. Compressive strength perpendicular-to-grain for loads applied in the radial direction, however, is more sensitive to changes in juvenile wood content and may be up to eight times less than that suggested by changes in density alone. The juvenile wood to mature wood ratio is lower for higher grades of lumber than for lower grades, which indicates that juvenile wood has greater influence in reducing the mechanical properties of high-grade structural lumber. Only a limited amount of research has been done on juvenile wood in hardwood species.

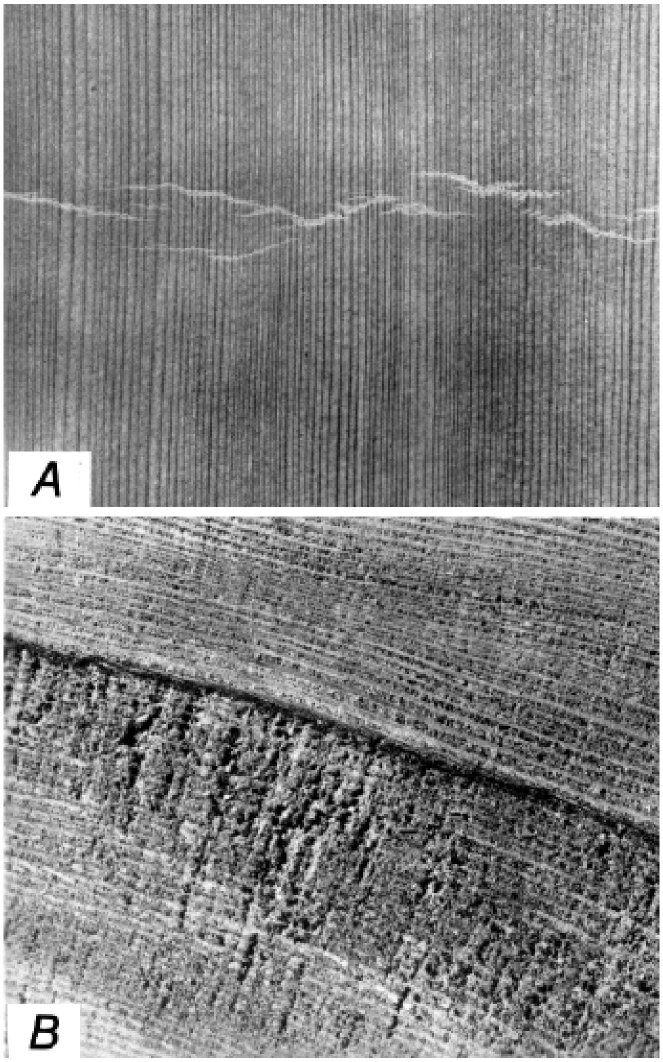

Figure 4–10. Compression failures. A, compression failure shown by irregular lines across grain; B, fiber breakage in end-grain surfaces of spruce lumber caused by compression failures below dark line.

Compression Failures

Excessive compressive stresses along the grain that produce minute compression failures can be caused by excessive bending of standing trees from wind or snow; felling of trees across boulders, logs, or irregularities in the ground; or rough handling of logs or lumber. Compression failures should not be confused with compression wood. In some instances, compression failures are visible on the surface of a board as minute lines or zones formed by crumpling or buckling of cells (Fig. 4–10A), although the failures usually appear as white lines or may even be invisible to the naked eye. The presence of compression failures may be indicated by fiber breakage on end grain (Fig. 4–10B). Since compression failures are often difficult to detect with the unaided eye, special efforts, including optimum lighting, may be required for detection. The most difficult cases are detected only by microscopic examination.

Products containing visible compression failures have low strength properties, especially in tensile strength and shock resistance. The tensile strength of wood containing compression failures may be as low as one-third the strength of matched clear wood. Even slight compression failures, visible only under a microscope, may seriously reduce strength and cause brittle fracture. Because of the low strength associated with compression failures, many safety codes require certain structural members, such as ladder rails and scaffold planks, to be entirely free of such failures.

Pitch Pockets

A pitch pocket is a well-defined opening that contains free resin. The pocket extends parallel to the annual rings; it 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.

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 with pitch pockets should be inspected for shake or separation 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 bird pecks often occur in horizontal rows, sometimes encircling the tree, and a brown or black discoloration known as a mineral streak originates from each hole. 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 of structural lumber, although they do impair the appearance of the wood.

Extractives

Many wood species contain removable extraneous materials or extractives that do not degrade the cellulose–lignin structure of the wood. These extractives are especially abundant in species such as larch, redwood, western redcedar, and black locust.

A small decrease in modulus of rupture and strength in compression parallel to grain has been measured for some species after the extractives have been removed. The extent to which extractives influence strength is apparently a function of the amount of extractives, the moisture content of the piece, and the mechanical property under consideration.

Properties of Timber From 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 drying degrade has not occurred. In a living tree, the heartwood is entirely dead and only a comparatively few sapwood cells are alive. 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 eventually the heartwood will be similarly affected. Such deterioration also occurs in logs that have been cut from live trees and improperly cared for afterwards. Because of variations in climatic and other factors that affect deterioration, the time that 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 strong as wood from live trees. Also, the heartwood of logs of some more durable species has been found to be thoroughly sound after lying in the forest for many years.

On the other hand, in nonresistant species, 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 wood products are cut are alive or dead, but whether the products themselves are free from decay or other degrading factors that would render them unsuitable for use.

Effects of Manufacturing and Service Environments

Moisture Content

Many mechanical properties are affected by changes in moisture content below the fiber saturation point. Most properties reported in Tables 4–3, 4–4, and 4–5 increase with decrease in moisture content. The relationship that describes these changes in clear wood property at about 21ºC (70ºF) is

$$P = P_{12}\left(\frac{P_{12}}{P_g}\right)^{\left(\frac{12-M}{M_p-12}\right)} \quad (4\text{–}3)$$

where P is the property at moisture content M (%), P_{12} the same property at 12% MC, P_g the same property for green wood, and M_p moisture content at the intersection of a horizontal line representing the strength of green wood and an inclined line representing the logarithm of the strength–moisture content relationship for dry wood. This assumed linear relationship results in an M_p value that is slightly less than the fiber saturation point. Table 4–13 gives values of M_p for a few species; for other species, $M_p = 25$ may be assumed.

Average property values of P_{12} and P_g are given for many species in Tables 4–3 to 4–5. The formula for moisture content adjustment is not recommended for work to maximum load, impact bending, and tension perpendicular to grain. These properties are known to be erratic in their response to moisture content change.

The formula can be used to estimate a property at any moisture content below M_p from the species data given. For example, suppose you want to find the modulus of rupture of white ash at 8% moisture content. Using information from Tables 4–3a and 4–13,

$$P_8 = 103,000\left[\frac{103,000}{66,000}\right]^{4/12} = 119,500 \text{ kPa}$$

Table 4–13. Intersection moisture content values for selected species[a]

Species	M_p (%)
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

[a]Intersection moisture content is point at which mechanical properties begin to change when wood is dried from the green condition.

Care should be exercised when adjusting properties below 12% moisture. Although most properties will continue to increase while wood is dried to very low moisture content levels, for most species some properties may reach a maximum value and then decrease with further drying (Fig. 4–11). For clear Southern Pine, the moisture content at which a maximum property has been observed is given in Table 4–14.

This increase in mechanical properties with drying assumes small, clear specimens in a drying process in which no deterioration of the product (degrade) occurs. For 51-mm- (2-in.-) thick lumber containing knots, the increase in property with decreasing moisture content is dependent upon lumber quality. Clear, straight-grained lumber may show increases in properties with decreasing moisture content that approximate those of small, clear specimens. However, as the frequency and size of knots increase, the reduction in strength resulting from the knots begins to negate the increase in property in the clear wood portion of the lumber. Very low quality lumber, which has many large knots, may be insensitive to changes in moisture content. Figures 4–12 and 4–13 illustrate the effect of moisture content on the properties of lumber as a function of initial lumber strength (Green and others 1989). Application of these results in adjusting allowable properties of lumber is discussed in Chapter 6.

Additional information on influences of moisture content on dimensional stability is included in Chapter 12.

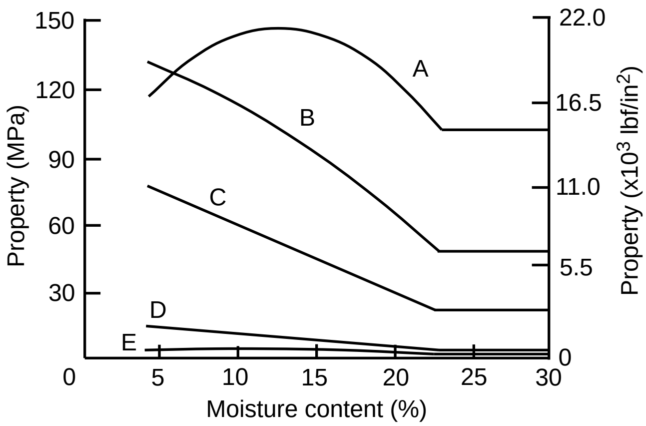

Figure 4–11. Effect of moisture content on wood strength properties. A, tension parallel to grain; B, bending; C, compression parallel to grain; D, compression perpendicular to grain; and E, tension perpendicular to grain.

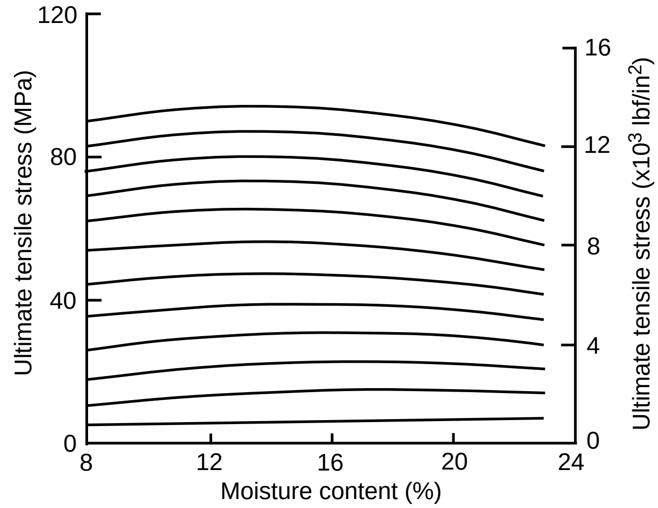

Figure 4–12. Effect of moisture content on tensile strength of lumber parallel to grain.

Table 4–14. Moisture content for maximum property value in drying clear Southern Pine from green to 4% moisture content

Property	Moisture content at which peak property occurs (%)
Ultimate tensile stress parallel to grain	12.6
Ultimate tensile stress perpendicular to grain	10.2
MOE tension perpendicular to grain	4.3
MOE compression parallel to grain	4.3
Modulus of rigidity, G_{RT}	10.0

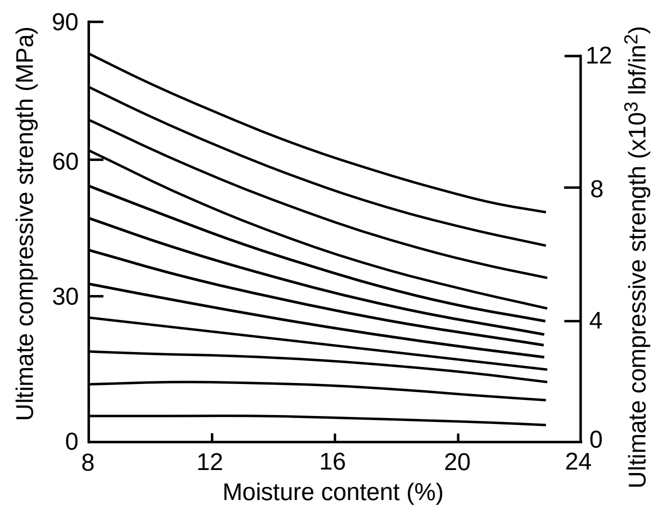

Figure 4–13. Effect of moisture content on compressive strength of lumber parallel to grain.

Temperature

Reversible Effects

In general, the mechanical properties of wood decrease when heated and increase when cooled. At a constant moisture content and below approximately 150ºC (302ºF), mechanical properties are approximately 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 100ºC (212ºF), 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 4–14 illustrates the immediate effect of temperature on modulus of elasticity parallel to grain, modulus of rupture, and compression parallel to grain, 20°C (68°F), based on a composite of results for clear, defect-free wood. This figure represents an interpretation of data from several investigators. The width of the bands illustrates variability between and within reported trends.

Table 4–15 lists changes in clear wood properties at −50°C (−58°F) and 50°C (122°F) relative to those at 20°C (68°F) for a number of moisture conditions. The large changes at −50°C (−58°F) for green wood (at fiber saturation point or wetter) reflect the presence of ice in the wood cell cavities.

The strength of dry lumber, at about 12% moisture content, may change little as temperature increases from −29°C (−20°F) to 38°C (100°F). For green lumber, strength generally decreases with increasing temperature. However, for temperatures between about 7°C (45°F) and 38°C (100°F), the changes may not differ significantly from those at room temperature. Table 4–16 provides equations that have been

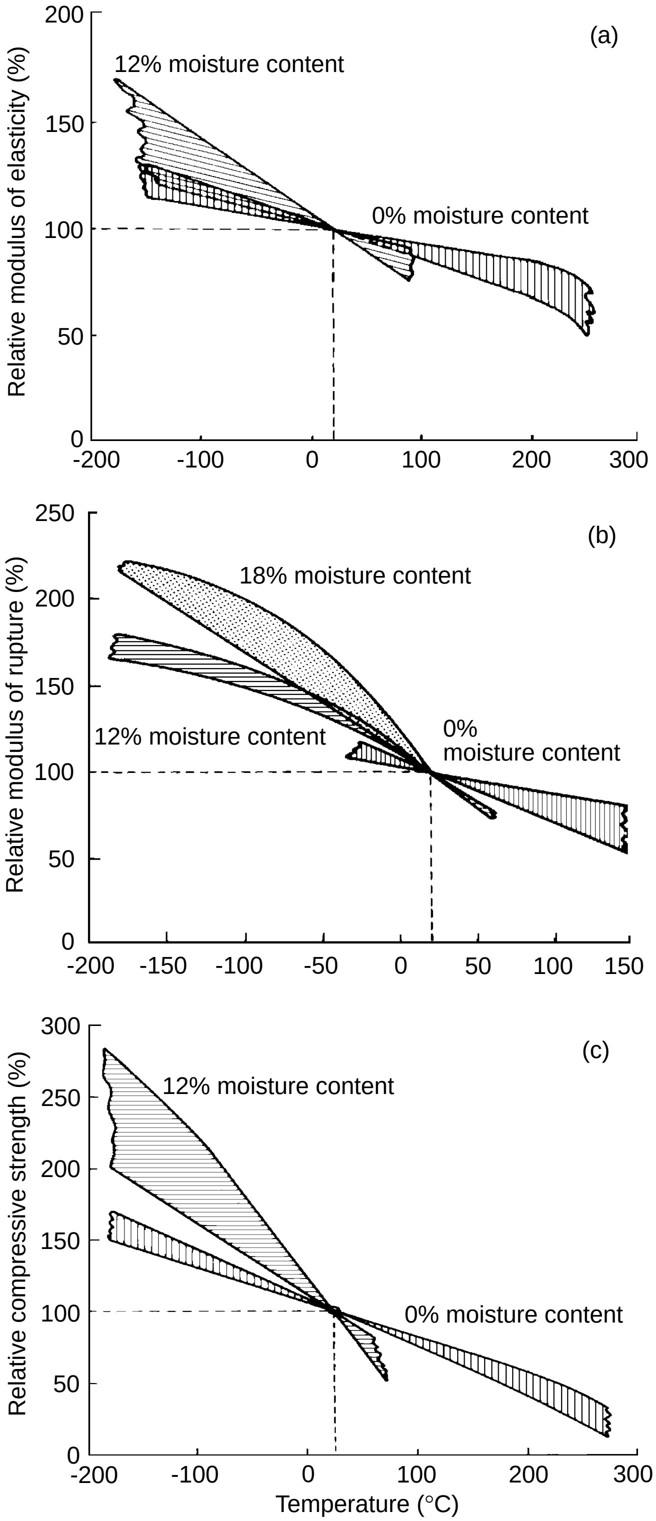

Figure 4–14. Immediate effect of temperature at two moisture content levels relative to value at 20°C (68°F) for clear, defect-free wood: (a) modulus of elasticity parallel to grain, (b) modulus of rupture in bending, (c) compressive strength parallel to grain. The plot is a composite of results from several studies. Variability in reported trends is illustrated by width of bands.

Table 4–15. Approximate middle-trend effects of temperature on mechanical properties of clear wood at various moisture conditions

		Relative change in mechanical property from 20°C (68°F) at	
Property	Moisture condition[a] (%)	–50°C (–58°F) (%)	+50°C (+122°F) (%)
MOE parallel to grain	0	+11	–6
	12	+17	–7
	>FSP	+50	—
MOE perpendicular to grain	6	—	–20
	12	—	–35
	≥20	—	–38
Shear modulus	>FSP	—	–25
Bending strength	≤4	+18	–10
	11–15	+35	–20
	18–20	+60	–25
	>FSP	+110	–25
Tensile strength parallel to grain	0–12	—	–4
Compressive strength parallel to grain	0 12–45	+20 +50	–10 –25
Shear strength parallel to grain	>FSP	—	–25
Tensile strength perpendicular to grain	4–6 11–16 ≥18	— — —	–10 –20 –30
Compressive strength perpendicular to grain at proportional limit	0–6 ≥10	— —	–20 –35

[a]FSP indicates moisture content greater than fiber saturation point.

used to adjust some lumber properties for the reversible effects of temperature.

Irreversible Effects

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. The loss depends on factors that include moisture content, heating medium, temperature, exposure period, and to some extent, species and size of piece involved.

The permanent decrease of modulus of rupture caused by heating in steam and water is shown as a function of temperature and heating time in Figure 4–15, based on tests of clear pieces of Douglas-fir and Sitka spruce. In the same studies, heating in water affected work to maximum load more than modulus of rupture (Fig. 4–16). The effect of heating dry wood (0% moisture content) on modulus of rupture and modulus of elasticity is shown in Figures 4–17 and 4–18, respectively, as derived from tests on four softwoods and two hardwoods.

Table 4–16. Percentage change in bending properties of lumber with change in temperature[a]

Property	Lumber grade[b]	Moisture content	$((P–P_{70}) / P_{70})100 = A + BT + CT^2$			Temperature range	
			A	B	C	T_{min}	T_{max}
MOE	All	Green	22.0350	–0.4578	0	0	32
		Green	13.1215	–0.1793	0	32	150
		12%	7.8553	–0.1108	0	–15	150
MOR	SS	Green	34.13	–0.937	0.0043	–20	46
		Green	0	0	0	46	100
		12%	0	0	0	–20	100
	No. 2	Green	56.89	–1.562	0.0072	–20	46
	or less	Green	0	0	0	46	100
		Dry	0	0	0	–20	100

[a]For equation, P is property at temperature T in °F; P_{70}, property at 21°C (70°F).
[b]SS is Select Structural.

Figure 4–19 illustrates the permanent loss in bending strength of Spruce–Pine–Fir standard 38- by 89-mm (nominal 2- by 4-in.) lumber heated at 66°C (150°F) and about 12% moisture content. During this same period, modulus of elasticity barely changed. Most in-service exposures at 66°C (150°F) would be expected to result in much lower moisture content levels. Additional results for other lumber products and exposure conditions will be reported as Forest Products Laboratory studies progress.

The permanent property losses discussed here are based on tests conducted after the specimens were cooled to room temperature and conditioned to a range of 7% to 12% moisture content. If specimens are tested hot, the percentage of strength reduction resulting from permanent effects is based on values already reduced by the immediate effects. 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 1-month exposure as it would be after a single 6-month exposure.

The shape and size of wood pieces are important in analyzing the influence of temperature. If 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 the inner parts will be less than that for the outer parts. However, the type of loading must be considered. If the member is to be stressed in bending, the outer fibers of a piece will be subjected to the greatest stress 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, in ordinary construction wood often will not reach the daily temperature extremes of the air around it; thus, long-term effects should be based on the accumulated temperature experience of critical structural parts.

Time Under Load

Rate of Loading

Mechanical property values, as given in Tables 4–3, 4–4, and 4–5, are usually referred to as static strength values. Static strength tests are typically conducted at a rate of loading or rate of deformation to attain maximum load in about 5 min. Higher values of strength are obtained for wood loaded at a more rapid rate and lower values are obtained at slower rates. For example, the load required to produce failure in a wood member in 1 s is approximately 10% higher than that obtained in a standard static strength test. Over several orders of magnitude of rate of loading, strength is approximately an exponential function of rate. See Chapter 6 for application to treated woods.

Figure 4–20 illustrates how strength decreases with time to maximum load. The variability in the trend shown is based on results from several studies pertaining to bending, compression, and shear.

Creep and Relaxation

When initially loaded, a wood member deforms elastically. If the load is maintained, additional time-dependent deformation occurs. This is called creep. Creep occurs at even very low stresses, and it will continue over a period of years. For sufficiently high stresses, failure eventually occurs. This failure phenomenon, called duration of load (or creep rupture), is discussed in the next section.

