Chapter 2

Structure of Wood

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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.

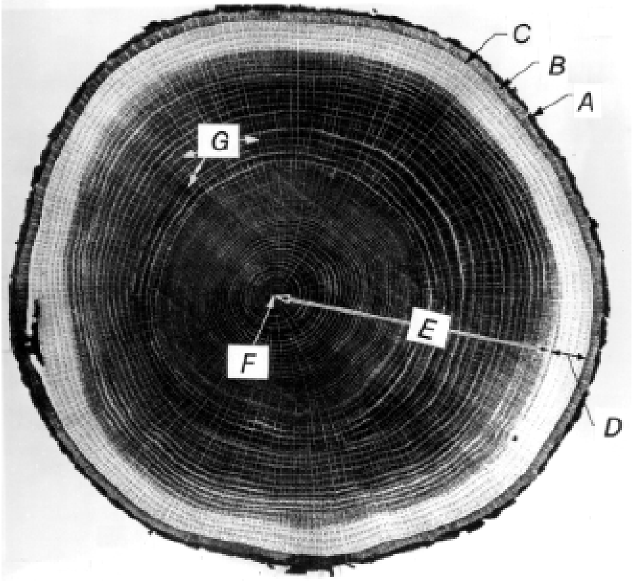

Figure 2–1. Cross section of white oak tree trunk: (A) outer bark (dry dead tissue), (B) inner bark (living tissue), (C) cambium, (D) sapwood, (E) heartwood, (F) pith, and (G) wood rays.

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

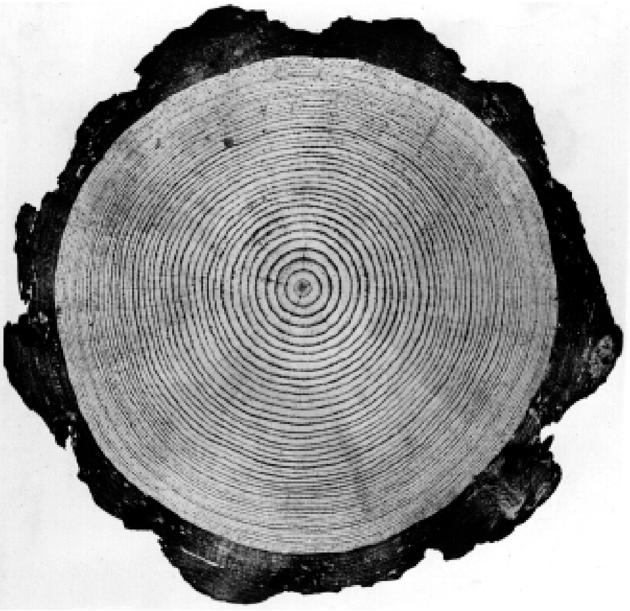

Figure 2–2. Cross section of ponderosa pine log showing growth rings. Light bands are earlywood, dark bands latewood. An annual (growth) ring is composed of an inner earlywood zone and outer latewood zone.

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.

References

Bratt, L.C. 1965. Trends in the production of silvichemicals in the United States and abroad. Tappi Journal. 48(7): 46A–49A.

Browning, B.L. 1975. The chemistry of wood. Huntington, NY: Robert E. Krieger Publishing Company.

Core, H.A.; Côté, W.A.; Day, A.C. 1979. Wood structure and identification. 7th ed. Syracuse, NY: Syracuse University Press.

Desch, H.E.; revised by Dinwoodie, J.M. 1996. Timber, structure, properties, conversion, and use. 7th ed. London: MacMillan Press, Ltd.

Fengel, D.; Wegener, G. 1984. Wood: Chemistry, ultrastructure, reactions. Berlin and New York: W. deGruyter.

Hamilton, J.K.; Thompson, N.C. 1959. A comparison of the carbohydrates of hardwoods and softwoods. Tappi Journal. 42: 752–760.

Hoadley, R.B. 1980. Identifying wood: Accurate results with simple tools. Newtown, CT: Taunton Press.

Hoadley, R.B. 1990. Understanding wood: A craftsmen's guide to wood technology. Newtown, CT: Taunton Press.

Kribs, D.A. 1968. Commercial woods on the American market. New York: Dover Publications.

Panshin, A.J.; de Zeeuw, C. 1980. Textbook of wood technology. 4th ed. New York: McGraw–Hill.

Rowell, R.M. 1984. The chemistry of solid wood. Advances in Chemistry Series No. 207. Washington, DC: American Chemical Society.

Sarkanen, K.V.; Ludwig, C.H. (eds.). 1971. Lignins: occurrence, formation, structure and reactions. New York: Wiley–Interscience.

Sjöström, E. 1981. Wood chemistry: fundamentals and applications. New York: Academic Press.

Stamm, A.J. 1964. Wood and cellulose science. New York: Ronald Press Company.

From
Forest Products Laboratory. 1999. Wood handbook—Wood as an engineering material.
Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service,
Forest Products Laboratory. 463 p.