HISTORY, NATURE, AND PRODUCTS OF WOOD

Youngs Robert L
Professor Emeritus, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

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1. Introduction

Wood has been used and adapted by humans since the earliest recognition that they could make use of the materials they found around them. As they used it to meet a varying array of human needs, in peace and in war, in farming and in industry, people gradually came to understand something of the unique nature of wood. Its properties were first understood by experience, more recently by systematic research and refined observation. Wood is still essential to human life, but has evolved over the ages from a simple, readily available natural material to a modern industrial and engineering material, with a unique ability to contribute to human life both as a material for use and as a key element in the natural world of the forest.

2. History of Wood Use

The tree and its wood have played a prominent role in human life throughout history. Wood has been one of our most important building materials from early Paleolithic times, both for building and for the manufacture of tools, weapons, and furniture. From the earliest times, the use of wood involved consideration of quality, cost and availability, as well as the intended use of the product. Scarcity of valuable timber led to careful and economic use. Boards were carefully matched and fitted; blemishes were removed and filled. Practices begun many centuries ago are still carried over, with refinement, to the current use of wood for high quality applications. Early humans used wood because it was available and no elaborate tools were needed to work it. In the early days, however, the quality of the products depended more on the quality of the wood and the skill of the workman than on the tools available for woodworking. The development of copper tools by about 5000 BC opened new opportunities for craftsmanship – opportunities that have been carried forward to this day.

From the tenth to the eighteenth centuries in Europe, wood was the material primarily used for buildings, tools, machines, mills, carts, buckets, shoes, furniture and barrels, to name just a few of the thousands of kinds of wood products of the time. The first printing press was made of wood and such presses continued to be made of wood for a hundred years. Most of the machines and inventions to make possible the machine age were formed of wood during that period. In Europe, wood use reached a peak during the sixteenth century, then began to diminish, not due to the limitations of wood, but due to limits on its accessibility as a result of increasing demands for fuel and materials and the expansion of agriculture into formerly forested lands. Wood use in North America continued to expand long after the decline of use in Europe and continues to increase today as part of the general world trend toward increasing wood use. Many of the uses now take different forms, reflecting new product demands and new technology.

Wood has historically played a key role in the transportation of people and their possessions, both as a fuel and as a raw material. Sledges made of wood were used in northern Europe as early as 7000 BC. As wheels were invented in 3-4000 BC, this led to the development of carts. In the nineteenth century in North America, railroads used wood for fuel, as well as for sleepers, bridges, trestles, and vehicles. Fuel use on railroads contributed to wood being the primary energy source in North America at the middle of the nineteenth century. Wood for water transport evolved from the early barges and hollowed out logs of 4500 BC to the sleek sail-powered clipper ships of the mid nineteenth century. Steam for power and steel for ship construction made that uneconomical by the end of the century, however.

Wood has been a most versatile and useful construction material for thousands of years and is still used more than any other construction material. The style and durability of structures built at various times and places have depended on the type and quality of timber available and the conditions of use, as well as the culture and way of life of the people concerned. In forested zones, where timber was plentiful, solid walls were built of tree trunks or heavy timbers. Timber houses in Neolithic Europe were frequently made by splitting logs and setting them vertically in the ground or on a sill plate on the ground. Also thousands of years old is the concept of construction with logs placed horizontally, as in a log cabin. It has been used most frequently in the northern, central, and mountainous area of Europe and North America where there have been plentiful supplies of large, straight trees. As construction with stone and concrete became common, wood was used for concrete forms and supplementary structural components such as trusses and roof supports. Wood construction has had an interesting evolution in North America because of the relatively abundant timber resource and the scattered development of much of the country. Native Americans built homes of poles or planks.

The architecture of the early colonists from Europe used wood intensively, adapting the concepts used in their homelands to the cultural conditions of the times and the availability of materials. Wood remained the principal construction material in North America well into the nineteenth century and remains so for housing today, as it does in some other parts of the world where timber supplies are plentiful and the tradition of wood construction remains strong.

Wood has been the dominant material for furniture construction since early times. Decoration and style of furniture have evolved as part of the artistic, cultural and technical development of society. Design and complexity were greatly enhanced by the development of copper tools. Efficiency and economy of wood use were spurred by the gradual depletion of fine furniture woods and increasing international trade in both furniture and the woods from which it was made.

Plywood and veneer, like most other basic forms of wood product, can be traced back to at least 3000 BC. The purpose until relatively recent times was to extend as far as possible the use of valuable decorative woods. Such woods were high value items of international trade and supplies were expensive and uncertain. Egypt, Greece, and Rome all had highly developed arts in veneered wood products. As compared with the ancient arts of decorative plywood, made primarily from hardwoods, softwood plywood is of relatively recent origin. Manufacture of softwood plywood began in the early 1900s in the USA and the industry is still active there, but has spread to many other parts of the world. It was developed as an alternative to lumber by gluing together thin layers of knife-cut wood (cut usually on a rotary lathe) with the grain of alternate layers at right angles to each other. The industry began growing rapidly following World War I and was further spurred by the demands of World War II and the development of weather resistant adhesives. Production of plywood panels has increased substantially in most parts of the world during the past few decades.