At typical design levels and use environments, after several years the additional deformation caused by creep may approximately equal the initial, instantaneous elastic deformation. For illustration, a creep curve based on creep as a function of initial deflection (relative creep) at several stress levels is shown in Figure 4–21; creep is greater under higher stresses than under lower ones.

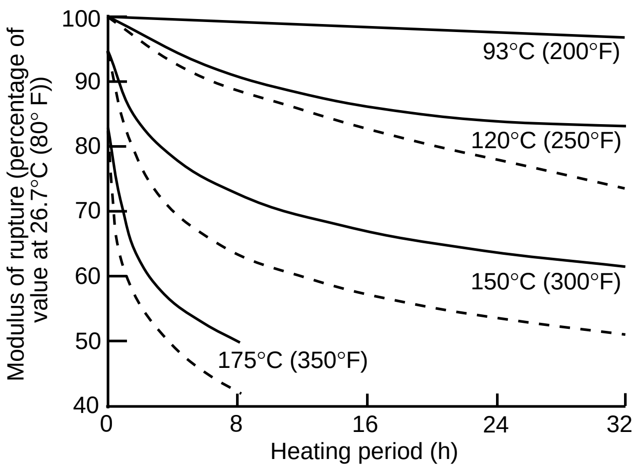

Figure 4–15. Permanent effect of heating in water (solid line) and steam (dashed line) on modulus of rupture of clear, defect-free wood. All data based on tests of Douglas-fir and Sitka spruce at room temperature.

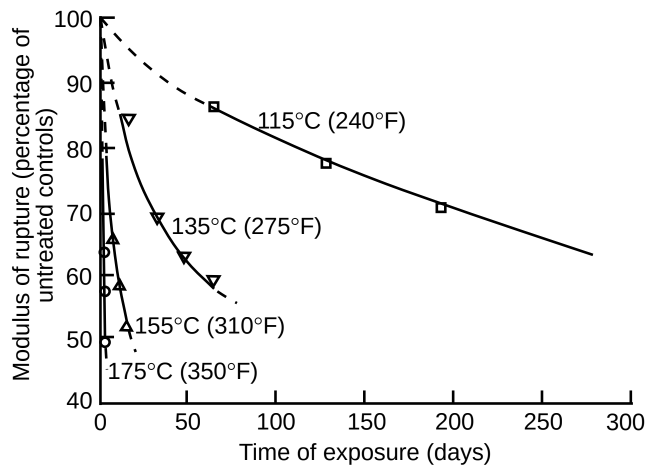

Figure 4–17. Permanent effect of oven heating at four temperatures on modulus of rupture, based on clear pieces of four softwood and two hardwood species. All tests conducted at room temperature.

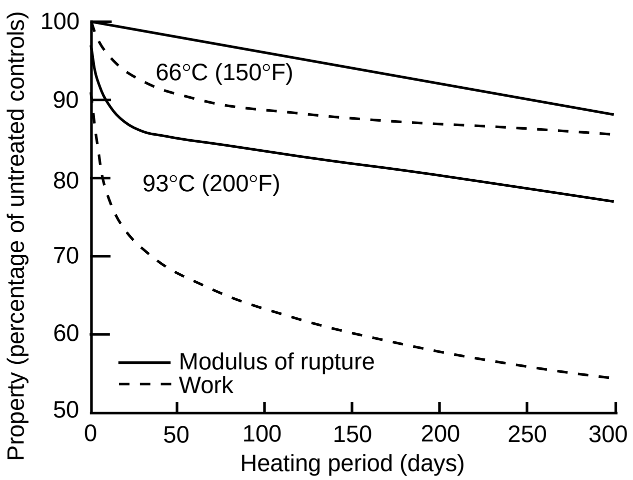

Figure 4–16. Permanent effect of heating in water on work to maximum load and modulus of rupture of clear, defect-free wood. All data based on tests of Douglas-fir and Sitka spruce at room temperature.

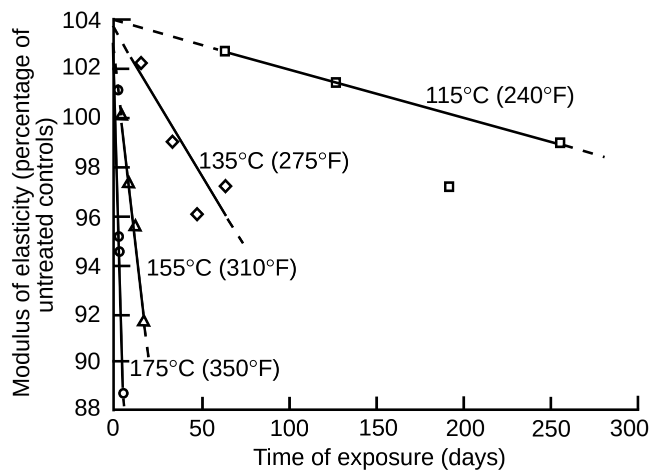

Figure 4–18. Permanent effect of oven heating at four temperatures on modulus of elasticity, based on clear pieces of four softwood and two hardwood species. All tests conducted at room temperature.

Ordinary climatic variations in temperature and humidity will cause creep to increase. An increase of about 28°C (50°F) in temperature can cause a two- to threefold increase in creep. Green wood may creep four to six times the initial deformation as it dries under load.

Unloading a member results in immediate and complete recovery of the original elastic deformation and after time, a recovery of approximately one-half the creep at deformation as well. Fluctuations in temperature and humidity increase the magnitude of the recovered deformation.

Relative creep at low stress levels is similar in bending, tension, or compression parallel to grain, although it may be somewhat less in tension than in bending or compression under varying moisture conditions. Relative 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 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% of its original value within a few months. This reduction of stress with time is commonly called relaxation.

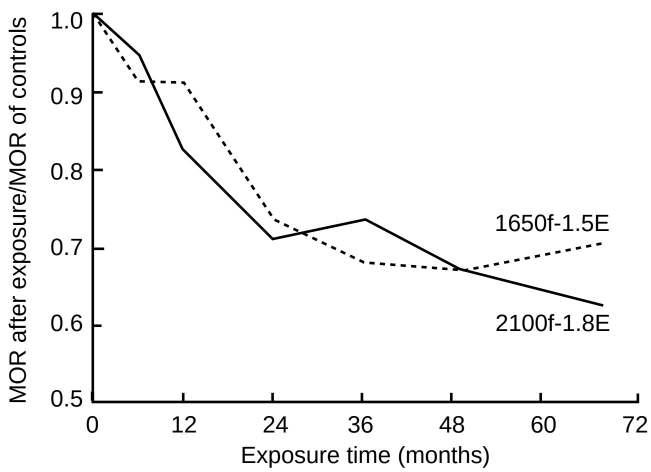

Figure 4–19. Permanent effect of heating at 66°C (150°F) on modulus of rupture for two grades of machine-stress-rated Spruce–Pine–Fir lumber at 12% moisture content. All tests conducted at room temperature.

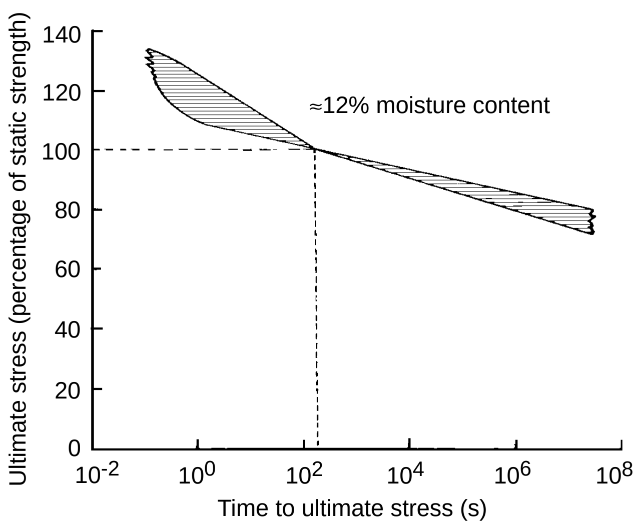

Figure 4–20. Relationship of ultimate stress at short-time loading to that at 5-min loading, based on composite of results from rate-of-load studies on bending, compression, and shear parallel to grain. Variability in reported trends is indicated by width of band.

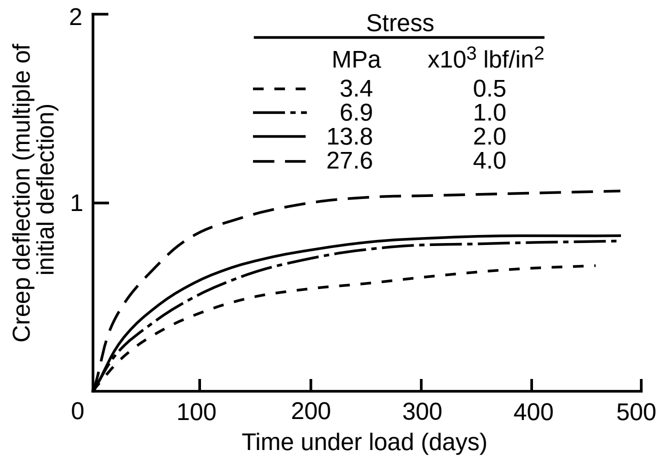

Figure 4–21. Influence of four levels of stress on creep (Kingston 1962).

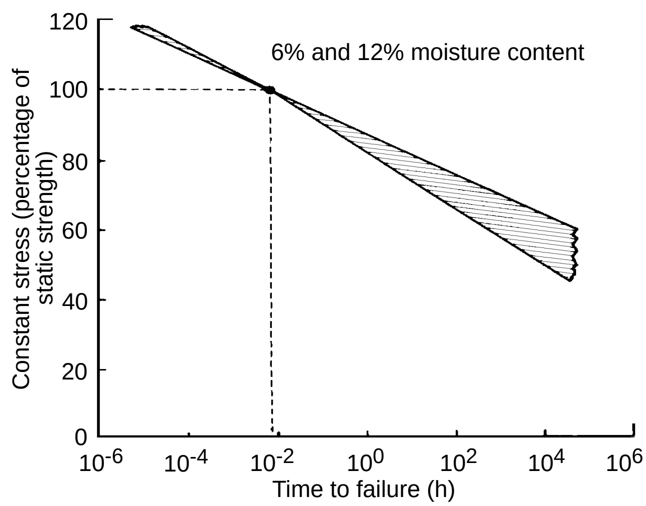

Figure 4–22. Relationship between stress due to constant load and time to failure for small clear wood specimens, based on 28 s at 100% stress. The figure is a composite of trends from several studies; most studies involved bending but some involved compression parallel to grain and bending perpendicular to grain. Variability in reported trends is indicated by width of band.

In limited bending tests carried out between approximately 18°C (64°F) and 49°C (120°F) over 2 to 3 months, the curve of stress as a function of time that expresses relaxation is approximately the mirror image of the creep curve (deformation as a function of time). These tests were carried out at initial stresses up to about 50% of the bending strength of the wood. As with creep, relaxation is markedly affected by fluctuations in temperature and humidity.

Duration of Load

The duration of load, or the time during which a load acts on a wood member either continuously or intermittently, is an important factor in determining the load that the member can safely carry. The duration of load may be affected by changes in temperature and relative humidity.

The constant stress that a wood member can sustain is approximately an exponential function of time to failure, as illustrated in Figure 4–22. This relationship is a composite of results of studies on small, clear wood specimens, conducted at constant temperature and relative humidity.

For a member that continuously carries a load for a long period, the load required to produce failure is much less than that determined from the strength properties in Tables 4–3 to 4–5. Based on Figure 4–22, a wood member under the continuous action of bending stress for 10 years may carry only 60% (or perhaps less) of the load required to produce failure in the same specimen loaded in a standard bending strength test of only a few minutes duration. Conversely, if the duration of load is very short, the load-carrying capacity may be higher than that determined from strength properties given in the tables.

Time under intermittent loading has a cumulative effect. In tests where a constant load was periodically placed on a beam and then removed, the cumulative time the load was actually applied to the beam before failure was essentially equal to the time to failure for a similar beam under the same load applied continuously.

The time to failure under continuous or intermittent loading is looked upon as a creep–rupture process; a member has to undergo substantial deformation before failure. Deformation at failure is approximately the same for duration of load tests as for standard strength tests.

Changes in climatic conditions increase the rate of creep and shorten the duration during which a member can support a given load. This effect can be substantial for very small wood specimens under large cyclic changes in temperature and relative humidity. Fortunately, changes in temperature and relative humidity are moderate for wood in the typical service environment.

Fatigue

In engineering, the term fatigue is defined as the progressive damage that occurs in a material subjected to cyclic loading. This loading may be repeated (stresses of the same sign; that is, always compression or always tension) or reversed (stresses of alternating compression and tension). When sufficiently high and repetitious, cyclic loading stresses can result in fatigue failure.

Fatigue life is a term used to define the number of cycles that are sustained before failure. Fatigue strength, the maximum stress attained in the stress cycle used to determine fatigue life, is approximately exponentially related to fatigue life; that is, fatigue strength decreases approximately linearly as the logarithm of number of cycles increases. Fatigue strength and fatigue life also depend on several other factors: frequency of cycling; repetition or reversal of loading; range factor (ratio of minimum to maximum stress per cycle); and other factors such as temperature, moisture content, and specimen size. Negative range factors imply repeated reversing loads, whereas positive range factors imply nonreversing loads.

Results from several fatigue studies on wood are given in Table 4–17. Most of these results are for repeated loading with a range ratio of 0.1, meaning that the minimum stress per cycle is 10% of the maximum stress. The maximum stress per cycle, expressed as a percentage of estimated static strength, is associated with the fatigue life given in millions of cycles. The first three lines of data, which list the same cyclic frequency (30 Hz), demonstrate the effect of range ratio on fatigue strength (maximum fatigue stress that can be maintained for a given fatigue life); fatigue bending strength decreases as range ratio decreases. Third-point bending results show the effect of small knots or slope of grain on fatigue strength at a range ratio of 0.1 and frequency of 8.33 Hz. Fatigue strength is lower for wood containing small knots or a 1-in-12 slope of grain than for clear straight-grained wood and even lower for wood containing a combination of small knots and a 1-in-12 slope of grain. Fatigue strength is the same for a scarf joint in tension as for tension parallel to the grain, but a little lower for a finger joint in tension. Fatigue strength is slightly lower in shear than in tension parallel to the grain. Other comparisons do not have much meaning because range ratios or cyclic frequency differ; however, fatigue strength is high in compression parallel to the grain compared with other properties. Little is known about other factors that may affect fatigue strength in wood.

Table 4–17. Summary of reported results on cyclic fatigue[a]

Property	Range ratio	Cyclic frequency (Hz)	Maximum stress per cycle[b] (%)	Approximate fatigue life ($\times 10^6$ cycles)
Bending, clear, straight grain				
Cantilever	0.45	30	45	30
Cantilever	0	30	40	30
Cantilever	–1.0	30	30	30
Center-point	–1.0	40	30	4
Rotational	–1.0	—	28	30
Third-point	0.1	8-1/3	60	2
Bending, third-point				
Small knots	0.1	8-1/3	50	2
Clear, 1:12 slope of grain	0.1	8-1/3	50	2
Small knots, 1:12 slope of grain	0.1	8-1/3	40	2
Tension parallel to grain				
Clear, straight grain	0.1	15	50	30
Clear, straight grain	0	40	60	3.5
Scarf joint	0.1	15	50	30
Finger joint	0.1	15	40	30
Compression parallel to grain				
Clear, straight grain	0.1	40	75	3.5
Shear parallel to grain				
Glue-laminated	0.1	15	45	30

[a]Initial moisture content about 12% to 15%.
[b]Percentage of estimated static strength.

Creep, temperature rise, and loss of moisture content occur in tests of wood for fatigue strength. At stresses that cause failure in about 106 cycles at 40 Hz, a temperature rise of

15°C (27°F) has been reported for parallel-to-grain compression fatigue (range ratio slightly greater than zero), parallel-to-grain tension fatigue (range ratio = 0), and reversed bending fatigue (range ratio = –1). The rate of temperature rise is high initially but then diminishes to moderate; a moderate rate of temperature rise remains more or less constant during a large percentage of fatigue life. During the latter stages of fatigue life, the rate of temperature rise increases until failure occurs. Smaller rises in temperature would be expected for slower cyclic loading or lower stresses. Decreases in moisture content are probably related to temperature rise.

Aging

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 clear wood strength occur only 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.

Exposure to Chemicals

The effect of chemical solutions 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 depends largely on the amount of swelling, and this loss is regained upon removal of the swelling liquid. Anhydrous ammonia markedly reduces the strength and stiffness of wood, but these properties are regained to a great extent when the ammonia is removed. Heartwood generally is less affected than sapwood because it is more impermeable. Accordingly, wood treatments that retard liquid penetration usually enhance natural resistance to chemicals.

Chemical solutions that decompose wood substance (by hydrolysis or oxidation) have a permanent effect on strength. The following generalizations summarize the effect of chemicals:

- Some species are quite resistant to attack by dilute mineral and organic acids.
- Oxidizing acids such as nitric acid degrade wood more than do nonoxidizing acids.
- Alkaline solutions are more destructive than are acidic solutions.
- Hardwoods are more susceptible to attack by both acids and alkalis than are softwoods.
- Heartwood is less susceptible to attack by both acids and alkalis than is sapwood.

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 is also used extensively in cooling towers because of its superior resistance to mild acids and solutions of acidic salts.

Chemical Treatment

Wood is often treated with chemicals to enhance its fire performance or decay resistance in service. Each set of treatment chemicals and processes has a unique effect on the mechanical properties of the treated wood.

Fire-retardant treatments and treatment methods distinctly reduce the mechanical properties of wood. Some fire-retardant-treated products have experienced significant in-service degradation on exposure to elevated temperatures when used as plywood roof sheathing or roof-truss lumber. New performance requirements within standards set by the American Standards for Testing and Materials (ASTM) and American Wood Preservers' Association (AWPA) preclude commercialization of inadequately performing fire-retardant-treated products.

Although preservative treatments and treatment methods generally reduce the mechanical properties of wood, any initial loss in strength from treatment must be balanced against the progressive loss of strength from decay when untreated wood is placed in wet conditions. The effects of preservative treatments on mechanical properties are directly related to wood quality, size, and various pretreatment, treatment, and post-treatment processing factors. The key factors include preservative chemistry or chemical type, preservative retention, initial kiln-drying temperature, post-treatment drying temperature, and pretreatment incising (if required). North American design guidelines address the effects of incising on mechanical properties of refractory wood species and the short-term duration-of-load adjustments for all treated lumber. These guidelines are described in Chapter 6.

Oil-Type Preservatives

Oil-type preservatives cause no appreciable strength loss because they do not chemically react with wood cell wall components. However, treatment with oil-type preservatives can adversely affect strength if extreme in-retort seasoning parameters are used (for example, Boultonizing, steaming, or vapor drying conditions) or if excessive temperatures or pressures are used during the treating process. To preclude strength loss, the user should follow specific treatment processing requirements as described in the treatment standards.

Waterborne Preservatives

Waterborne preservative treatments can reduce the mechanical properties of wood. Treatment standards include specific processing requirements intended to prevent or limit strength reductions resulting from the chemicals and the waterborne preservative treatment process. The effects of waterborne preservative treatment on mechanical properties are related to species, mechanical properties, preservative chemistry or type, preservative retention, post-treatment drying temperature, size and grade of material, product type, initial kiln-drying temperature, incising, and both temperature and moisture in service.

Species—The magnitude of the effect of various waterborne preservatives on mechanical properties does not appear to vary greatly between different species.

Mechanical property—Waterborne preservatives affect each mechanical property differently. If treated according to AWPA standards, the effects are as follows: modulus of elasticity (MOE), compressive strength parallel to grain, and compressive stress perpendicular to grain are unaffected or slightly increased; modulus of rupture (MOR) and tensile strength parallel to grain are reduced from 0% to 20%, depending on chemical retention and severity of redrying temperature; and energy-related properties (for example, work to maximum load and impact strength) are reduced from 10% to 50%.

Preservative chemistry or type—Waterborne preservative chemical systems differ in regard to their effect on strength, but the magnitude of these differences is slight compared with the effects of treatment processing factors. Chemistry-related differences seem to be related to the reactivity of the waterborne preservative and the temperature during the fixation/precipitation reaction with wood.

Retention—Waterborne preservative retention levels of ≤16 kg/m^3 (≤1.0 lb/ft^3) have no effect on MOE or compressive strength parallel to grain and a slight negative effect (−5% to −10%) on tensile or bending strength. However, energy-related properties are often reduced from 15% to 30%. At a retention level of 40 kg/m^3 (2.5 lb/ft^3), MOR and energy-related properties are further reduced.

Post-treatment drying temperature—Air drying after treatment causes no significant reduction in the static strength of wood treated with waterborne preservative at a retention level of 16 kg/m^3 (1.0 lb/ft^3). However, energy-related properties are reduced. The post-treatment redrying temperature used for material treated with waterborne preservative has been found to be critical when temperatures exceed 75 °C (167 °F). Redrying limitations in treatment standards have precluded the need for an across-the-board design adjustment factor for waterborne-preservative-treated lumber in engineering design standards. The limitation on post-treatment kiln-drying temperature is set at 74°C (165°F).

Size of material—Generally, larger material, specifically thicker, appears to undergo less reduction in strength than does smaller material. Recalling that preservative treatments usually penetrate the treated material to a depth of only 6 to 51 mm (0.25 to 2.0 in.), depending on species and other factors, the difference in size effect appears to be a function of the product's surface-to-volume ratio, which affects the relative ratio of treatment-induced weight gain to original wood weight.

Grade of material—The effect of waterborne preservative treatment is a quality-dependent phenomenon. Higher grades of wood are more affected than lower grades. When viewed over a range of quality levels, higher quality lumber is reduced in strength to a proportionately greater extent than is lower quality lumber.

Product type—The magnitude of the treatment effect on strength for laminated veneer lumber conforms closely to effects noted for higher grades of solid-sawn lumber. The effects of waterborne preservative treatment on plywood seem comparable to that on lumber. Fiber-based composite products may be reduced in strength to a greater extent than is lumber. This additional effect on fiber-based composites may be more a function of internal bond damage caused by waterborne-treatment-induced swelling rather than actual chemical hydrolysis.

Initial kiln-drying temperature—Although initial kiln drying of some lumber species at 100°C to 116°C (212°F to 240°F) for short durations has little effect on structural properties, such drying results in more hydrolytic degradation of the cell wall than does drying at lower temperature kiln schedules. Subsequent preservative treatment and redrying of material initially dried at high temperatures causes additional hydrolytic degradation. When the material is subsequently treated, initial kiln drying at 113°C (235°F) has been shown to result in greater reductions over the entire bending and tensile strength distributions than does initial kiln drying at 91°C (196°F). Because Southern Pine lumber, the most widely treated product, is most often initially kiln dried at dry-bulb temperatures near or above 113°C (235°F), treatment standards have imposed a maximum redrying temperature limit of 74°C (165°F) to preclude the cumulative effect of thermal processing.

Incising—Incising, a pretreatment mechanical process in which small slits (incisions) are punched in the surface of the wood product, is used to improve preservative penetration and distribution in difficult-to-treat species. Incising may reduce strength; however, because the increase in treatability provides a substantial increase in biological performance, this strength loss must be balanced against the progressive loss in strength of untreated wood from the incidence of decay. Most incising patterns induce some strength loss, and the magnitude of this effect is related to the size of material being incised and the incision depth and density (that is, number of incisions per unit area). In less than 50 mm (2 in.) thick, dry lumber, incising and preservative treatment induces losses in MOE of 5% to 15% and in static strength properties of 20% to 30%. Incising and treating timbers or tie stock at an incision density of ≤1,500 incisions/m^2 (≤140 incisions/ft^2) and to a depth of 19 mm (0.75 in.) reduces strength by 5% to 10%.

In-service temperature—Both fire-retardant and preservative treatments accelerate the thermal degradation of bending strength of lumber when exposed to temperatures above 54˚C (130˚F).

In-service moisture content—Current design values apply to material dried to ≤19% maximum (15% average) moisture content or to green material. No differences in strength have been found between treated and untreated material when tested green or at moisture contents above 12%. When very dry treated lumber of high grade was tested at 10% moisture content, its bending strength was reduced compared with that of matched dry untreated lumber.

Duration of load—When subjected to impact loads, wood treated with chromated copper arsenate (CCA) does not exhibit the same increase in strength as that exhibited by untreated wood. However, when loaded over a long period, treated and untreated wood behave similarly.

Polymerization

Wood is also sometimes impregnated with monomers, such as methyl methacrylate, which are subsequently polymerized. Many of the mechanical properties of the resultant wood–plastic 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 influence composite properties.

Nuclear Radiation

Wood is occasionally subjected to nuclear radiation. Examples are wooden structures closely associated with nuclear reactors, the polymerization of wood with plastic using nuclear radiation, and nondestructive estimation of wood density and moisture content. 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 exceeds 1 megarad, tensile strength parallel to grain and toughness decrease. At a dosage of 300 megarads, tensile strength is reduced about 90%. Gamma rays also affect compressive strength parallel to grain at a dosage above 1 megarad, but higher dosage has a greater effect on tensile strength than on compressive strength; only approximately one-third of 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.

Mold and Stain Fungi

Mold and stain fungi do not seriously affect most mechanical properties of wood because such fungi feed on substances within the cell cavity or attached to the cell wall rather than on the structural wall itself. The duration of infection and the species of fungi involved are important factors in determining the extent of degradation.

Although low levels of biological stain cause little loss in strength, heavy staining may reduce specific gravity by 1% to 2%, surface hardness by 2% to 10%, bending and crushing strength by 1% to 5%, and toughness or shock resistance by 15% to 30%. Although molds and stains usually do not have a major effect on strength, conditions that favor these organisms also promote the development of wood-destroying (decay) fungi and soft-rot fungi (Ch. 13). Pieces with mold and stain should be examined closely for decay if they are used for structural purposes.

Decay

Unlike mold and stain fungi, wood-destroying (decay) fungi seriously reduce strength by metabolizing the cellulose fraction of wood that gives wood its strength.

Early stages of decay are virtually impossible to detect. For example, brown-rot fungi may reduce mechanical properties in excess of 10% before a measurable weight loss is observed and before decay is visible. When weight loss reaches 5% to 10%, mechanical properties are reduced from 20% to 80%. Decay has the greatest effect on toughness, impact bending, and work to maximum load in bending, the least effect on shear and hardness, and an intermediate effect on other properties. Thus, when strength is important, adequate measures should be taken to (a) prevent decay before it occurs, (b) control incipient decay by remedial measures (Ch. 13), or (c) replace any wood member in which decay is evident or believed to exist in a critical section. Decay can be prevented from starting or progressing if wood is kept dry (below 20% moisture content).

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 undried (unseasoned) or dried (seasoned) lumber. Although damage is difficult to control in the standing tree, insect damage can be eliminated to a great extent by proper control methods. Insect holes are generally classified as pinholes, grub holes, and powderpost holes. Because of their irregular burrows, powderpost larvae may destroy most of a piece's interior while only small holes appear on the surface, and the strength of the piece may be reduced virtually to zero. No method is known for estimating the reduction in strength from the appearance of insect-damaged wood. When strength is an important consideration, the safe procedure is to eliminate pieces containing insect holes.

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Commercial Lumber

Kent A. McDonald and David E. Kretschmann

Contents

In a broad sense, commercial lumber is any lumber that is bought or sold in the normal channels of commerce. Commercial lumber may be found in a variety of forms, species, and types, and in various commercial establishments, both wholesale and retail. Most commercial lumber is graded by standardized rules that make purchasing more or less uniform throughout the country.

When sawn, a log yields lumber of varying quality. To enable users to buy the quality that best suits their purposes, lumber is graded into use categories, each having an appropriate range in quality.

Generally, 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, which constitute the great bulk of lumber, contain fairly numerous knots and other features. With proper grading, lumber containing these features is entirely satisfactory for many uses.

The grading operation for most lumber takes place at the sawmill. Establishment of grading procedures is largely the responsibility of manufacturers' 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

The principal use of hardwood lumber is for remanufacture into furniture, cabinetwork, and pallets, or direct use as flooring, paneling, moulding, and millwork. Hardwood lumber is graded and marketed in three main categories: Factory lumber, dimension parts, and finished market products. Several hardwood species are graded under the American Softwood Lumber Standard and sold as structural lumber (Ch. 6). Also, specially graded hardwood lumber can be used for structural glued-laminated lumber.

Prior to 1898, hardwoods were graded by individual mills for local markets. In 1898, manufacturers and users formed the National Hardwood Lumber Association to standardize grading for hardwood lumber. Between 1898 and 1932, grading was based on the number and size of visual features. In 1932, the basis for grading was changed to standard clear-cutting sizes.

Both Factory lumber and dimension parts are intended to serve the industrial customer. The important difference is that for Factory lumber, the grades reflect the proportion of a piece that can be cut into useful smaller pieces, whereas the grades for dimension parts 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 moulding, stair treads, and hardwood flooring.

Factory Lumber

Grades

The rules adopted by the National Hardwood Lumber Association are considered standard in grading hardwood lumber intended 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, commonly called cuttings, which are generally clear on one side, have the reverse face sound, and are not smaller than a specified size.

The best grade in the Factory lumber category is termed FAS. The second grade is F1F. The third grade is Selects, which is followed by No. 1 Common, No. 2A Common, No. 2B Common, Sound Wormy, No. 3A Common, and No. 3B Common. Except for F1F and Selects, the poorer side of a piece is inspected for grade assignment. Standard hardwood lumber grades are described in Table 5–1. This table illustrates, for example, that FAS includes pieces that will allow at least 83-1/3% of their surface measure to be cut into clear face material. Except for Sound Wormy, the minimum acceptable length, width, surface measure, and percentage of piece that must work into a cutting decrease with decreasing grade. Figure 5–1 is an example of grading for cuttings.

This brief summary of grades for Factory lumber should not be regarded as a complete set of grading rules because many details, exceptions, and special rules for certain species are not included. The complete official rules of the National Hardwood Lumber Association (NHLA) should be followed as the only full description of existing grades (see Table 5–2 for addresses of NHLA and other U.S. hardwood grading associations). Table 5–3 lists names of commercial domestic hardwood species that are graded by NHLA rules.

Standard Dimensions

Standard lengths of hardwood lumber are in 300-mm (1-ft) increments from 1.2 to 4.8 m (4 to 16 ft). Standard thickness values for hardwood lumber, rough and surfaced on two sides (S2S), are given in Table 5–4. The thickness of S1S lumber is subject to contract agreement. Abbreviations commonly used in contracts and other documents for the purchase and sale of lumber are listed at the end of this chapter.

Hardwood lumber is usually manufactured to random width. The hardwood lumber grades do not specify standard widths; however, the grades do specify minimum width for each grade as follows:

Grade	Minimum width (mm (in.))
FAS	150 (6)
F1F	150 (6)
Selects	100 (4)
No. 1, 2A, 2B, 3A, 3B Common	80 (3)

If the width is specified by purchase agreement, S1E or S2E lumber is 10 mm (3/8 in.) scant of nominal size in lumber less than 200 mm (8 in.) wide and 13 mm (1/2 in.) scant in lumber ≥200 mm (≥8 in.) wide.

Dimension and Component Parts

The term “dimension parts” for hardwoods signifies stock that is processed in specific thickness, width, and length, or multiples thereof and ranges from semi-machined to completely machined component products. This stock is sometimes referred to as “hardwood dimension stock” or “hardwood lumber for dimension parts.” This stock should not be confused with “dimension lumber,” a term used in the structural lumber market to mean lumber standard 38 mm to less than 114 mm thick (nominal 2 in. to less than 5 in. thick).

Dimension component parts are normally kiln dried and generally graded under the rules of the Wood Components Manufacturers Association (WCMA). These rules encompass three classes of material, each of which is classified into various grades:

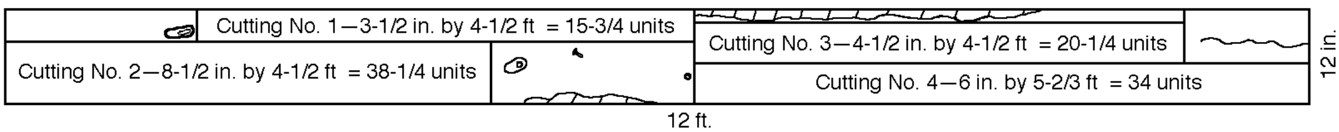
Hardwood dimension parts (flat stock)	Solid kiln-dried squares (rough)	Solid kiln-dried squares (surfaced)
Clear two faces	Clear	Clear
Clear one face	Select	Select
Paint	Sound	Paint
Core		Second
Sound		

Each class may be further defined as semifabricated (rough or surfaced) or completely fabricated, including edge-glued panels. The rough wood component parts are blank-sawn and ripped to size. Surfaced semifabricated parts have been through one or more manufacturing stages. Completely fabricated parts have been completely processed for their end use.

Table 5–1. Standard hardwood lumber grades[a,b]

Grade and allowable lengths	Allowable width (in.)	Allowable surface measure of pieces (ft^2)	Minimum amount of piece in clearface cuttings (%)	Allowable cuttings: Maximum no.	Allowable cuttings: Minimum size
FAS[c]	6+	4 to 9 10 to 14 15+	83-1/3	1 2 3	4 in. by 5 ft, or 3 in. by 7 ft
F1F[c]	6+	4 to 7 6 and 7 8 to 11 8 to 11 12 to 15 12 to 15 16+	83-1/3 91-2/3 83-1/3 91-2/3 83-1/2 91-2/3 83-1/3	1 2 2 3 3 4 4	4 in. by 5 ft, or 3 in. by 7 ft
Selects 6 to 16 ft (will admit 30% of 6 to 11 ft)	4+	2 and 3 4+	91-2/3 —[d]	1	4 in. by 5 ft, or 3 in. by 7 ft
No. 1 Common 4 to 16 ft (will admit 10% of 4 to 7 ft, 1/2 of which may be 4 and 5 ft)	3+	1 2 3 and 4 3 and 4 5 to 7 5 to 7 8 to 10 11 to 13 14+	100 75 66-2/3 75 66-2/3 75 66-2/3 66-2/3 66-2/3	0 1 1 2 2 3 3 4 5	4 in. by 2 ft, or 3 in. by 3 ft
No. 2 Common 4 to 16 ft (will admit 30% of 4 to 7 ft, 1/3 of which may be 4 and 5 ft)	3+	1 2 and 3 2 and 3 4 and 5 4 and 5 6 and 7 6 and 7 8 and 9 10 and 11 12 and 13 14+	66-2/3 50 66-2/3 50 66-2/3 50 66-2/3 50 50 50 50	1 1 2 2 3 3 4 4 5 6 7	3 in. by 2 ft
Sound Wormy[e] No. 3A Common 4 to 16 ft (will admit 50% of 4 to 7 ft, 1/2 of which may be 4 and 5 ft)	3+	1+	33-1/3[f]	—[g]	3 in. by 2 ft
Sound Wormy[e] No. 3B Common 4 to 16 ft (will admit 50% of 4 to 7 ft, 1/2 of which may be 4 and 5 ft)	3+	1+	25[h]	—[g]	1-1/2 in. by 2 ft

[a]Current grading rules are written only in the inch–pound system of measurement.
[b]Inspection made on poorer side of piece, except in Selects grade.
[c]FAS is a grade that designates Firsts and Seconds. F1F is a grade that designates FAS one face.
[d]Same as F1F, with reverse side of board not below No. 1 Common or reverse side of sound cuttings.
[e]Same requirements as those for No. 1 Common and better except that wormholes and limited sound knots and other imperfections are allowed in cuttings.
[f]Also admits pieces that grade not below No. 2 Common on the good face and reverse side of sound cuttings.
[g]Unlimited.
[h]Cuttings must be sound; clear face not required.



1. Determine Surface Measure (S.M.) using lumber scale stick or from formula:

   $$\frac{\text{Width in inches} \times \text{length in feet}}{12} = \frac{12 \text{ in.} \times 12 \text{ ft}}{12}$$

   $= 12\ \text{ft}^2$ S.M.

2. No. 1 Common is assumed grade of board. Percent of clear-cutting area required for No. 1 Common—$66\frac{2}{3}\%$ or $\frac{8}{12}$.

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 in. × 2 ft or 3 in. × 3 ft.

5. Determine clear-face cutting units needed.

   For No. 1 Common grade S.M. × 8 = 12 × 8 = 96 units

6. Determine total area of permitted clear-face cutting in units.

   Width in inches and fractions of inches × length in feet and fractions of feet

   Cutting #1—$3\frac{1}{2}$ in. × $4\frac{1}{2}$ ft = $15\frac{3}{4}$ units
   Cutting #2—$8\frac{1}{2}$ in. × $4\frac{1}{2}$ ft = 38 units
   Cutting #3—$4\frac{1}{2}$ in. × $4\frac{1}{2}$ ft = $20\frac{1}{4}$ units
   Cutting #4—6 in. × $5\frac{2}{3}$ ft = 34 units

   Total Units 108

   Units required for No. 1 Common—96.

7. Conclusion: Board meets requirements for No. 1 Common grade.

Figure 5–1. Example of hardwood grading for cuttings using No. 1 Common lumber grade. Current grading rules are written only in the inch–pound system of measurement.

Table 5–2. Hardwood grading associations in United States[a]

Name and address	Species covered by grading rules (products)
National Hardwood Lumber Association P.O. Box 34518 Memphis, TN 38184–0518	All hardwood species (furniture cuttings, construction lumber, siding, panels)
Wood Components Manufacturers Association 1000 Johnson Ferry Rd., Suite A-130 Marietta, GA 30068	All hardwood species (hardwood furniture dimension, squares, laminated stock, interior trim, stair treads and risers)
Maple Flooring Manufacturers Association 60 Revere Dr., Suite 500 Northbrook, IL 60062	Maple, beech, birch (flooring)
National Oak Flooring Manufacturers Association P.O. Box 3009 Memphis, TN 38173–0009 www.nofma.org	Oak, ash, pecan, hickory, pecan, beech, birch, hard maple (flooring, including prefinished)

[a]Grading associations that include hardwood species in structural grades are listed in Table 5–5.

Table 5–3. Nomenclature of commercial hardwood lumber

Commercial name for lumber	Common tree name	Botanical name
Alder, Red	Red alder	*Alnus rubra*
Ash, Black	Black ash	*Fraxinus nigra*
Ash, Oregon	Oregon ash	*Fraxinus latifolia*
Ash, White	Blue ash	*Fraxinus quadrangulata*
	Green ash	*Fraxinus pennsylvanica*
	White ash	*Fraxinus americana*
Aspen (popple)	Bigtooth aspen	*Populus grandidentata*
	Quaking aspen	*Populus tremuloides*
Basswood	American basswood	*Tilia americana*
	White basswood	*Tilia heterophylla*
Beech	American beech	*Fagus grandifolia*
Birch	Gray birch	*Betula populifolia*
	Paper birch	*Betula papyrifera*
	River birch	*Betula nigra*
	Sweet birch	*Betula lenta*
	Yellow birch	*Betula alleghaniensis*
Box Elder	Boxelder	*Acer negundo*
Buckeye	Ohio buckeye	*Aesculus glabra*
	Yellow buckeye	*Aesculus octandra*
Butternut	Butternut	*Juglans cinerea*
Cherry	Black cherry	*Prunus serotina*
Chestnut	American chestnut	*Castanea dentata*
Cottonwood	Balsam poplar	*Populus balsamifera*
	Eastern cottonwood	*Populus deltoides*
	Black cottonwood	*Populus trichocarpa*
Cucumber	Cucumbertree	*Magnolia acuminata*
Dogwood	Flowering dogwood	*Cornus florida*
	Pacific dogwood	*Cornus nuttallii*
Elm, Rock	Cedar elm	*Ulmus crassifolia*
	Rock elm	*Ulmus thomasii*
	September elm	*Ulmus serotina*
	Winged elm	*Ulmus alata*
Elm, Soft	American elm	*Ulmus americana*
	Slippery elm	*Ulmus rubra*
Gum	Sweetgum	*Liquidambar styraciflua*
Hackberry	Hackberry	*Celtis occidentalis*
	Sugarberry	*Celtis laevigata*
Hickory	Mockernut hickory	*Carya tomentosa*
	Pignut hickory	*Carya glabra*
	Shagbark hickory	*Carya ovata*
	Shellbark hickory	*Carya lacinosa*
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	*Magnolia virginiana*
Maple, Hard	Black maple	*Acer nigrum*
	Sugar maple	*Acer saccharum*
Maple, Oregon	Big leaf maple	*Acer macrophyllum*
Maple, Soft	Red maple	*Acer rubrum*
	Silver maple	*Acer saccharinum*
Oak, Red	Black oak	*Quercus velutina*
	Blackjack oak	*Quercus marilandica*
	California black oak	*Quercus kelloggi*
	Cherrybark oak	*Quercus falcata* var. *pagodaefolia*
	Laurel oak	*Quercus laurifolia*
	Northern pin oak	*Quercus ellipsoidalis*
	Northern red oak	*Quercus rubra*
	Nuttall oak	*Quercus nuttallii*
	Pin oak	*Quercus palustris*
	Scarlet oak	*Quercus coccinea*
	Shumard oak	*Quercus shumardii*
	Southern red oak	*Quercus falcata*
	Turkey oak	*Quercus laevis*
	Willow oak	*Quercus phellos*
Oak, White	Arizona white oak	*Quercus arizonica*
	Blue oak	*Quercus douglasii*
	Bur oak	*Quercus macrocarpa*
	Valley oak	*Quercus lobata*
	Chestnut oak	*Quercus prinus*
	Chinkapin oak	*Quercus muehlenbergii*
	Emory oak	*Quercus emoryi*
	Gambel oak	*Quercus gambelii*
	Mexican blue oak	*Quercus oblongifolia*
	Live oak	*Quercus virginiana*
	Oregon white oak	*Quercus garryana*
	Overcup oak	*Quercus lyrata*
	Post oak	*Quercus stellata*
	Swamp chestnut oak	*Quercus michauxii*
	Swamp white oak	*Quercus bicolor*
	White oak	*Quercus alba*
Oregon Myrtle	California-laurel	*Umbellularia californica*
Osage Orange	Osage-orange	*Maclura pomifera*
Pecan	Bitternut hickory	*Carya cordiformis*
	Nutmeg hickory	*Carya myristiciformis*
	Water hickory	*Carya aquatica*
	Pecan	*Carya illinoensis*
Persimmon	Common persimmon	*Diospyros virginiana*
Poplar	Yellow-poplar	*Liriodendron tulipifera*
Sassafras	Sassafras	*Sassafras albidum*
Sycamore	Sycamore	*Platanus occidentalis*
Tanoak	Tanoak	*Lithocarpus densiflorus*
Tupelo	Black tupelo, blackgum	*Nyssa sylvatica*
	Ogeechee tupelo	*Nyssa ogeche*
	Water tupelo	*Nyssa aquatica*
Walnut	Black walnut	*Juglans nigra*
Willow	Black willow	*Salix nigra*
	Peachleaf willow	*Salix amygdaloides*

Table 5–4. Standard thickness values for rough and surfaced (S2S) hardwood lumber

Rough (mm	(in.))	Surfaced (mm	(in.))
9.5	(3/8)	4.8	(3/16)
12.7	(1/2)	7.9	(5/16)
15.9	(5/8)	9.4	(7/16)
19.0	(3/4)	14.3	(9/16)
25.4	(1)	20.6	(13/16)
31.8	(1-1/4)	27.0	(1-1/16)
38.1	(1-1/2)	33.3	(1-5/16)
44.4	(1-3/4)	38.1	(1-1/2)
50.8	(2)	44.4	(1-3/4)
63.5	(2-1/2)	57.2	(2-1/4)
76.2	(3)	69.8	(2-3/4)
88.9	(3-1/2)	82.6	(3-1/4)
101.6	(4)	95.2	(3-3/4)
114.3	(4-1/2)	—[a]	—[a]
127.0	(5)	—[a]	—[a]
139.7	(5-1/2)	—[a]	—[a]
152.4	(6)	—[a]	—[a]

[a]Finished size not specified in rules. Thickness subject to special contract.

Finished Market Products

Some hardwood lumber products are graded in relatively finished form, with little or no further processing anticipated. Flooring is probably the finished market product with the highest volume. Other examples are lath, siding, ties, planks, carstock, construction boards, timbers, trim, moulding, 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 (MFMA) or the National Oak Flooring Manufacturers Association (NOFMA). Tongued-and-grooved, end-matched hardwood flooring is commonly furnished. Square-edge, square-end-strip flooring is also available as well as parquet flooring suitable for laying with mastic.

The grading rules of the Maple Flooring Manufacturers Association cover flooring that is manufactured from hard maple, beech, and birch. Each species is graded into four categories:

- First grade—one face practically free of all imperfections; variations in natural color of wood allowed
- Second grade—tight, sound knots (except on edges or ends) and other slight imperfections allowed; must be possible to lay flooring without waste
- Third grade—may contain all visual features common to hard maple, beech, and birch; will not admit voids on edges or ends, or holes over 9.5-mm (3/8-in.) in diameter; must permit proper laying of floor and provide a serviceable floor; few restrictions on imperfections; must be possible to lay flooring properly
- Fourth grade—may contain all visual features, but must be possible to lay a serviceable floor, with some cutting

Combination grades of “Second and Better” and “Third and Better” are sometimes specified. There are also special grades based on color and species.

The standard thickness of MFMA hard maple, beech, and birch flooring is 19.8 mm (25/32 in.). Face widths are 38, 51, 57, and 83 mm (1-1/2, 2, 2-1/4, and 3-1/4 in.). Standard lengths are 610 mm (2 ft) and longer in First- and Second-grade flooring and 381 mm (1-1/4 ft) and longer in Third-grade flooring.

The Official Flooring Grading Rules of NOFMA cover oak (unfinished and prefinished), beech, birch, hard maple, ash, and hickory/pecan. Flooring grades are determined by the appearance of the face surface.

Oak is separated as red oak and white oak and by grain direction: plain sawn (all cuts), quartersawn (50% quartered character), rift sawn (75% rift character), and quarter/rift sawn (a combination). Oak flooring has four main grade separations—Clear, Select, No. 1 Common, and No. 2 Common. Clear is mostly heartwood and accepts a 10-mm (3/8-in.) strip of bright sapwood or an equivalent amount not more than 25 mm (1 in.) wide along the edge and a minimum number of character marks and discoloration, allowing for all natural heartwood color variations. Select allows all color variations of natural heartwood and sapwood along with characters such as small knots, pinworm holes, and brown streaks. No. 1 Common contains prominent variations in coloration, which include heavy streaks, sticker stains, open checks, knots, and small knot holes that fill. No. 2 Common contains sound natural variation of the forest product and manufacturing imperfections to provide a serviceable floor.

Average lengths for unfinished oak grades are as follows:

Grade	Standard packaging		Shorter packaging	
Clear	1.14 m	(3-3/4 ft)	1.07 m	(3-1/2 ft)
Select	0.99 m	(3-1/4 ft)	0.91 m	(3 ft)
No. 1 Common	0.84 m	(2-3/4 ft)	0.76 m	(2-/1/2 ft)
No. 2 Common	0.69 m	(2-1/4 ft)	0.61 m	(2 ft)

Standard packaging refers to nominal 2.4-m (8-ft) pallets or nested bundles. Shorter packaging refers to nominal 2.13-m (7-ft) and shorter pallets or nested bundles.

Standard and special NOFMA grades for species other than oak are as follows:

Species	Grade
	Standard grades
Beech, birch, and hard maple	First, Second, Third, Second & Better, Third & Better
Hickory and pecan	First, Second, Third, Second & Better, Third & Better
Ash	Clear, Select, No. 1 Common, No. 2 Common
	Special grades
Beech and birch	First Grade Red
Hard maple	First Grade White
Hickory and pecan	First Grade White, First Grade Red, Second Grade Red

Standard thickness values for NOFMA tongue and groove flooring are 19, 12, 9.5 (3/4, 1/2, 3/8 in.), with 19.8, and 26.2 mm (25/32 and 33/32 in.) for maple flooring. Standard face widths are 38, 51, 57, and 83 mm (1-1/2, 2, 2-1/4, and 3-1/4 in.). Strips are random length from minimum 0.23 m to maximum 2.59 m (9 to 102 in.).

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. United States agencies and associations that prepare rules for and supervise grading of hardwoods are given in Table 5–2.

Softwood Lumber

For many years, softwood lumber has demonstrated the versatility of wood by serving as a primary raw material for construction and manufacture. In this role, softwood lumber has been produced in a wide variety of products from many different species. The first industry-sponsored grading rules (product descriptions) for softwoods, which were established before 1900, were comparatively simple because 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; thus, lumber from various regions differed in size, grade name, and allowable grade characteristics. When different species were graded under different rules and competed in the same consuming areas, confusion and dissatisfaction were inevitable.

To minimize unnecessary differences in the grading rules of softwood lumber and to improve and simplify these rules, a number of conferences were organized by the U.S. Department of Commerce from 1919 to 1925. These meetings 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 allowable design properties, formulated as a voluntary American Lumber Standard. This standard has been modified several times, including addition of hardwood species to the standard beginning in 1970. The current edition is the American Softwood Lumber Standard PS–20. Lumber cannot be graded as American Standard lumber unless the grade rules have been approved by the American Lumber Standard Committee (ALSC), Inc., Board of Review.

Softwood lumber is classified for market use by form of manufacture, species, and grade. For many products, the American Softwood Lumber Standard and the grading rules certified through it serve as a basic reference. For specific information on other products, reference must be made to grade rules, industry marketing aids, and trade journals.

Lumber Grades

Softwood lumber grades can be classified into three major categories of use: (a) yard lumber, (b) structural lumber, and (c) Factory and Shop lumber. Yard lumber and structural lumber relate principally to lumber expected to function as graded and sized after primary processing (sawing and planing). Factory and Shop refer to lumber that will undergo a number of further manufacturing steps and reach the consumer in a significantly different form.

Yard Lumber

The grading requirements of yard lumber are specifically related to the construction uses intended, and little or no further grading occurs once the piece leaves the sawmill. Yard lumber can be placed into two basic classifications, Select and Common. Select and Common lumber, as categorized here, encompass those lumber products in which appearance is of primary importance; structural integrity, while sometimes important, is a secondary feature.

Select Lumber—Select lumber is generally non-stress-graded, but it forms a separate category because of the distinct importance of appearance in the grading process. Select lumber is intended for natural and paint finishes. This category of lumber includes lumber that has been machined to a pattern and S4S lumber. Secondary manufacture of these items is usually restricted to on-site fitting such as cutting to length and mitering. The Select category includes trim, siding, flooring, ceiling, paneling, casing, base, stepping, and finish boards.

Most Select lumber grades are generally described by letters and combinations of letters (B&BTR, C&BTR, D) or names (Superior, Prime) depending upon the species and the grading rules under which the lumber is graded. (See list of commonly used lumber abbreviations at the end of this chapter.) The specifications FG (flat grain), VG (vertical grain), and MG (mixed grain) are offered as a purchase option for some Select lumber products.

In cedar and redwood, there is a pronounced difference in color between heartwood and sapwood. Heartwood also has high natural resistance to decay, so some grades are denoted as “heart.” Because Select lumber grades emphasize the quality of one face, the reverse side may be lower in quality. Select lumber grades are not uniform across species and products, so certified grade rules for the species must be used for detailed reference.

Common Lumber—Common lumber is normally a non-stress-graded product. The grades of Common lumber are suitable for construction and utility purposes. Common lumber is generally separated into three to five different grades depending upon the species and grading rules involved. Grades may be described by number (No. 1, No. 2, No. 1 Common, No. 2 Common) or descriptive term (Select Merchantable, Construction, Standard).

Because there are differences in the inherent properties of various species and their corresponding names, the grades for different species are not always interchangeable. The top-grade boards (No. 1, No. 1 Common, Select Merchantable) are usually graded for serviceability, but appearance is also considered. These grades are 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. Intermediate-grade boards are often used for such purposes as subfloors, roof and wall sheathing, and rough concrete work. The lower grade boards are selected for adequate strength, not appearance. They are used for roof and wall sheathing, subfloor, and rough concrete form work (Fig. 5–2).

Grading provisions for other non-stress-graded products vary by species, product, and applicable grading rules. For detailed descriptions, consult the appropriate grade rule for these products (see Table 5–5 for softwood grading organizations).

Structural Lumber—Almost all softwood lumber standard 38 to 89 mm thick (nominal 2 to 4 in. thick, actual 1-1/2 to 3-1/2 in. thick) is produced as dimension lumber. Dimension lumber is stress graded and assigned allowable properties under the National Grading Rule, a part of the American Softwood Lumber Standard. For dimension lumber, a single set of grade names and descriptions is used throughout the United States, although the allowable properties vary with species. Timbers (lumber standard 114 mm (nominal 5 in.) or more in least dimension) are also structurally graded under ALSC procedures. Unlike grade descriptions for dimension lumber, grade descriptions for structural timbers are not standardized across species. For most species, timber grades are classified according to intended use. Beams and stringers are members standard 114 mm (nominal 5 in.) or more in thickness with a width more than 51 mm (2 in.) greater than the thickness. Beams and stringers are primarily used to resist bending stresses, and the grade description for the middle third of the length of the beam is more stringent than that for the outer two-thirds. Posts and timbers are members standard 114 by 114 mm (nominal 5 by 5 in.) and larger, where the width is not more than 51 mm (2 in.) greater than the thickness. Post and timbers are primarily used to resist axial stresses. Structural timbers of Southern Pine are graded without regard to anticipated use, as with dimension lumber. Other stress-graded products include decking and some boards. Stress-graded lumber may be graded visually or mechanically. Stress grades and the National Grading Rule are discussed in Chapter 6.

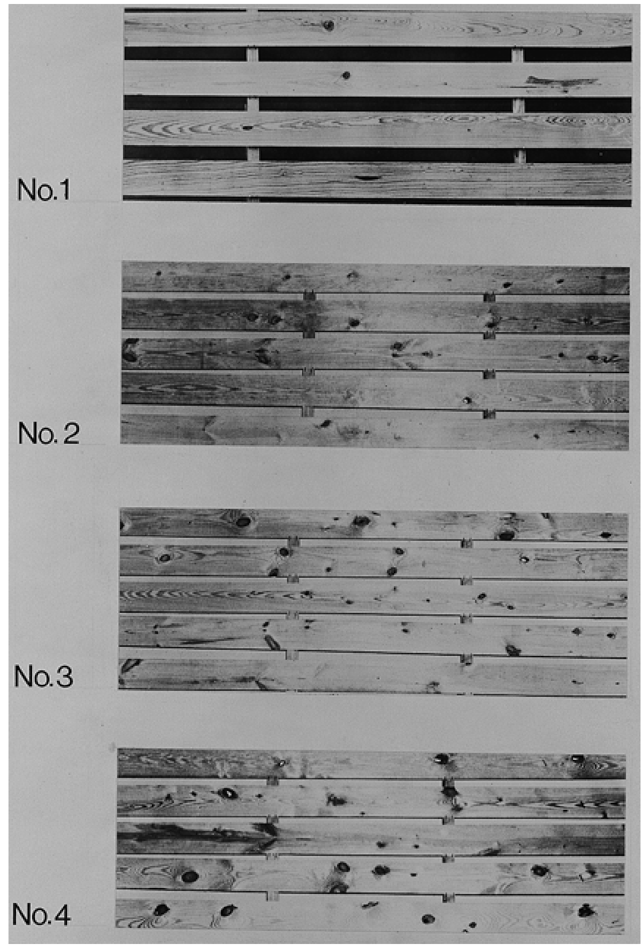


Figure 5–2. Typical examples of softwood boards in the lower grades.

Structural Laminations—Structural laminating grades describe the characteristics used to segregate lumber to be used in structural glued-laminated (glulam) timbers. Generally, allowable properties are not assigned separately to laminating grades; rather, the rules for laminating grades are based on the expected effect of that grade of lamination on the combined glulam timber.

Table 5–5. Organizations promulgating softwood grades

Name and address	Species covered by grading rules
Cedar Shingle & Shake Bureau 515 116th Avenue NE, Suite 275 Bellevue, WA 98004–5294	Western redcedar (shingles and shakes)
National Hardwood Lumber Association P.O. Box 34518 Memphis, TN 38184–0518	Baldcypress, eastern redcedar
National Lumber Grades Authority[a] 406 First Capital Place 960 Quamside Drive New Westminister, BC, Canada V3M6G2	Northern white cedar, western red cedar, yellow cedar, alpine fir, amabilis fir, balsam fir, Douglas-fir, grand fir, eastern hemlock, western hemlock, western larch, eastern white pine, jack pine, lodgepole pine, ponderosa pine, red pine, western white pine, black spruce, sitka spruce, red spruce, Engelmann spruce, white spruce, tamarack, aspen, black cottonwood, balsam poplar, red alder, white birch
Northeastern Lumber Manufacturers Association, Inc. 272 Tuttle Road, P.O. Box 87A Cumberland Center, ME 04021	Balsam fir, eastern white pine, red pine, eastern hemlock, black spruce, white spruce, red spruce, pitch pine, tamarack, jack pine, northern white cedar, aspen, red maple, mixed maple, beech, birch, hickory, mixed oaks, red oak, northern red oak, white oak, yellow poplar
Northern Softwood Lumber Bureau[a] 272 Tuttle Road, P.O. Box 87A Cumberland Center, ME 04021	Eastern white pine, jack pine, red pine, pitch pine, eastern spruce (red, white, and black), balsam fir, eastern hemlock, tamarack, eastern cottonwood, aspen (bigtooth and quaking), yellow poplar
Redwood Inspection Service 405 Enfrente Drive, Suite 200 Novato, CA 94949	Redwood
Southern Cypress Manufacturers Association 400 Penn Center Boulevard Suite 530 Pittsburgh, PA 15235	Baldcypress
Southern Pine Inspection Bureau[a] 4709 Scenic Highway Pensacola, FL 32504	Longleaf pine, slash pine, shortleaf pine, loblolly pine, Virginia pine, pond pine, pitch pine
West Coast Lumber Inspection Bureau[a] Box 23145 6980 SW. Varns Road Portland, OR 97223	Douglas-fir, western hemlock, western redcedar, incense-cedar, Port-Orford-cedar, yellow-cedar, western true firs, mountain hemlock, Sitka spruce, western larch
Western Wood Products Association[a] Yeon Building, 522 SW Fifth Avenue Portland, OR 97204–2122	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, aspen, alpine fir, Idaho white pine

[a]Publishes grading rules certified by the Board of Review of the American Lumber Standard Committee as conforming to the American Softwood Lumber Standard PS–20.

There are two kinds of graded material: visually graded and E-rated. Visually graded material is graded according to one of three sets of grading rules: (1) the first set is based on the grading rules certified as meeting the requirements of the American Softwood Lumber Standard with additional requirements for laminating; (2) the second set involves laminating grades typically used for visually graded western species and includes three basic categories (L1, L2, L3); and (3) the third set includes special requirements for tension members and outer tension laminations on bending members. The visual grades have provisions for dense, close-grain, medium-grain, or coarsegrain lumber.

The E-rated grades are categorized by a combination of visual grading criteria and lumber stiffness. These grades are expressed in terms of the size of maximum edge characteristic permitted (as a fraction of the width) along with a specified long-span modulus of elasticity (for example, 1/6–2.2E).

Factory and Shop Lumber

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 the secondary manufacturing process, grade descriptions, sizes, and often the entire appearance of the wood piece are changed. Thus, for Factory and Shop lumber, the role of the grading process is to reflect 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, moulding 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 sections briefly outline some of the more common classifications. For details, reference must be made to industry sources, such as certified grading rules. Availability and grade designation often vary by region and species.

Factory (Shop) Grades—Traditionally, softwood lumber used for cuttings has been called Factory or Shop. This lumber forms the basic raw material for many secondary manufacturing operations. Some grading rules refer to these grades as Factory, while others refer to them as Shop. All impose a somewhat similar nomenclature in the grade structure. Shop lumber is graded on the basis of characteristics that affect its use for general cut-up purposes or on the basis of size of cutting, such as for sash and doors. Factory Select and Select Shop are typical high grades, followed by No. 1 Shop, No. 2 Shop, and No. 3 Shop.

Grade characteristics of boards 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, Factory Select and Select Shop lumber would be required to contain 70% of cuttings of specified size, clear on both sides. No. 1 Shop would be required to have 50% cuttings and No. 2 Shop, 33-1/3%. Because of different characteristics assigned to grades with similar nomenclature, the grades of Factory and Shop lumber must be referenced to the appropriate certified grading rules.

Industrial Clears—These grades are used for trim, cabinet stock, garage 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 Industrial. Grading is primarily based on the best face, although the influence of edge characteristics is important and varies depending upon piece width and thickness. In redwood, the Industrial Clear All Heart grade includes an "all heart" requirement for decay resistance in the manufacture of cooling towers, tanks, pipe, and similar products.

Moulding, Ladder, Pole, Tank, and Pencil Stock— Within producing regions, grading rules delineate the requirements for a variety of lumber classes oriented to specific consumer products. Custom and the characteristics of the wood supply have led 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. Moulding stock, tank stock, pole stock, stave stock, stadium seat stock, box lumber, and pencil stock are other typical classes oriented to the final product. Some product classes 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 certified grading rules.

Lumber Manufacture

Size

Lumber length is recorded in actual dimensions, whereas width and thickness are traditionally recorded in "nominal" dimensions—actual dimensions are somewhat less.

Softwood lumber is manufactured in length multiples of 300 mm (1 ft) as specified in various grading rules. In practice, 600-mm (2-ft) multiples (in even numbers) are common for most construction lumber. Width of softwood lumber varies, commonly from standard 38 to 387 mm (nominal 2 to 16 in.). The thickness of lumber can be generally categorized as follows:

- Boards—lumber less than standard 38 mm (nominal 2 in.) in thickness
- Dimension—lumber from standard 38 mm (nominal 2 in.) to, but not including, 114 mm (5 in.) in thickness
- Timbers—lumber standard 114 mm (nominal 5 in.) or more in thickness in least dimension

To standardize and clarify nominal to actual sizes, the American Softwood Lumber Standard PS–20 specifies the actual thickness and width for lumber that falls under the standard. The standard sizes for yard and structural lumber are given in Table 5–6. Timbers are usually surfaced while "green" (unseasoned); therefore, only green sizes are given.

Because dimension lumber and boards may be surfaced green or dry at the prerogative of the manufacturer, 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 to about 15% moisture content. The definition of dry is lumber that has been seasoned or dried to a maximum moisture content of 19%. Lumber may also be designated as kiln dried (KD), meaning the lumber has been seasoned in a chamber to a predetermined moisture content by applying heat.

Table 5–6. American Standard Lumber sizes for yard and structural lumber for construction

	Thickness					Face width				
		Minimum dressed					Minimum dressed			
	Nominal	Dry		Green		Nominal	Dry		Green	
Item	(in.)	(mm	(in.))	(mm	(in.))	(in.)	(mm	(in.))	(mm	(in.))
Boards	1	19	(3/4)	20	(25/32)	2	38	(1-1/2)	40	(1-9/16)
	1-1/4	25	(1)	26	(1-1/32)	3	64	(2-1/2)	65	(2-9/16)
	1-1/2	32	(1-1/4)	33	(1-9/32)	4	89	(3-1/2)	90	(3-9/16)
						5	114	(4-1/2)	117	(4-5/8)
						6	140	(5-1/2)	143	(5-5/8)
						7	165	(6-1/2)	168	(6-5/8)
						8	184	(7-1/4)	190	(7-1/2)
						9	210	(8-1/4)	216	(8-1/2)
						10	235	(9-1/4)	241	(9-1/2)
						11	260	(10-1/4)	267	(10-1/2)
						12	286	(11-1/4)	292	(11-1/2)
						14	337	(13-1/4)	343	(13-1/2)
						16	387	(15-1/4)	394	(15-1/2)
Dimension	2	38	(1-1/2)	40	(1-9/16)	2	38	(1-1/2)	40	(1-9/16)
	2-1/2	51	(2)	52	(2-1/16)	3	64	(2-1/2)	65	(2-9/16)
	3	64	(2-1/2)	65	(2-9/16)	4	89	(3-1/2)	90	(3-9/16)
	3-1/2	76	(3)	78	(3-1/16)	5	114	(4-1/2)	117	(4-5/8)
	4	89	(3-1/2)	90	(3-9/16)	6	140	(5-1/2)	143	(5-5/8)
	4-1/2	102	(4)	103	(4-1/16)	8	184	(7-1/4)	190	(7-1/2)
						10	235	(9-1/4)	241	(9-1/2)
						12	286	(11-1/4)	292	(11-1/2)
						14	337	(13-1/4)	343	(13-1/2)
						16	387	(15-1/4)	394	(15-1/2)
Timbers	≥5	13 mm off	(1/2 in. off)	13 mm off	(1/2 in. off)	≥5	13 mm off	(1/2 in. off)	13 mm off	(1/2 in. off)

Factory and Shop lumber for remanufacture is offered in specified sizes to fit end-product requirements. Factory (Shop) grades for general cuttings are offered in thickness from standard 19 to 89 mm (nominal 1 to 4 in.). Thicknesses of door cuttings start at 35 mm (nominal 1-3/8 in.). Cuttings are of various lengths and widths. Laminating stock is sometimes offered oversize, compared with standard dimension sizes, to permit resurfacing prior to laminating. Industrial Clears can be offered rough or surfaced in a variety of sizes, starting from standard 38 mm (nominal 2 in.) and thinner and as narrow as standard 64 mm (nominal 3 in.). Sizes for special product grades such as moulding 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 greater than target size 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 roughsawn surface is common in post and timber products. Because of surface roughness, grading of rough lumber is generally more difficult.

Surfaced lumber has been surfaced by a machine on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or combinations of sides and edges (S1S1E, S2S1E, S1S2, S4S). Lumber is surfaced to attain smoothness and uniformity of size.

Imperfections or blemishes defined in the grading rules and caused by machining are classified as “manufacturing imperfections.” For example, chipped and torn grain are surface irregularities in which surface fibers 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 surfacing are other manufacturing imperfections. Manufacturing imperfections are defined in the American Softwood

Lumber Standard and further detailed in the grading rules. Classifications of manufacturing imperfections (combinations of imperfections allowed) are established in the rules as Standard A, Standard B, and so on. 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 rule description of some lumber products to specify the allowable surface quality.

Patterns

Lumber that has been matched, shiplapped, or otherwise patterned, in addition to being surfaced, is often classified as "worked lumber." Figure 5–3 shows typical patterns.

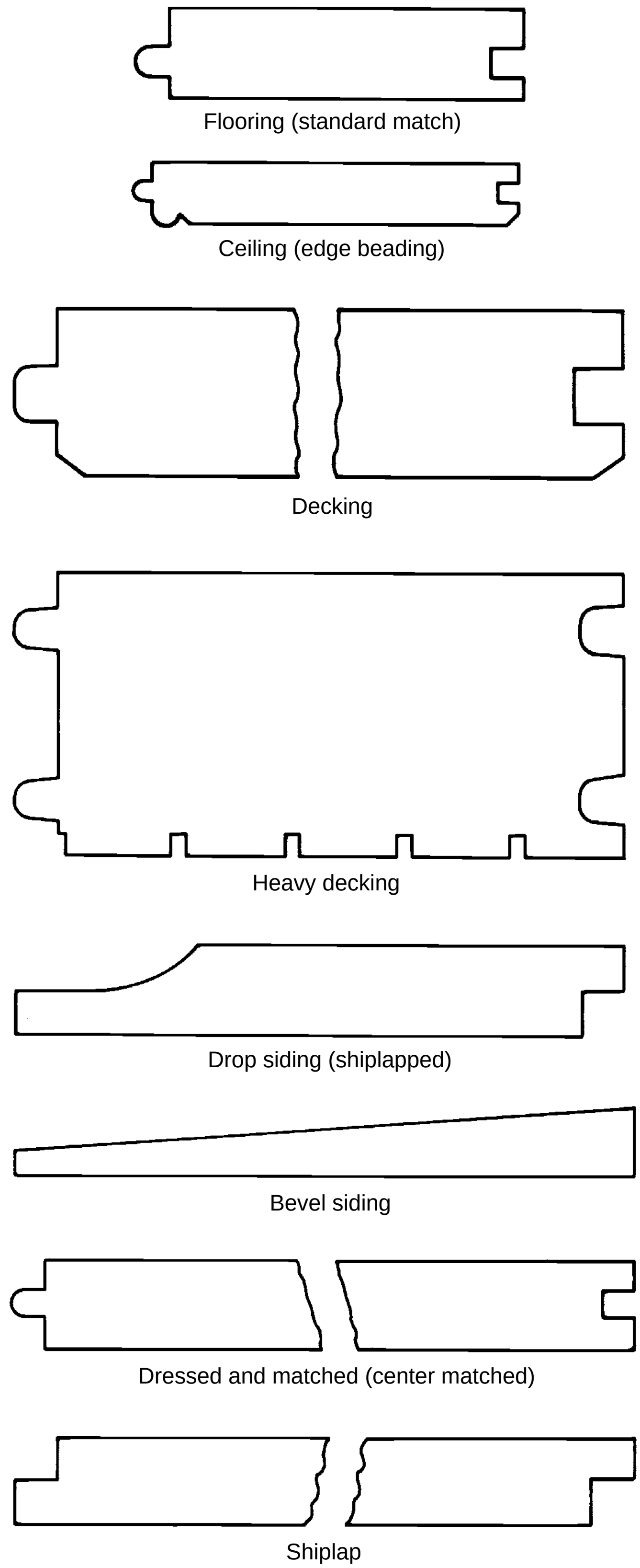


Figure 5–3. Typical patterns of worked lumber.

Softwood Lumber Species

The names of lumber species adopted by the trade as standard may vary from the names of trees adopted as official by the USDA Forest Service. Table 5–7 shows the American Softwood Lumber Standard commercial names for lumber, the USDA Forest Service tree names, and the botanical names. Some softwood species are marketed primarily in combinations. Designations such as Southern Pine and Hem–Fir represent typical combinations. Grading rule agencies (Table 5–5) should be contacted for questions regarding combination names and species not listed in Table 5–7. Species groups are discussed further in Chapter 6.

Softwood Lumber Grading

Most lumber is graded under the supervision of inspection bureaus and grading agencies. These organizations supervise lumber mill grading and provide re-inspection services to resolve disputes concerning lumber shipments. Some of these agencies also write grading rules that reflect the species and products in the geographic regions they represent. These grading rules follow the American Softwood Lumber Standard (PS–20). This is important because it provides for recognized uniform grading procedures. Names and addresses of rules-writing organizations in the United States and the species with which they are concerned are listed in Table 5–5. Canadian softwood lumber imported into the United States and graded by inspection agencies in Canada also follows the PS–20 standard. Names and addresses of accredited Canadian grading agencies may be obtained from the American Lumber Standard Committee, P.O. Box 210, Germantown, Maryland 20874.

Purchase of Lumber

After primary manufacture, most lumber products are marketed through wholesalers to remanufacturing plants or retail outlets. Because of the extremely wide variety of lumber products, wholesaling is very specialized—some organizations deal with only a limited number of species or products. Where the primary manufacturer can readily identify the customers, direct sales may be made. Primary manufacturers often sell directly to large retail-chain contractors, manufacturers of mobile and modular housing, and truss fabricators.

Table 5–7. Nomenclature of commercial softwood lumber

Commercial species or species group names under American Softwood Lumber Standard	Tree name used in this handbook	Botanical name
Cedar		
Alaska	yellow-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	*Chamaecyparis thyoides*
Western Red	western redcedar	*Thuja plicata*
Cypress		
Baldcypress	baldcypress	*Taxodium distichum*
Pond cypress	pond cypress	*Taxodium distichum* var. *nutans*
Fir		
Alpine	subalpine fir (alpine fir)	*Abies lasiocarpa*
Balsam	balsam fir	*Abies balsamea*
California Red	California red fir	*Abies magnifica*
Douglas Fir	Douglas-fir	*Pseudotsuga menziesii*
Fraser	Fraser fir	*Abies fraseri*
Grand	grand fir	*Abies grandis*
Noble Fir	noble fir	*Abies procera*
Pacific Grand	Pacific silver fir	*Abies amabilis*
White	white fir	*Abies concolor*
Hemlock		
Carolina	Carolina hemlock	*Tsuga caroliniana*
Eastern	eastern hemlock	*Tsuga canadensis*
Mountain	mountain hemlock	*Tsuga mertensiana*
Western	western hemlock	*Tsuga heterophylla*
Juniper		
Western	alligator juniper	*Juniperus deppeana*
	Rocky Mountain juniper	*Juniperus scopulorum*
	Utah juniper	*Juniperus osteosperma*
	western juniper	*Juniperus occidentalis*
Larch		
Western	western larch	*Larix occidentalis*
Pine		
Bishop	bishop pine	*Pinus muricata*
Coulter	Coulter pine	*Pinus coulteri*
Digger	Digger pine	*Pinus sabibiana*
Knobcone	knobcone pine	*Pinus attenuata*
Idaho White	western white pine	*Pinus monticola*
Jack	jack pine	*Pinus banksiana*
Jeffrey	Jeffrey pine	*Pinus jeffreyi*
Limber	limber pine	*Pinus flexilis*
Lodgepole	lodgepole pine	*Pinus contorta*
Longleaf	longleaf pine	*Pinus palustris*
	slash pine	*Pinus elliottii*
Northern White	eastern white pine	*Pinus strobus*
Norway	red pine	*Pinus resinosa*
Pitch	pitch pine	*Pinus rigida*
Ponderosa	ponderosa pine	*Pinus ponderosa*
Southern Pine Major	loblolly pine	*Pinus taeda*
	longleaf pine	*Pinus palustris*
	shortleaf pine	*Pinus echinata*
	slash pine	*Pinus elliottii*
Southern Pine Minor	pond pine	*Pinus serotina*
	sand pine	*Pinus clausa*
	spruce pine	*Pinus glabra*
	Virginia pine	*Pinus virginiana*
Southern Pine Mixed	loblolly pine	*Pinus taeda*
	longleaf pine	*Pinus palustris*
	pond pine	*Pinus serotina*
	shortleaf pine	*Pinus echinata*
	slash pine	*Pinus elliottii*
	Virginia pine	*Pinus virginiana*
Radiata/Monterey Pine	Monterey pine	*Pinus radiata*

Table 5–7. Nomenclature of commercial softwood lumber—con.

Commercial species or species group names under American Softwood Lumber Standard	Tree name used in this handbook	Botanical name
Pine—con.		
Sugar	sugar pine	*Pinus lambertiana*
Whitebark	whitebark pine	*Pinus albicaulis*
Redwood		
Redwood	redwood	*Sequoia sempervirens*
Spruce		
Blue	blue spruce	*Picea pungens*
Eastern	black spruce	*Picea mariana*
	red spruce	*Picea rubens*
	white spruce	*Picea glauca*
Engelmann	Engelmann spruce	*Picea engelmannii*
Sitka	Sitka spruce	*Picea sitchensis*
Tamarack		
Tamarack	tamarack	*Larix larcinia*
Yew		
Pacific	Pacific yew	*Taxus brevifolia*
Coast Species	Douglas-fir	*Pseudotsuga menziesii*
	western larch	*Larix occidentalis*
Eastern Softwoods	black spruce	*Picea mariana*
	red spruce	*Picea rubens*
	white spruce	*Picea glauca*
	balsam fir	*Abies balsamea*
	eastern white pine	*Pinus strobus*
	jack pine	*Pinus banksiana*
	pitch pine	*Pinus rigida*
	red pine	*Pinus resinosa*
	eastern hemlock	*Tsuga canadensis*
	tamarack	*Larix occidentalis*
Hem–Fir	western hemlock	*Tsuga heterophylla*
	California red fir	*Abies magnifica*
	grand fir	*Abies grandis*
	noble fir	*Abies procera*
	Pacific silver fir	*Abies amabilis*
	white fir	*Abies concolor*
Hem–Fir (North)	western hemlock	*Tsuga heterophylla*
	Pacific silver fir	*Abies amabilis*
Northern Pine	jack pine	*Pinus banksiana*
	pitch pine	*Pinus rigida*
	red pine	*Pinus resinosa*
North Species	northern white cedar	*Thuja occidentalis*
	western redcedar	*Thuja plicanta*
	yellow-cedar	*Chamaecyparis nootkatensis*
	eastern hemlock	*Tsuga canadensis*
	western hemlock	*Tsuga heterophylla*
	Douglas-fir	*Pseudotsuga menziesii*
	balsam fir	*Abies balsamea*
	grand fir	*Abies grandis*
	Pacific silver fir	*Abies amabilis*
	subalpine (alpine) fir	*Abies lasiocarpa*
	western larch	*Larix occidentalis*
	tamarack	*Larix laricina*
	eastern white pine	*Pinus strobus*
	jack pine	*Pinus banksiana*
	lodgepole pine	*Pinus contorta*
	ponderosa pine	*Pinus ponderosa*
	red pine	*Pinus resinosa*
	western white pine	*Pinus monticola*
	whitebark pine	*Pinus albicaulis*
	black spruce	*Picea mariana*
	Engelmann spruce	*Picea engelmannii*
	red spruce	*Picea rubens*
	Sitka spruce	*Picea sitchensis*

Table 5–7. Nomenclature of commercial softwood lumber—con.

Commercial species or species group names under American Softwood Lumber Standard	Tree name used in this handbook	Botanical name
North Species—con.	white spruce	*Picea glauca*
	bigtooth aspen	*Populus grandidentata*
	quaking aspen	*Populus tremuloides*
	black cottonwood	*Populus trichocarpa*
	balsam poplar	*Populus balsamifera*
Southern Pine	loblolly pine	*Pinus taeda*
	longleaf pine	*Pinus palustris*
	shortleaf pine	*Pinus echinata*
	slash pine	*Pinus elliottii*
Spruce–Pine–Fir	black spruce	*Picea mariana*
	Engelmann spruce	*Picea engelmannii*
	red spruce	*Picea rubens*
	balsam fir	*Abies balsamea*
	subalpine (alpine) fir	*Abies lasiocarpa*
	jack pine	*Pinus banksiana*
	lodgepole pine	*Pinus contorta*
Spruce–Pine–Fir (South)	black spruce	*Picea mariana*
	Engelmann spruce	*Picea engelmannii*
	red spruce	*Picea rubens*
	Sitka spruce	*Picea sitchensis*
	white spruce	*Picea glauca*
	balsam fir	*Abies balsamea*
	jack pine	*Pinus banksiana*
	lodgepole pine	*Pinus contorta*
	red pine	*Pinus resinosa*
Western Cedars	incense cedar	*Libocedrus decurrens*
	western redcedar	*Thuja plicata*
	Port-Orford-cedar	*Chamaecyparis lawsoniana*
	yellow-cedar	*Chamaecyparis nootkatensis*
Western Cedar (North)	western redcedar	*Thuja plicata*
	yellow-cedar	*Chamaecyparis nootkatensis*
Western Woods	Douglas-fir	*Pseudotsuga menziesii*
	California red fir	*Abies magnifica*
	grand fir	*Abies grandis*
	noble fir	*Abies procera*
	Pacific silver fir	*Abies amabilis*
	subalpine fir	*Abies lasiocarpa*
	white fir	*Abies concolor*
Hemlock	mountain	*Tsuga mertensiana*
	western hemlock	*Tsuga heterophylla*
	western larch	*Larix occidentalis*
	Engelmann spruce	*Picea engelmannii*
	Sitka spruce	*Picea sitchensis*
	lodgepole pine	*Pinus contorta*
	ponderosa pine	*Pinus ponderosa*
	sugar pine	*Pinus lambertiana*
	western white pine	*Pinus monticola*
White Woods	California red fir	*Abies magnifica*
	grand fir	*Abies grandis*
	noble fir	*Abies procera*
	Pacific silver fir	*Abies amabilis*
	subalpine fir	*Abies lasiocarpa*
	white fir	*Abies concolor*
	mountain hemlock	*Tsuga mertensiana*
	western hemlock	*Tsuga heterophylla*
	Engelmann spruce	*Picea engelmannii*
	Sitka spruce	*Picea sitchensis*
	lodgepole pine	*Pinus contorta*
	ponderosa pine	*Pinus ponderosa*
	sugar pine	*Pinus lambertiana*
	western white pine	*Pinus monticola*

Some primary manufacturers and wholesalers set up distribution yards in lumber-consuming areas to distribute both hardwood and softwood products more effectively. Retail yards draw inventory from distribution yards and, in wood-producing areas, from local lumber producers. The wide range of grades and species covered in the grade rules may not be readily available in most retail outlets.

Transportation is a vital factor in lumber distribution. 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 usually kiln-dried because rail shipping rates are based on weight. A shorter rail haul places southern and northeastern species in a favorable economic position in regard to shipping costs in this 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.

The increased production capacity of foreign hardwood and softwood manufacturing and the availability of water transport has brought foreign lumber products to the U.S. market, particularly in coastal areas.

Retail Yard Inventory

The small retail yards throughout the United States carry softwoods for construction purposes and often carry small stocks of one or two hardwoods in grades suitable for finishing or cabinetwork. Special orders must be made for other hardwoods. Trim items such as moulding in either softwood or hardwood are available cut to standard size and pattern. Millwork plants usually make ready-for-installation cabinets, and retail yards carry or catalog many common styles and sizes. Hardwood flooring is available to the buyer only in standard patterns. Most retail yards carry stress grades of lumber.

The assortment of species in general construction items carried by retail yards depends to a great extent upon geographic location, and both transportation costs and tradition are important factors. Retail yards within, or close to, a major lumber-producing region commonly emphasize local timber. For example, a local retail yard on the Pacific Northwest Coast may stock only green Douglas Fir and cedar in dimension grades, dry pine and hemlock in boards and moulding, and assorted special items such as redwood posts, cedar shingles and shakes, and rough cedar siding. The only hardwoods may be walnut and “Philippine mahogany” (the common market name encompassing many species, including tanguile, red meranti, and white lauan). Retail yards located farther from a major softwood supply, such as in the Midwest, may draw from several growing areas and may stock spruce and Southern Pine, for example. Because they are located in a major hardwood production area, these yards may 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 construction lumber (6 to 8 m (20 to 26 ft)) is required, West Coast species are often marketed because the height of the trees in several species makes long lengths a practical market item. Ease of preservative treatability makes treated Southern Pine construction lumber available in a wide geographic area.

Structural Lumber for Construction

Dimension lumber is the principal stress-graded lumber 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 lumber is stocked in almost all yards, frequently in only one or two of the general purpose construction woods such as pine, fir, hemlock, or spruce. Standard 38- by 89-mm (nominal 2- by 4-in.) and wider dimension lumber is found in Select Structural, No. 1, No. 2, and No. 3 grades. Standard 38- by 89-mm (nominal 2- by 4-in.) dimension lumber may also be available as Construction, Standard, Utility, and STUD grades. STUD grade is also available in wider widths.

Dimension lumber is often found in standard 38-, 89-, 140-, 184-, 235-, and 286-mm (nominal 2-, 4-, 6-, 8-, 10-, and 12-in.) widths and 2.4- to 5.4-m (8- to 18-ft) lengths in multiples of 0.6 m (2 ft). Dimension lumber formed by structural end-jointing procedures may be available. Dimension lumber thicker than standard 38 mm (nominal 2 in.) and longer than 5.4 m (18 ft) is not commonly available in many retail yards.

Other stress-graded products generally available are posts and timbers; some beams and stringers may also be in stock. Typical grades in these products are Select Structural, No. 1, and No. 2.

Yard Lumber for Construction

Boards are the most common non-stress-graded general purpose construction lumber in the retail yard. Boards are stocked in one or more species, usually in standard 19 mm (nominal 1 in.) thickness. Common widths are standard 38, 64, 89, 140, 184, 235, and 286 mm (nominal 2, 3, 4, 6, 8, 10, and 12 in.). Grades generally available in retail yards are No. 1 Common, No. 2 Common, and No. 3 Common (Construction, Standard, No. 1, No. 2, etc.). Boards are sold square edged, dressed (surfaced) and matched (tongued and grooved), or with a shiplapped joint. Boards formed by end-jointing of shorter sections may constitute an appreciable portion of the inventory.

Select Lumber

Completion of a construction project usually depends on the availability of lumber items in finished or semi-finished form. The following items often may be stocked in only a few species, finishes, or sizes depending on the lumber yard.

Finish—Finish boards usually are available in a local yard in one or two species, principally in grade C&BTR. Cedar and redwood have different grade designations: grades such as Clear Heart, A, or B are used in cedar; Clear All Heart, Clear, and B grade are typical in redwood. Finish boards are usually standard 19 mm (nominal 1 in.) thick, surfaced on two sides to 19 mm (3/4 in.); 38- to 286-mm (2- to 12-in.) widths are usually stocked, in even increments.

Siding—Siding is specifically intended 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 or barn siding, is usually stocked in the same species as is beveled siding. Siding may be stocked as B&BTR or C&BTR except in cedar, where Clear, A, and B grades may be available, and redwood, where Clear All Heart, Clear, and B grades may be found. Vertical grain (VG) is sometimes part of the grade designation. Drop siding is also sometimes stocked in sound knotted C and D grades of Southern Pine, Douglas Fir, and hemlock. Drop siding may be surfaced and matched, or shiplapped. Knotty grades of cedar (Select Tight Knot (STK)) and redwood (Rustic) are commonly available.

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 19 mm (3/4 in.) thick. Thicker flooring is available for heavy-duty floors. Thinner flooring is available, especially for re-covering old floors. Vertical- and flat-grained (also called quartersawn and plainsawn) flooring is manufactured from both softwoods and hardwoods. Vertical-grained flooring shrinks and swells less than flat-grained flooring, is more uniform in texture, and wears more uniformly, and the edge joints have less tendency to open.

Softwood flooring is usually available in B&BTR, C Select, or D Select grades. In maple, the chief grades are Clear, No. 1, and No. 2. The grades in quartersawn oak are Clear and Select, and in plainsawn, Clear, Select, and No. 1 Common. Quartersawn hardwood flooring has the same advantages as does vertical-grained softwood flooring. In addition, the silver or flaked grain of quartersawn flooring is frequently preferred to the figure of plainsawn flooring.

Casing and Base—Casing and base are standard items in the more important softwoods and are stocked in most yards in at least one species. The chief grade, B&BTR, is designed to meet the requirements of interior trim for dwellings. Many casing and base patterns are surfaced to 17.5 by 57 mm (11/16 by 2-1/4 in.); other sizes include 14.3 mm (9/16 in.) by 76 mm (3 in.), by 83 mm (3-1/4 in.), and by 89 mm (3-1/2 in.). Hardwoods for the same purposes, such as oak and birch, may be carried in stock in the retail yard or obtained on special order.

Shingles and Shakes—Commonly available shingles are sawn from western redcedar and northern white-cedar. For western redcedar, the shingle grades are No. 1, No. 2, and No. 3; for northern white-cedar, Extra, Clear, 2nd Clear, Clearwall, and Utility.

Shingles that contain only heartwood are more resistant to decay than are shingles that contain sapwood. Edge-grained shingles are less likely to warp and split than flat-grained shingles, thick-butted shingles less likely than thin-butted shingles, and narrow shingles less likely than wide shingles. The standard thickness values of thin-butted shingles are described as 4/2, 5/2-1/4, and 5/2 (four shingles to 51 mm (2 in.) of butt thickness, five shingles to 57 mm (2-1/4 in.) of butt thickness, and five shingles to 51 mm (2 in.) of butt thickness). Lengths may be 406, 457, or 610 mm (16, 18, or 24 in.). Random widths and specified ("dimension" shingle) widths are available in western redcedar, redwood, and cypress.

Shingles are usually packed four bundles to a square. A square of shingles will cover roughly 9 m^2 (100 ft^2) of roof area when the shingles are applied at standard weather exposures.

Shakes are hand split or hand split and resawn from western redcedar. Shakes are of a single grade and must be 100% clear. In the case of hand split and resawn material, shakes are graded from the split face. Hand-split shakes are graded from the best face. Shakes must be 100% heartwood. The standard thickness of shakes ranges from 9.5 to 32 mm (3/8 to 1-1/4 in.). Lengths are 457 and 610 mm (18 and 24 in.), with a special "Starter–Finish Course" length of 381 mm (15 in.).

Important Purchase Considerations

Some points to consider when ordering lumber or timbers are the following:

1. Quantity—Lineal measure, board measure, surface 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 these must be clearly delineated. In other words, such features as nominal or actual dimensions and pattern size must be considered.
2. Size—Thickness in millimeters or inches—nominal or actual if surfaced on faces; width in millimeters or inches—nominal or actual if surfaced on edges; length in meters or 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. 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. In softwoods that are in compliance with the American Softwood Lumber Standard, each piece of lumber may be grade stamped with its official grade species identification, 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.

Working or recutting a graded product to a pattern may change or invalidate the original grade. The purchase specification should be clear in regard to regrading or acceptance of worked lumber. In softwood lumber, grades for dry lumber generally are determined after kiln drying and surfacing. However, this practice is not general for hardwood Factory lumber, where the grade is generally based on quality and size prior to kiln drying. To be certain the product grade is correct, refer to the grading rule by number and paragraph.

4. Species or species group of wood—Such as Douglas Fir, Southern Pine, Hem–Fir. Some species have been grouped for marketing convenience; others are sold under a variety of names. Be sure the species or species group is correctly and clearly described on the purchase specification.
5. Product—Such as flooring, siding, timbers, boards. 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—Such as air dry, kiln dry. Softwood lumber less than 114 mm (nominal 5 in.) in thickness dried to 19% moisture content or less is defined as dry by the American Softwood Lumber Standard. Kiln-dried lumber is lumber that has been seasoned in a chamber to a predetermined moisture content by applying heat. Green lumber is lumber less than 114 mm (nominal 5 in.) in thickness, which has a moisture content in excess of 19%. If the moisture requirement is critical, the level of moisture content and the method by which it will be achieved must be specified.
7. Surfacing and working—Rough (unplaned), surfaced (dressed, planed), or patterned stock. Specify condition. If surfaced, indicate code (S4S, S1S1E). If patterned, list pattern number with reference to appropriate grade rules.
8. Grading rules—Official grading agency name and name of official rules under which product is graded, product identification, paragraph and page number of rules, and date of rules or official rule edition may be specified by the buyer.
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 Softwood Lumber Standard provides for procedures to be followed in resolution of manufacturer–wholesaler–consumer conflicts over quality or quantity of ALS lumber grades. 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.

Commonly Used 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
AF	alpine fir
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
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
CONST	construction
CS	caulking 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
DF–L	Douglas-fir plus larch
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
ES	Engelmann spruce
F_b, F_t, F_c, F_v, F_{cx}	allowable stress (MPa (lb/in^2)) in bending; tension, compression and shear parallel to grain; and in compression perpendicular to grain, respectively
FA	facial area
Fac	factory
FAS	free alongside (vessel)
FAS	Firsts and Seconds
FAS1F	Firsts and Seconds one face
FBM, Ft. BM	feet board measure
FG	flat or slash grain
FJ	finger joint; end-jointed lumber using 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, feet
FT. SM	feet surface measure
G	girth
GM	grade marked
G/R	grooved roofing
HB, H.B.	hollow back
HEM	hemlock
H-F	mixed hemlock and fir (Hem–Fir)
Hrt	heart
H&M	hit and miss
H or M	hit or miss
IC	incense cedar
IN, in.	inch, inches
Ind	industrial
IWP	Idaho white pine
J&P	joists and planks
JTD	jointed
KD	kiln dried
KDAT	kiln-dried after treatment
L	western larch
LBR, Lbr	lumber
LCL	less than carload
LGR	longer
LGTH	length
Lft, Lf	lineal foot, feet
LIN, Lin	lineal
LL	longleaf
LNG, Lng	lining
LP	lodgepole pine
M	thousand
MBM, MBF, M.BM	thousand (feet) board measure
MC, M.C.	moisture content
MERCH, Merch	merchantable
MFMA	Maple Flooring Manufacturers Association
MG	medium grain or mixed grain
MH	mountain hemlock
MLDG, Mldg	moulding
Mft	thousand feet
M-S	mixed species
MSR	machine stress rated
N	nosed
NBM	net board measure
NOFMA	National Oak Flooring Manufacturers Association
No.	number

N1E or N2E	nosed one or two edges
Ord	order
PAD	partially air-dried
PAR, Par	paragraph
PART, Part	partition
PAT, Pat	pattern
Pcs.	pieces
PE	plain end
PET	precision end-trimmed
PP	ponderosa pine
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 $\leq$ 19% moisture content per ALS 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, >19% moisture content per ALS for softwood
SGSSND	sapwood, gum spots and streaks, no defect
SIT. SPR	Sitka spruce
S/L, SL, S/Lap	shiplap
SM	surface measure
Specs	specifications
SP	sugar pine
SQ	square
SQRS	squares
SRB	stress-rated board
STD, Std	standard
Std. lgths.	standard lengths
STD. M	standard matched
SS	Sitka spruce
SSE	sound square edge
SSND	sap stain, no defect (stained)
STK	Select tight knot
STK	stock
STPG	stepping
STR, STRUCT	structural
SYP	Southern 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 caulking 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
TBR	timber
T&G	tongued and grooved
TSO	treating service only (nonconforming to standard)
UTIL	utility
VG	vertical (edge) grain
V1S	see EV1S, CV1S, and E&CV1S
V2S	see EV2S, CV2S, and E&CV2S
WC	western cedar
WCH	West Coast hemlock
WCW	West Coast woods
WDR, wdr	wider
WF	white fir
WHAD	worm holes (defect)
WHND	worm holes (no defect)
WT	weight
WTH	width
WRC	western redcedar
WW	white woods (Engelmann spruce, any true firs, any hemlocks, any pines)

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Chapter 6

Lumber Stress Grades and Design Properties

David E. Kretschmann and David W. Green

Contents

Lumber sawn from a log, regardless of species and size, is quite variable in mechanical properties. Pieces may differ in strength by several hundred percent. For simplicity and economy in use, pieces of lumber of similar mechanical properties are placed in categories called stress grades, which are characterized by (a) one or more sorting criteria, (b) a set of properties for engineering design, and (c) a unique grade name.

This chapter briefly discusses the U.S. Department of Commerce American Softwood Lumber Standard PS20 (1994) sorting criteria for two stress-grading methods, and the philosophy of how properties for engineering design are derived. The derived properties are then used in one of two design formats: (a) the load and resistance factor design (LRFD), which is based on a reference strength at the 5th percentile 5-min bending stress (AF&PA 1996), or (b) the allowable stress design (ASD), which is based on a design stress at the lower 5th percentile 10-year bending stress. The properties depend on the particular sorting criteria and on additional factors that are independent of the sorting criteria. Design properties are lower than the average properties of clear, straight-grained wood tabulated in Chapter 4.

From one to six design properties are associated with a stress grade: bending modulus of elasticity for an edgewise loading orientation and stress in tension and compression parallel to the grain, stress in compression perpendicular to the grain, stress in shear parallel to the grain, and extreme fiber stress in bending. As is true of the properties of any structural material, the allowable engineering design properties must be either inferred or measured nondestructively. In wood, the properties are inferred through visual grading criteria, nondestructive measurement such as flatwise bending stiffness or density, or a combination of these properties. These nondestructive tests provide both a sorting criterion and a means of calculating appropriate mechanical properties.

The philosophies contained in this chapter are used by a number of organizations to develop visual and machine stress grades. References are made to exact procedures and the resulting design stresses, but these are not presented in detail.

Responsibilities and Standards for 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 6–1. Stress-grading principles are developed from research findings and engineering concepts, often within committees and subcommittees of the American Society for Testing and Materials.

American Lumber Standard Committee

Voluntary product standards are developed under procedures published by the U.S. Department of Commerce. The Department of Commerce National Institute of Standards and Technology (NIST), working with rules-writing agencies, lumber inspection agencies, lumber producers, distributors and wholesalers, retailers, end users, and members of Federal agencies, work through the American Lumber Standard Committee (ALSC) to maintain a voluntary consensus softwood standard, called the American Softwood Lumber Standard (PS 20–94). The PS 20–94 Standard prescribes the ways in which stress-grading principles can be used to formulate grading rules designated as conforming to the American Lumber Standard. Under the auspices of the ALSC is the National Grading Rule, which specifies grading characteristics for different grade specifications.

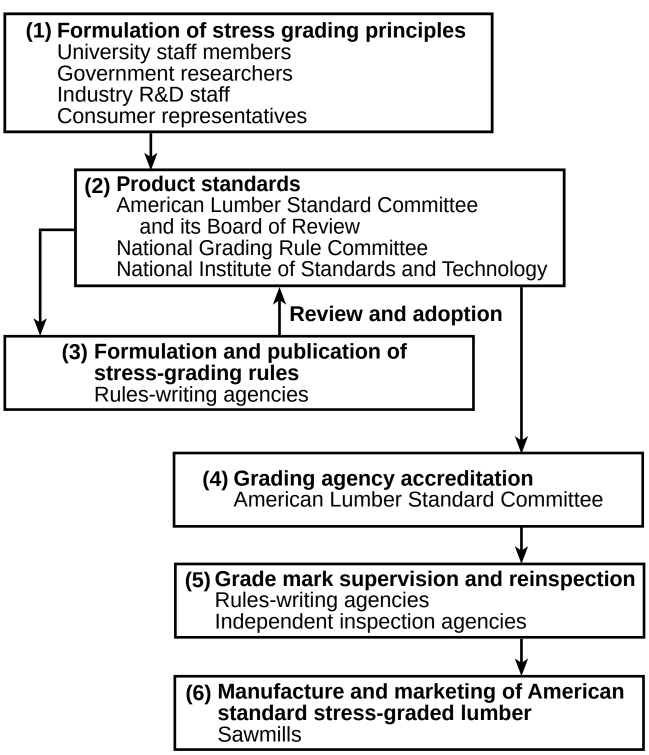

Figure 6–1. Voluntary system of responsibilities for stress grading under the American Softwood Lumber Standard.

Organizations that write and publish grading rule books containing stress-grade descriptions are called rules-writing agencies. Grading rules that specify American Softwood Lumber Standard PS 20–94 must be certified by the ALSC Board of Review for conformance with this standard. Organizations that write grading rules, as well as independent agencies, can be accredited by the ALSC Board of Review to provide grading and grade-marking supervision and reinspection services to individual lumber manufacturers. Accredited rules-writing and independent agencies are listed in Table 6–1. The continued accreditation of these organizations is under the scrutiny of the ALSC Board of Review.

Most commercial softwood species manufactured in the United States are stress graded under American Lumber Standard practice. Distinctive grade marks for each species or species grouping are provided by accredited agencies. The principles of stress grading are also applied to several hardwood species under provisions of the American Softwood Lumber Standard. Lumber found in the marketplace may be stress graded under grading rules developed in accordance

Table 6–1. Sawn lumber grading agencies[a]

Rules-writing agencies

Northeastern Lumber Manufacturers Association (NELMA)
Northern Softwood Lumber Bureau (NSLB)
Redwood Inspection Service (RIS)
Southern Pine Inspection Bureau (SPIB)
West Coast Lumber Inspection Bureau (WCLIB)
Western Wood Products Association (WWPA)
National Lumber Grades Authority (NLGA)

Independent agencies

California Lumber Inspection Service
Pacific Lumber Inspection Bureau, Inc.
Renewable Resource Associates, Inc.
Timber Products Inspection
Alberta Forest Products Association
Canadian Lumbermen's Association
Canadian Mill Services Association
Canadian Softwood Inspection Agency, Inc.
Cariboo Lumber Manufacturers Association
Central Forest Products Association
Coniferous Lumber Inspection Bureau
Council of Forest Industries of British Columbia
Interior Lumber Manufacturers Association
MacDonald Inspection
Maritime Lumber Bureau
Newfoundland Lumber Producers Association
Northern Forest Products Association
Ontario Lumber Manufacturers Association
Pacific Lumber Inspection Bureau
Quebec Lumber Manufacturers Association

[a]For updated information, contact American Lumber Standard Committee, P.O. Box 210, Germantown, MD 20874.

with methods approved by the ALSC or by some other stress-grading rule, or it may not be stress graded. Only those stress grades that meet the requirements of the voluntary American Softwood Lumber Standard system are discussed in this chapter.

National Grading Rule

Stress grading under the auspices of the ALSC is applied to many sizes and several patterns of lumber that meet the American Softwood Lumber Standard provision. However, most stress-graded lumber is dimension lumber (standard 38 to 89 mm (nominal 2 to 4 in.) thick) and is governed by uniform specifications under the National Grading Rule. The National Grading Rule provides guidelines for writing grading rules for lumber in this thickness range and specifies grading characteristics for different grade specifications. American Softwood Lumber Standard dimension lumber in this thickness range is required to conform to the National Grading Rule, except for special products such as scaffold planks. Grade rules for other sizes, such as nominal 5-in. (standard 114-mm) or larger structural timbers may vary between rules-writing agencies or species.

The National Grading Rule establishes the lumber classifications and grade names for visually stress-graded dimension lumber (Table 6–2) and also provides for the grading of dimension lumber by a combination of machine and visual methods. Visual requirements for this type of lumber are developed by the respective rules-writing agencies for particular species grades.

Table 6–2. Visual grades described in National Grading Rule

Lumber classification[a]	Grade name	Bending strength ratio (%)
Light framing[b]	Construction	34
	Standard	19
	Utility	9
Structural light framing[b]	Select Structural	67
	1	55
	2	45
	3	26
Stud[c]	Stud	26
Structural joists and planks[d]	Select Structural	65
	1	55
	2	45
	3	26

[a]Contact rules-writing agencies for additional information.
[b]Standard 38 to 89 mm (nominal 2 to 4 in.) thick and wide. Widths narrower than 89 mm (4 in.) may have different strength ratio than shown.
[c]Standard 38 to 89 mm (nominal 2 to 4 in.) thick, ≥38 mm (≥4 in.) wide.
[d]Standard 38 to 89 mm (nominal 2 to 4 in.) thick, ≥140 mm (≥6 in.) wide.

Standards

Table 6–2 also shows associated minimum bending strength ratios to provide a comparative index of quality. The strength ratio is the hypothetical ratio of the strength of a piece of lumber with visible strength-reducing growth characteristics to its strength if those characteristics were absent. Formulas for calculating strength ratios are given in American Society of Testing and Materials (ASTM) standard D245. The corresponding visual description of the dimension lumber grades can be found in the grading rule books of the rules-writing agencies listed in Table 6–1. Design properties will vary by species. The design properties for each species and grade are published in the appropriate rule books and in the *National Design Specification for Wood Construction* (AF&PA 1997).

Grouping of Species

Most species are grouped together and the lumber from them treated as equivalent. Species are usually grouped when they have about the same mechanical properties, when the wood of two or more species is very similar in appearance, or for marketing convenience. For visual stress grades, ASTM D2555 contains procedures for calculating clear wood properties for groups of species to be used with ASTM D245. ASTM D1990 contains procedures for calculating design properties for groups of species tested as full-sized members. The properties assigned to a group by such procedures will often be different from those of any species that make up the group. The group will have a unique identity, with nomenclature approved by the Board of Review of the ALSC. The identities, properties, and characteristics of individual species of the group are found in the grade rules for any particular species or species grouping. In the case of machine stress grading, the inspection agency that supervises the grading certifies by testing that the design properties in that grade are appropriate for the species or species grouping and the grading process.

Foreign species

Currently, the importation of structural lumber is governed by two ALSC guidelines that describe the application of the American Lumber Standard and ASTM D1990 procedures to foreign species. The approval process is outlined in Table 6–3.

Visually Graded Structural Lumber

Visual Sorting Criteria

Visual grading is the original method for stress grading. It is based on the premise that mechanical properties of lumber differ from mechanical properties of clear wood because many growth characteristics affect properties and these characteristics can be seen and judged by eye. Growth characteristics are used to sort lumber into stress grades. The typical visual sorting criteria discussed here are knots, slope of grain,

Table 6–3. Approval process for acceptance of design values for foreign species

1	Rules-writing agency seeks approval to include species in grade-rule book.
2	Agency develops sampling and testing plan, following American Lumber Standard Committee (ALSC) foreign importation guidelines, which must then be approved by ALSC Board of Review.
3	Lumber is sampled and tested in accordance with approved sampling and testing plan.
4	Agency analyzes data by ALSC Board of Review and ASTM D1990 procedures and other appropriate criteria (if needed).
5	Agency submits proposed design values to ALSC Board of Review.
6	Submission is reviewed by ALSC Board of Review and USDA Forest Service, Forest Products Laboratory.
7	Submission is available for comment by other agencies and interested parties.
8	ALSC Board of Review approves (or disapproves) design values, with modification (if needed) based on all available information.
9	Agency publishes new design values for species.

checks and splits, shake, density, decay, heartwood and sapwood, pitch pockets, and wane.

Knots

Knots cause localized cross grain with steep slopes. A very damaging aspect of knots in sawn lumber is that the continuity of the grain around the knot is interrupted by the sawing process.

In general, knots have a greater effect on strength in tension than compression; in bending, the effect depends on whether a knot is in the tension or compression side of a beam (knots along the centerline have little or no effect). Intergrown (or live) knots resist (or transmit) some kinds of stress, but encased knots (unless very tight) or knotholes resist (or 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 of equivalent size. As a result, overall strength effects are roughly equalized, and often no distinction is made in stress grading between intergrown knots, dead knots, and knotholes.

The zone of distorted grain (cross grain) around a knot has less "parallel to piece" stiffness than does straight-grained wood; thus, localized areas of low stiffness are often associated with knots. However, such zones generally constitute only a minor part of the total volume of a piece of lumber. Because overall stiffness of a piece reflects the character of all parts, stiffness is not greatly influenced by knots.

The presence of a knot has a greater effect on most strength properties than on stiffness. The effect on strength depends approximately on the proportion of the cross section of the piece of lumber occupied by the knot, knot location, and distribution of stress in the piece. Limits on knot sizes are therefore made in relation to the width of the face 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 cause an eccentricity that induces bending stresses, and they should therefore be more restricted than knots away from the edge. In simply supported structural members subjected to bending, stresses are greater in the middle of the length and at the top and bottom edges than at midheight. These facts are recognized in some grades by differing limitations on the sizes of knots in different locations.

Knots in glued-laminated structural members are not continuous as in sawn structural lumber, and different methods are used for evaluating their effect on strength (Ch. 11).

Slope of Grain

Slope of grain (cross grain) reduces the mechanical properties of lumber because the fibers are not parallel to the edges. 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 straight-grained specimens and are increased in zones of sloping or distorted grain. To provide a margin of safety, the reduction in design properties resulting from cross grain in visually graded structural lumber is considerably greater than that observed in small, clear specimens that contain similar cross grain.

Checks and Splits

Checks are separations of the wood that normally occur across or through the annual rings, usually as a result of seasoning. Splits are a separation of the wood through the piece to the opposite surface or to an adjoining surface caused by tearing apart of the wood cells. As opposed to shakes, checks and splits are rated by only 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 on strength and the principles of their limitation are the same as those for shake.

Shake

Shake is a separation or a weakness of fiber bond, between or through the annual rings, that is presumed to extend lengthwise without limit. Because shake reduces resistance to shear in members subjected to bending, grading rules therefore restrict shake most closely in those parts of a bending member where shear stresses are highest. In members with limited cross grain, which are subjected only to tension or compression, shake does not affect strength greatly. Shake may be limited in a grade because of appearance and because it permits entrance of moisture, which results in decay.

Density

Strength is related to the mass per unit volume (density) of clear wood. Properties assigned to lumber are sometimes modified by using the rate of growth and percentage of latewood as measures of density. Typically, selection for density requires that the rings per unit length and the percentage of latewood be within a specified range. It is possible to eliminate some very low-strength pieces from a grade by excluding those that are exceptionally low in density.

Decay

Decay in most forms should be prohibited or severely restricted in stress grades because the extent of decay is difficult to determine and its effect on strength is often greater than visual observation would indicate. Decay of the pocket type (for example, *Fomes pini*) can be permitted to some extent in stress grades, as can decay that occurs in knots but does not extend into the surrounding wood.

Heartwood and Sapwood

Heartwood does not need to be taken into account in stress grading because heartwood and sapwood have been assumed to have equal mechanical properties. However, heartwood is sometimes specified in a visual grade because the heartwood of some species is more resistant to decay than is the sapwood; heartwood may be required if untreated wood will be exposed to a decay hazard. On the other hand, sapwood takes preservative treatment more readily than heartwood and it is preferable for lumber that will be treated with preservatives.

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.

Wane

Wane refers to bark or lack of wood on the edge or corner of a piece of lumber, regardless of cause (except eased edges). Requirements of appearance, fabrication, or ample bearing or nailing surfaces generally impose stricter limitations on wane than does strength. Wane is therefore limited in structural lumber on those bases.

Procedures for Deriving Design Properties

The mechanical properties of visually graded lumber may be established by (a) tests of a representative sample of full-size members (ASTM D1990 in-grade testing procedure) or (b) appropriate modification of test results conducted on small clear specimens (ASTM D245 procedure for small clear wood). Design properties for the major commercial softwood dimension lumber species given in current design specification and codes in the United States have been derived from full-size member test results. However, design properties for most hardwood dimension and structural timbers (larger than standard 89-mm- (nominal 4-in.-, actual 3-1/2-in.-) thick “timbers”) of all species are still derived using results of tests on small clear samples.

Procedure for Small Clear Wood

The derivation of mechanical properties of visually graded lumber was historically based on clear wood properties with appropriate modifications for the lumber characteristics allowed by visual sorting criteria. Sorting criteria that influence mechanical properties are handled with “strength ratios” for the strength properties and with “quality factors” for the modulus of elasticity.

From piece to piece, there is variation in both the clear wood properties and the occurrence of growth characteristics. The influence of this variability on lumber properties is handled differently for strength properties than for modulus of elasticity.

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 growth 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. Therefore, the strength ratio assigned to a growth characteristic serves as a predictor of lumber strength. Strength ratio is expressed as a percentage, ranging from 0 to 100.

Estimated strength ratios for cross grain and density have been obtained empirically; strength ratios for other growth 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 6–2. For a beam containing an edge knot, the bending strength ratio can be idealized as the ratio of the bending moment that can be resisted by a beam with a reduced cross section to that of a beam with a full cross section:

$$\mathrm{SR} = 1 - \left(k/h\right)^2$$

where SR is strength ratio, k knot size, and h width of 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 6–3 shows how strength ratio changes with knot size according to the formula.

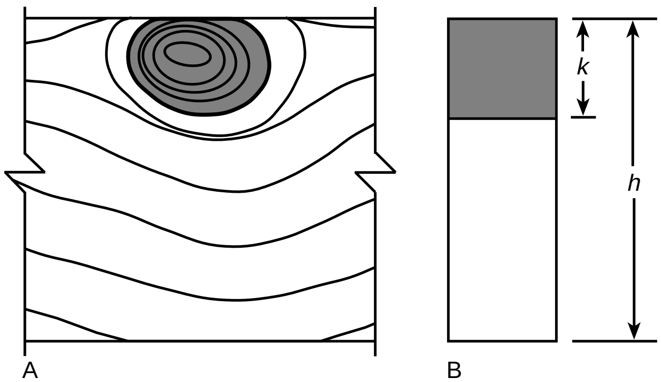

Figure 6–2. Effect of edge knot: A, edge knot in lumber and B, assumed loss of cross section (cross-hatched area).

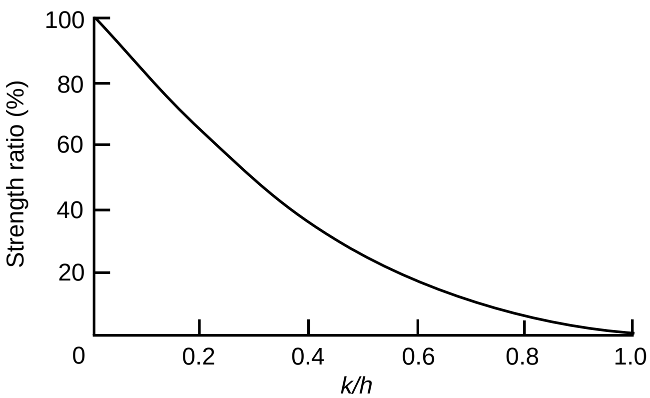

Figure 6–3. Relation between bending strength ratio and size of edge knot expressed as fraction of face width. *k* is knot size; *h*, width of face containing the knot.

Strength ratios for all knots, shakes, checks, and splits are derived using similar concepts. Strength ratio formulas are given in ASTM D245. The same reference contains guidelines for measuring various growth characteristics.

An individual piece of lumber will often 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 strength of the piece. In theory, a visual stress grade contains lumber ranging from pieces with the minimum strength ratio permitted in the grade up to pieces with the strength ratio just below the next higher grade. In practice, there are often pieces in a grade with strength ratios of a higher grade. This is a result of grade reduction for appearance factors such as wane that do not affect strength.

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 to ensure safety in design, it is intended that the actual strength of at least 95% of the pieces in a grade exceed the design properties (before reduction for duration of load and safety) assigned to that grade. In visual grading, according to ASTM D245, this is handled by using a near-minimum clear wood strength as a base 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% exclusion limit. ASTM D2555 provides clear wood strength data and gives a method for estimating the 5% exclusion limit.

For example, suppose a 5% exclusion limit for the clear wood bending strength of a species in the green condition is 48 MPa (7,000 lb/in^2). 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%. Using the numbers, the bending strength for the grade is estimated by multiplying the strength ratio (0.40) by 48 MPa (7,000 lb/in^2), equaling 19 MPa (2,800 lb/in^2) (Fig. 6–4). The bending strength in the green condition of 95% of the pieces in this species in a grade that has a strength ratio of 40% is expected to be ≥19 MPa (≥2,800 lb/in^2). Similar procedures are followed for other strength properties, using the appropriate clear wood property value and strength ratio. Additional multiplying factors are then applied to produce properties for design, as summarized later in this chapter.

Modulus of Elasticity—Modulus of elasticity *E* is a measure of the ability of a beam to resist deflection or of a column to resist buckling. The assigned *E* is an estimate of the average modulus, adjusted for shear deflection, of the lumber grade when tested in static bending. The average modulus of elasticity for clear wood of the species, as recorded in ASTM D2555, 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 for pieces tested in an edgewise orientation. This procedure is outlined in ASTM D245.

For example, assume a clear wood average modulus of elasticity of 12.4 GPa (1.8×10^6 lb/in^2) for the example shown earlier. The limiting bending strength ratio was 40%. ASTM D245 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; that is, $12.4 \times 0.8 = 9.9$ GPa ($1.8 \times 0.8 = 1.44 \times 10^6$ lb/in^2).

Actual modulus of elasticity of individual pieces of a grade varies from the average assumed for design (Fig. 6–5). Small individual lots of lumber can be expected to deviate from the distribution shown by this histogram. The additional multiplying factors used to derive final design values of modulus of elasticity are discussed later in this chapter.

In-Grade Procedure

To establish the mechanical properties of specified grades of lumber from tests of full-size specimens, a representative sample of the lumber population is obtained following procedures in ASTM D2915 and D1990. The specimens are tested using appropriate procedures given in ASTM D198

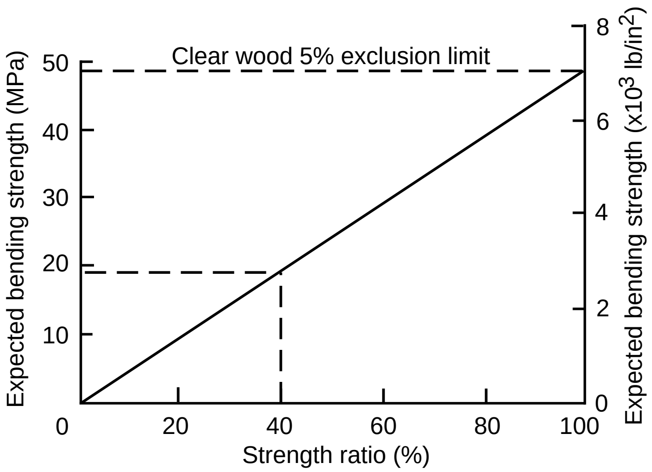

Figure 6–4. Example of relation between strength and strength ratio.

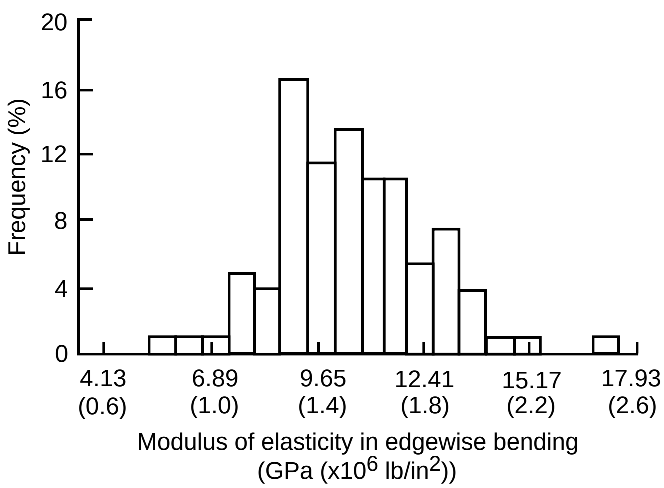

Figure 6–5. Histogram of modulus of elasticity observed in a single visual grade, from pieces selected over a broad geographical range.

or D4761. Because the range of quality with any one specific grade may be large, it is necessary to assess the grade quality index (GQI) of the sampled material in relation to the assumed GQI. In the North American In-Grade Program, GQI was the strength ratio calculated according to formulas in ASTM D245. The sample GQI and the assumed GQI are compared to see if adjustment to the test data is necessary. An average value for the edgewise modulus of elasticity or a near-minimum estimate of strength properties is obtained using ASTM D1990 procedures. The grade GQI is also used as a scaling perimeter that allows for modeling of strength and modulus of elasticity with respect to grade. These properties are further modified for design use by consideration of service moisture content, duration of load, and safety.

Machine-Graded Structural Lumber

Machine-graded lumber is lumber evaluated by a machine using a nondestructive test followed by visual grading to evaluate certain characteristics that the machine cannot or may not properly evaluate. Machine-stress-rated (MSR), machine-evaluated-lumber (MEL), and *E*-rated lumber are three types of machine-graded lumber. Machine-graded lumber allows for better sorting of material for specific applications in engineered structures. The basic components of a machine-grading system are as follows:

1. sorting and prediction of strength through machine-measured nondestructive determination of properties coupled with visual assessment of growth characteristics,
2. assignment of design properties based on strength prediction, and
3. quality control to ensure that assigned properties are being obtained. The quality control procedures ensure
   a. proper operation of the machine used to make the nondestructive measurements,
   b. appropriateness of the predictive parameter–bending strength relationship, and
   c. appropriateness of properties assigned for tension and compression.

The MSR and MEL systems differ in grade names, quality control, and coefficient of variation (COV) for *E* values. Grade names for MSR lumber are a combination of the design bending stress and average modulus of elasticity, whereas grade names for MEL lumber start with an M designation. For quality control, MSR requires pieces to be tested daily for at least one strength property and bending modulus of elasticity in an edgewise orientation, whereas MEL requires daily tension quality control and edgewise bending strength and stiffness testing. Finally, MSR grades are assigned a COV = 11% on *E*, whereas MEL grades are assigned a COV ≤ 15% on *E*. Grade names for a wide range of machine-graded lumber commonly available across North America are given in Table 6–4. Not all grades are available in all sizes or species.

Machine Sorting Criteria

The most common method of sorting machine-graded lumber is modulus of elasticity *E*. When used as a sorting criterion for mechanical properties of lumber, *E* can be measured in a variety of ways. Usually, the apparent *E*, or deflection related to stiffness, is actually measured. Because lumber is heterogeneous, the apparent *E* depends on span, orientation (edge- or flatwise in bending), load speed of test (static or dynamic), and method of loading (tension, bending, concentrated, or uniform). Any of the apparent *E* values can be used, as long as the grading machine is properly calibrated, to

Table 6–4. Common grades for machine-graded lumber[a]

Grade name	F_b (MPa (lb/in^2))	E (GPa (×10^6 lb/in^2))	F_t (MPa (lb/in^2))	$F_{c\|\|}$ (MPa (lb/in^2))
MSR				
1350f–1.3E	9.3 (1,350)	9.0 (1.3)	5.2 (750)	11.0 (1,600)
1450f–1.3E	10.0 (1,450)	9.0 (1.3)	5.5 (800)	11.2 (1,625)
1650f–1.5E	11.4 (1,650)	10.3 (1.5)	7.0 (1,020)	11.7 (1,700)
1800f–1.6E	12.4 (1,800)	11.0 (1.6)	8.1 (1,175)	12.1 (1,750)
1950f–1.7E	13.4 (1,950)	11.7 (1.7)	9.5 (1,375)	12.4 (1,800)
2100f–1.8E	14.5 (2,100)	12.4 (1.8)	10.9 (1,575)	12.9 (1,875)
2250f–1.9E	15.5 (2,250)	13.1 (1.9)	12.1 (1,750)	13.3 (1,925)
2400f–2.0E	16.5 (2,400)	13.8 (2.0)	13.3 (1,925)	13.6 (1,975)
2550f–2.1E	17.6 (2,550)	14.5 (2.1)	14.1 (2,050)	14.0 (2,025)
2700F–2.2E	18.6 (2,700)	15.2 (2.2)	14.8 (2,150)	14.4 (2,100)
2850f–2.3E	19.7 (2,850)	15.9 (2.3)	15.9 (2,300)	14.8 (2,150)
MEL				
M–10	9.7 (1,400)	8.3 (1.2)	5.5 (800)	11.0 (1,600)
M–11	10.7 (1,550)	10.3 (1.5)	5.9 (850)	11.5 (1,675)
M–14	12.4 (1,800)	11.7 (1.7)	6.9 (1,000)	12.1 (1,750)
M–19	13.8 (2,000)	11.0 (1.6)	9.0 (1,300)	12.6 (1,825)
M–21	15.9 (2,300)	13.1 (1.9)	9.7 (1,400)	13.4 (1,950)
M–23	16.5 (2,400)	12.4 (1.8)	13.1 (1,900)	13.6 (1,975)
M–24	18.6 (2,700)	13.1 (1.9)	12.4 (1,800)	14.5 (2,100)

[a]Forest Products Society 1997. Other grades are available and permitted.
F_b is allowable 10-year load duration bending stress parallel to grain.
E is modulus of elasticity.
F_t is allowable 10-year load duration tensile stress parallel to grain.
$F_{c||}$ is allowable 10-year load duration compressive stress parallel to grain.

assign the graded piece to a “not to exceed” grade category. Most grading machines in the United States are designed to detect the lowest flatwise bending E that occurs in any approximately 1.2-m (4-ft) span and the average flatwise E for the entire length of the piece.

Another method of sorting machine-graded lumber is using density measurements to estimate knot sizes and frequency. X-ray sources in conjunction with a series of detectors are used to determine density information. Density information is then used to assign the graded piece to a “not to exceed” grade category.

In the United States and Canada, MSR and MEL lumber are also subjected to a visual override because the size of edge knots in combination with E is a better predictor of strength than is E alone. Maximum edge knots are limited to a specified proportion of the cross section, depending on grade level. Other visual restrictions, which are primarily appearance rather than strength criteria, are placed on checks, shake, skips (portions of board “skipped” by the planer), splits, wane, and warp.

Procedures for Deriving Design Properties

Allowable Stress for Bending

A stress grade derived for machine-graded lumber relates design strength to a nondestructive parameter. For this example, it will be considered to be E. Because E is an imperfect predictor of strength, lumber sorted solely by average E falls into one of four categories, one of which is sorted correctly and three incorrectly (Fig. 6–6).

Consider, for example, the most simple case (sometimes referred to as “go” or “no go”) where lumber is sorted into two groups: one with sufficient strength and stiffness for a specific application, the other without. In Figure 6–6a, a regression line relating E and strength is used as the prediction model. The “accept–reject” groups identified by the regression sort can be classified into four categories:

- Category 1—Material that has been accepted correctly, that is, pieces have sufficient strength and stiffness as defined
- Category 2—Material that has been accepted incorrectly, that is, pieces do not have sufficient strength

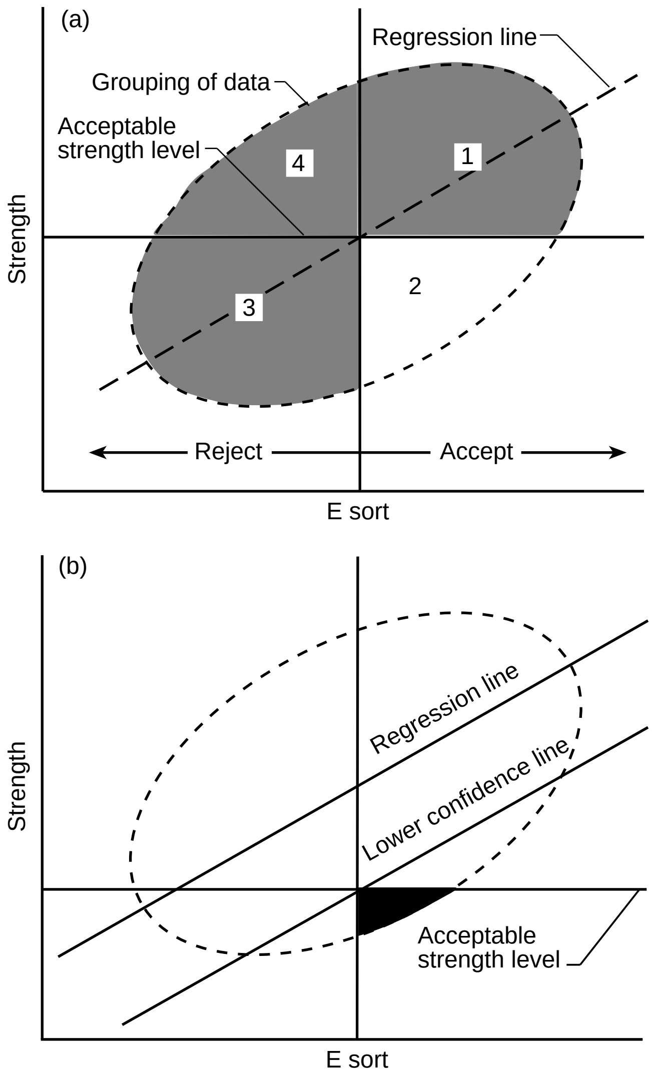

Figure 6–6. Schematic *E* sort: (a) using a regression line as the predictor showing four categories: 1—accepted correctly; 2—accepted incorrectly; 3—rejected correctly; and 4—rejected correctly; (b) using a lower confidence line as the predictor and showing the relatively low proportion of material in the accepted incorrectly category (lower right).

- Category 3—Material that has been rejected correctly because it does not have sufficient strength
- Category 4—Material that has been rejected correctly because it does not have sufficient stiffness

Thus, the sort shown in Figure 6–6a has worked correctly for categories 1, 3, and 4 but incorrectly for category 2. Pieces in category 2 present a problem. These pieces are accepted as having sufficient strength but in reality they do not, and they are mixed with the accepted pieces of category 1. The number of problem pieces that fall in category 2 depends on the variability in the prediction model.

To minimize the material that falls into category 2, adjustments are made to the property assignment claims made about the sorted material. An appropriate model is one that minimizes the material in category 2 or at least reduces it to a lower risk level. Additional grading criteria (edge-knot limitations, for example) are also added to improve the efficiency of the sorting system relative to the resource and the claimed properties.

Commonly, a lower confidence line is used as the prediction model (Fig. 6–6b). The number of pieces that fall into category 2 is now low compared with the regression line model. Furthermore, the probability of a piece (and thus the number of pieces) falling into category 2 is controlled by the confidence line selected.

In actual MSR systems, the lumber is sorted (graded) into *E* classes. In the United States and Canada, the number of grades has increased as specific market needs have developed for MSR lumber. Today, individual grading agencies list as many as 13 *E* classifications and more than 20 different grades. The grades are designated by the recommended extreme fiber stress in bending F_b and edgewise modulus of elasticity *E*. For example, "2100F–1.8E" designates an MSR grade with a design stress F_b = 14 MPa (2,100 lb/in^2) and *E* = 12.4 GPa (1.8×10^6 lb/in^2).

In theory, any *F*–*E* combination can be marketed that can be supported by test data. In practice, a mill will usually produce only a few of the possible existing *F*–*E* classifications depending on the potential of the timber being harvested, mill production capabilities, and product or market demand. When a mill has determined the grades it would like to produce (based on their lumber resource and marketing issues), grade boundary machine settings are used to separate the lumber into *F*–*E* classifications. A qualification sample of lumber is tested by a grading agency for strength and stiffness, to verify that the proper machine settings are being used. After initial qualification, additional quality control tests are performed during production.

Figure 6–7 illustrates how F_b–*E* classifications have been developed historically for species groups. Data for a particular species group are collected, the relationship of *E* and MOR is evaluated, and a lower confidence line is established for the species, as illustrated in Figure 6–6b. Using the lower confidence line of this relationship, an MOR value corresponding to the "minimum *E*" assigned to the grade is determined. The "minimum *E*" assigned to the grade represents the 5th percentile of the *E* distribution. The 5th percentile value is expected to be exceeded by 95% of the pieces in a grade or class. In this example, for a grade with an assigned *E* of 13.8 GPa (2.0×10^6 lb/in^2), the "minimum *E*" is 11.3 GPa (1.64×10^6 lb/in^2). The corresponding MOR value from the lower confidence line prediction model, approximately a 5th percentile MOR value, is 34.8 MPa (5.04×10^3 lb/in^2). This value is then adjusted by a factor (2.1) for assumed 10-year duration of load and safety to obtain F_b. This factor applied to an estimated 5th percentile

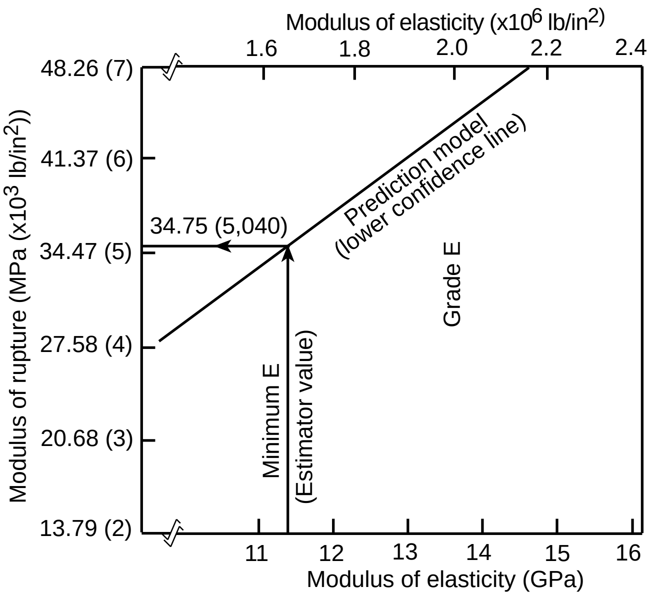

Figure 6–7. Typical assignment of F_b–*E* values for MSR lumber in United States (solid lines are minimum *E* for the F_b–*E* classification and bending strengths predicted by minimum *E* values).

MOR value of 34.8 MPa (5.04×10^3 lb/in^2) yields an F_b of 16.5 MPa (2.40×10^3 lb/in^2) for the 2.0E grade; in other words, a 2400f –2.0E MSR grade.

Design Stresses for Other Properties

Properties in tension and compression are commonly developed from relationships with bending rather than estimated directly by the nondestructive parameter *E*. In Canada and the United States, the relationships between the 5th percentile 10-year bending stress and those in tension and compression are based upon limited lumber testing for the three properties but supported by years of successful experience in construction with visual stress grades of lumber. For tension, it is assumed that the ratio of design bending stress F_b to design tensile stress F_c is between 0.5 and 0.8, depending on the grade, whereas the relationship between F_b and fiber stress in design compressive stress F_c is assumed to be

$$F_c = [0.338\ (2.1F_b) + 2060.7]/1.9$$

Strength in shear parallel to the grain and in compression perpendicular to the grain is poorly related to modulus of elasticity. Therefore, in machine stress grading these properties are assumed to be grade-independent and are assigned the same values as those for visual lumber grades, except when predicted from specific gravity on a mill-by-mill basis. It is permissible to assign higher allowable stress for shear parallel to grain and compression perpendicular to grain to specific grades based on additional specific gravity research.

Quality Control

Quality control procedures are necessary to ensure that stresses assigned by a machine-grading system reflect the actual properties of the lumber graded. These procedures must check for correct machine operation. Verification of the relationships between bending and other properties may also be required by the rules-writing agency, particularly for fiber stress in tension F_t.

Daily or even more frequent calibration of machine operation may be necessary. Depending upon machine principle, calibration may involve operating the machine on a calibration bar of known stiffness, comparing grading machine *E* values to those obtained on the same pieces of lumber by calibrated laboratory test equipment, determining if machine-predicted density matches a calibration sample density, or in some instances, using two or more procedures. Machine operation should be certified for all sizes of lumber being produced. Machine settings may need to be adjusted to produce the same grade material from different widths.

Quality control procedures of the MSR prediction model (*E*–bending strength relationship) have been adopted in Canada and the United States. Daily, or more frequently, lumber production is representatively sampled and proof-loaded, usually in bending, with supplementary testing in tension. The pieces are proof-loaded to at least twice the design stress (F_b or F_t) for the assigned F_b –*E* classification. In bending, the pieces are loaded on a random edge with the maximum-edge defect within the maximum moment area (middle one-third span in third-point loading) or as near to that point as possible. In tension, the pieces are tested with a 2.4-m (8-ft) gauge length.

If the number of pieces in the sample failing the proof-test load indicates a high probability that the population from which the pieces came does not meet the minimum grade criteria, a second sampling and proof test are conducted immediately. If the second sample confirms the results of the first sample, the MSR grading system is declared “out of control” and the operation is shut down to isolate and correct the problem. The lumber that was incorrectly labeled is then correctly labeled.

Cumulative machine calibration records are useful for detecting trends or gradual change in machine operation that might coincide with use and wear of machine parts. The proof-test results are also accumulated. Standard statistical quality control procedures (such as control charts) are used to monitor the production process so that it can be modified as needed in response to change in the timber resource, and to make the output fit the assumed model.

Too many failures in one, or even consecutive, samples do not necessarily indicate that the system is out of control. If the prediction line is based on 95% confidence, it can be expected by chance alone that 1 sample in 20 will not meet the proof-load requirements. One or more out-of-control samples may also represent a temporary aberration in material properties (E–strength relationship). In any event, this situation would call for inspection of the cumulative quality control records for trends to determine if machine adjustment might be needed. A "clean" record (a period when the system does not go out of control) rectifies the evaluation of a system thought to be out of control.

Adjustment of Properties for Design Use

The mechanical properties associated with lumber quality are adjusted to give design unit stresses and a modulus of elasticity suitable for engineering uses. First, a lower confidence level is determined for the material, and this value is then adjusted for shrinkage, size, duration of load, and in ASD, an additional factor of safety. These adjustment factors are discussed in the following text (specific adjustments are given in ASTM designations D245 and D1990).

Shrinkage

As described in Chapter 3, lumber shrinks and swells with changes in moisture content. The amount of dimensional change depends on a number of factors, such as species and ring angle. The American Softwood Lumber Standard, PS 20, lists specific shrinkage factors from green to 15% moisture content that were used historically to set green lumber dimensions for most species (2.35% for thickness and 2.80% for width). The standard does not provide a means of adjusting lumber dimensions to any other moisture content. The standard also does not provide specific shrinkage factors for species such as redwood and the cedars, which shrink less than most species. Using the PS 20 recommendations and an assumed green moisture content M_g, we derive equations that can be used with most species to calculate the shrinkage of lumber as a function of percentage of moisture content M. The equation is applicable to lumber of all annual ring orientations. For dimension lumber, the dimensions at different moisture contents can be estimated with the following equation:

$$d_2 = d_1 \frac{1-(a-bM_2)/100}{1-(a-bM_1)/100}$$

where d_1 is dimension (mm, in.) at moisture content M_1, d_2 dimension (mm, in.) at moisture content M_2, M_1 moisture content (%) at d_1, M_2 moisture content (%) at d_2, and a and b are variables from Table 6–5.

Size Factor

In general, a size effect causes small members to have a greater unit strength than that of large members. There are two procedures for calculating size-adjustment factors, small clear and In-grade.

Table 6–5. Coefficients for equations to determine dimensional changes with moisture content change in dimension lumber

	Width		Thickness		
Species	*a*	*b*	*a*	*b*	M_g[a]
Redwood, western redcedar, and northern white cedar	3.454	0.157	2.816	0.128	22
Other species	6.031	0.215	5.062	0.181	28

[a]M_g is assumed green moisture content.

Table 6–6. Exponents for adjustment of dimension lumber mechanical properties with change in size[a]

Exponent	MOR	UTS	UCS
w	0.29	0.29	0.13
l	0.14	0.14	0

[a]MOR is modulus of rupture;
UTS, ultimate tensile stress; and
UCS, ultimate compressive stress.

Small Clear Procedure

ASTM D245 provides only a formula for adjusting bending strength. The bending strength for lumber is adjusted to a new depth F_n other than 2 in. (51 mm) using the formula

$$F_n = \left(\frac{d_o}{d_n}\right)^{\frac{1}{9}} F_o$$

where d_o is original depth (51 mm, 2 in.), d_n new depth, and F_o original bending strength.

This formula is based on an assumed center load and a span-to-depth ratio of 14. A depth effect formula for two equal concentrated loads applied symmetrical to the midspan points is given in Chapter 8.

In–Grade Test Procedures

ASTM D1990 provides a formula for adjusting bending, tension, and compression parallel to grain. No size adjustments are made to modulus of elasticity or for thickness effects in bending, tension, and compression. The size adjustments to dimension lumber are based on volume using the formula

$$P_1 = P_2 \left(\frac{W_1}{W_2}\right)^w \left(\frac{L_1}{L_2}\right)^l$$

where P_1 is property value (MPa, lb/in^2) at volume 1, P_2 property value (MPa, lb/in^2) at volume 2, W_1 width (mm, in.) at P_1, W_2 width (mm, in.) at P_2, L_1 length (mm, in.) at P_1, and L_2 length (mm, in.) at P_2. Exponents are defined in Table 6–6.

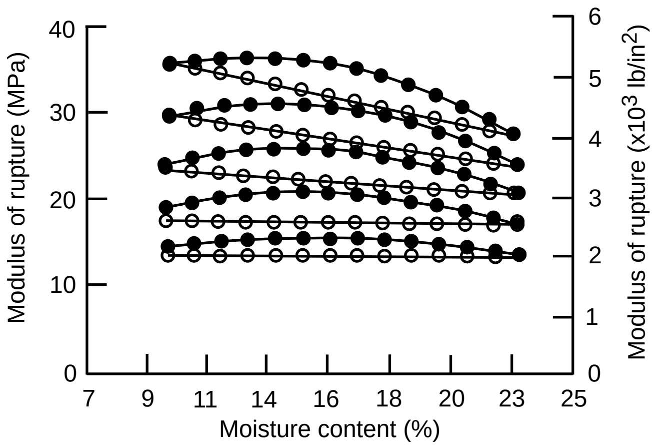

Figure 6–8. Modulus of rupture as a function of moisture content for dimension lumber. Open dots represent the ASTM D1990 model, and solid dots represent the more precise quadratic surface model on which the ASTM D1990 model was based.

Moisture Adjustments

For lumber ≤102 mm (≤4 in.) thick that has been dried, strength properties have been shown to be related quadratically to moisture content. Two relationships for modulus of rupture at any moisture content are shown in Figure 6–8. Both models start with the modulus of elasticity of green lumber. The curves with solid dots represent a precise quadratic model fit to experimental results. In typical practice, adjustments are made to correspond to average moisture contents of 15% and 12% with expected maximum moisture contents of 19% and 15%, respectively, using simplified expressions represented by the open dot curves. Below about 8% moisture content, some properties may decrease with decreasing moisture content values, and care should be exercised in these situations. Equations applicable to adjusting properties to other moisture levels between green and 10% moisture content are as follows:

For MOR, ultimate tensile stress (UTS), and ultimate compressive stress (UCS), the following ASTM D1990 equations apply:

For MOR ≤ 16.7 MPa (2,415 lb/in^2)
UTS ≤ 21.7 MPa (3,150 lb/in^2)
UCS ≤ 9.7 MPa (1,400 lb/in^2)

$$P_1 = P_2$$

Thus, there is no adjustment for stresses below these levels.

For MOR > 16.6 MPa (2,415 lb/in^2)
UTS > 21.7 MPa (3,150 lb/in^2)
UCS > 9.7 MPa (1,400 lb/in^2)

Table 6–7. Coefficients for moisture adjustment of dimension lumber mechanical properties with change in moisture content[a]

Coefficients	Property (MPa (lb/in^2)) MOR	UTS	UCS
B_1	16.6 (2,415)	21.7 (3,150)	9.6 (1,400)
B_2	0.276 (40)	0.552 (80)	0.234 (34)

[a]MOR is modulus of rupture; UTS, ultimate tensile stress; and UCS, ultimate compressive stress.

$$P_2 = P_1 + \left(\frac{P_1 - B_1}{B_2 - M_1}\right)(M_1 - M_2)$$

where M_1 is moisture content 1 (%), M_2 is moisture content 2 (%), and B_1, B_2 are constants from Table 6–7.

For E, the following equation applies:

$$E_1 = E_2\left(\frac{1.857 - (0.0237M_2)}{1.857 - (0.0237M_1)}\right)$$

where E_1 is property (MPa, lb/in^2) at moisture content 1 and E_2 is property (MPa, lb/in^2) at moisture content 2.

For lumber thicker than 102 mm (4 in.), often no adjustment for moisture content is made because properties are assigned on the basis of wood in the green condition. This lumber is usually put in place without drying, and it is assumed that drying degrade offsets the increase in strength normally associated with loss in moisture.

Duration of Load

Design may be based on either design stresses and a duration of load factor or on ultimate limit state design stresses and a time effects factor. Both the duration of load and time effects factor describe the same phenomenon. In allowable stress design, design stresses are based on an assumed 10-year loading period (called normal loading). If duration of loading, either continuously or cumulatively, is expected to exceed 10 years, design stresses are reduced 10%. If the expected duration of loading is for shorter periods, published design stresses can be increased using Figure 6–9. Ultimate limit-state design stresses are based on a 5-min loading period. If the duration of loading is expected to exceed 5 min, limit-state design stresses are reduced by applying the time effects factor. Intermittent loading causes cumulative effects on strength and should be treated as continuous load of equivalent duration. The effects of cyclic loads of short duration must also be considered in design (see discussion of fatigue in Ch. 4). These duration of load modifications are not applicable to modulus of elasticity.

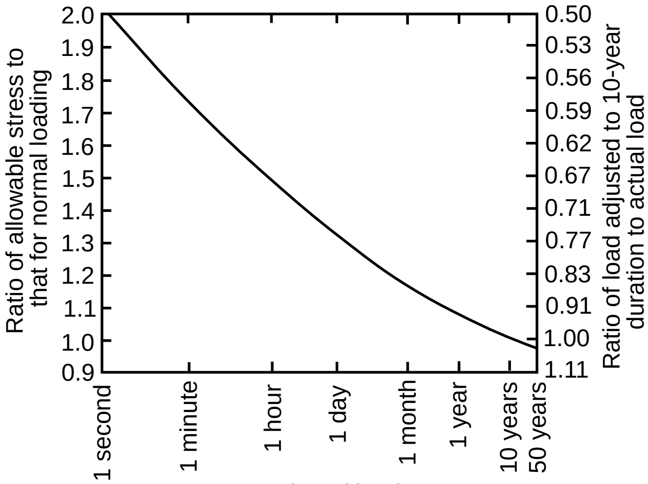

Figure 6–9. Relation of strength to duration of load.

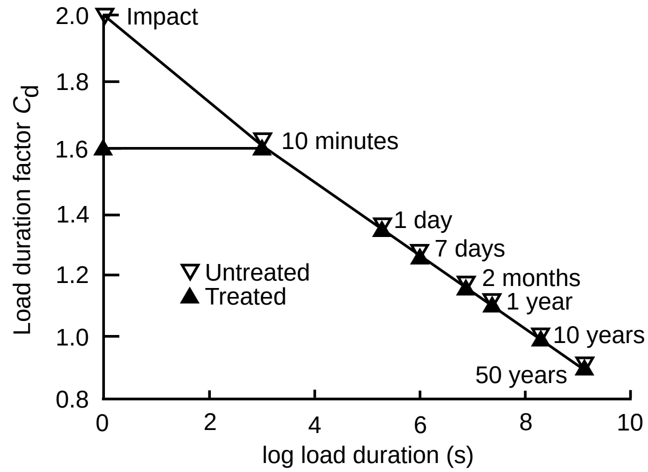

Figure 6–10. Load duration factor for material treated with waterborne preservative.

In many design circumstances there are several loads on the structure, some acting simultaneously and each with a different duration. When loads of different time duration are applied, the load duration factor corresponding to the shortest time duration is used. 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 design stress or the total design load (but not both) can be adjusted using Figure 6–9.

For example, suppose a structure is expected to support a load of 4.8 kPa (100 lb/ft^2) on and off for a cumulative duration of 1 year. Also, it is expected to support its own dead load of 0.96 kPa (20 lb/ft^2) for the anticipated 50-year life of the structure. The adjustments to be made to arrive at an equivalent 10-year design load are listed in Table 6–8.

The more severe design load is 5.36 kPa (112 lb/ft^2), and this load and the design stress for lumber would be used to select 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 design stress.

Treatment Effects

Treatments have been shown to affect the final strength of wood (Ch. 4 for detailed discussion). There is a 5% reduction in *E* and a 15% reduction in strength properties of incised and treated dimension lumber for both dry- and wet-use conditions in the United States. In Canada, a 10% reduction in *E* and a 30% reduction in all strength properties from incising is applied to dry-use conditions whereas 5% and 15% reductions are used for wet-use conditions. The wet-use factors are applied in addition to the traditional wet-use service factor. Reductions in energy-related properties are about 1.5 to 2 times those reported for static strength properties. There is no difference in long-term duration of load behavior between treated and untreated material (Fig. 6–10). Current design standards prohibit increases in design stresses beyond the 1.6 factor for short-term duration of load when considering impact-type loading for material treated with waterborne preservative.

Table 6–8. Example of duration of load adjustments

Time (year)	Total load (kPa (lb/ft^2))	Load adjustment[a]	Equivalent 10-year design load (kPa (lb/ft^2))
1	4.8 (100) + 0.96 (20) = 5.7 (120)	0.93	5.36 (112)
50	0.96 (20)	1.04	1.0 (21)

[a]Figure 6–9.

Table 6–9. Property adjustment factors for in-service temperature exposures

Design values	In-service moisture content	Factor $T \le 37^\circ C$ ($T \le 100^\circ F$)	$37^\circ C < T \le 52^\circ C$ ($100^\circ F < T \le 125^\circ F$)	$52^\circ C < T \le 65^\circ C$ ($125^\circ F < T \le 150^\circ F$)
F_t, E	Wet or dry	1.0	0.9	0.9
F_b, F_v, F_c, $F_{c\perp}$	Dry	1.0	0.8	0.7
	Wet	1.0	0.7	0.5

Temperature Effects

As wood is cooled below normal temperatures, its properties increase. When heated, its properties decrease. The magnitude of the change depends upon moisture content. Up to 65°C (150°F), the effect of temperature is assumed by design codes to be reversible. For structural members that will be exposed to temperatures up to 65°C (150°F), design values are multiplied by the factors given in Table 6–9 (AF&PA 1997). Prolonged exposure to heat can lead to a permanent loss in strength (see Ch. 4).

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