The development of wood-based composite materials, mostly within the 20th century, has had a significant effect on wood use and opened new opportunities for creative and versatile products from a changing wood resource. The capability to make engineered structural panels in a variety of forms and combinations with resins and other materials and the opportunity to economically use residues from other types of wood production `provides incentives for further development and application of the concept, of wood composites.

Wet process fiberboard was developed late in the 19th century and was commonly used for sheathing, interior paneling, and roof insulation early in the 20th. Particleboard evolved early in the 20th century from efforts to use shavings, sawdust, or small wood particles for panel materials, and production greatly expanded following World War II. Modern composites using flakes or strands of wood are replacing plywood for many structural applications. The composites field is expanding rapidly in volume and variety of production. Medium density fiberboard for core stock in furniture, mineral bonded products using wood wool and cement to make structural panels, products molded from wood particles, and composites of wood and other materials are greatly extending the wood resource and improving its utility while providing practical and economical materials for many kinds of construction.

3. The Nature of Wood

Wood is a natural product of the growth of trees. It is primarily composed of hollow, elongate, spindle-shaped cells that are arranged more or less parallel to each other in the direction of the tree trunk. This makes wood basically fibrous in nature and the characteristics of these fibrous cells and their arrangement in the tree strongly affect properties such as strength and stiffness, as well as the grain pattern of the wood.

3.1. Structure and Formation of Wood

Trees are divided into two broad classes, usually referred to as hardwoods and softwoods. This can be confusing, because the wood of some softwoods is harder than that of many hardwoods. For example, Scots pine and Douglas-fir are softwoods, but their wood is harder than that of poplar or mahogany, which are classed as hardwoods. Botanically, the hardwoods are angiosperms, which refers to the fact that the seeds are enclosed in the ovary of the flower. Anatomically, hardwoods are porous in that they contain vessel cells (pores in the transverse section) that form tubes for transporting water or sap in the tree. Typically, hardwoods have broad leaves that, in temperate and semi-tropical regions are shed in winter. Botanically, softwoods are gymnosperms, which refers to the fact that the seeds are naked (not enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements. Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years, though a few of them such as the larches, drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

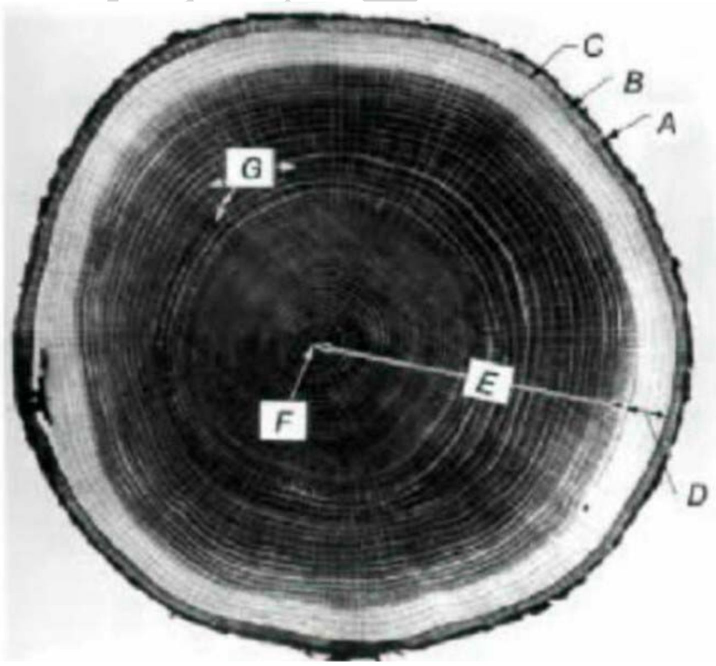

Figure 1. Cross section of white oak tree trunk. A. Outer bark. B. Inner bark. C. Cambium. D. Sapwood. E. Heartwood. F. Pith. G. Wood rays.

A cross section of a tree (Fig, 1) shows several features that are essential to the understanding of the properties and use of wood products. Beginning at the outside of the tree, one can see the outer, corky, dead bark (A) of varying thickness, useful primarily for protection of the tree, and thin, living bark (B) which carries food from the leaves to the growing parts of the tree. Both of these are known as phloem. Inside this is the xylem, or wood, which is usually differentiated into sapwood (D) and heartwood (E). At the very center is the pith (F), a small core of tissue within which initial growth takes place. Sapwood contains both living and dead tissue; its interior cells serve for storage of nutrients, while its outer cells carry sap from the roots to the leaves. Heartwood is formed by gradual change in the sapwood, often with deposition of extractive materials, and serves primarily as mechanical support for the tree. Extractive deposits may darken the wood and interfere with transmission of liquids and gases through the wood, as in drying or preservation processes. The wood rays (G) run radially in the tree and serve for storage and transfer of nutrients. Between the xylem and phloem (wood and bark) is the cambium (C), visible only under a microscope, which forms wood cells to the inside and bark cells to the outside as the tree grows laterally. Lateral tree growth is due entirely to the addition of wood and bark cells by the cambium, not to the enlargement of existing cells.

Figure 2. Cross section of ponderosa pine log showing growth rings. Light bands are earlywood and dark bands are latewood. A growth ring is composed of an inner earlywood zone and an outer latewood zone. (Forest Products Laboratory).

Most woods grown in temperate regions show a distinct demarcation between cells formed early in the growing season (earlywood) and those formed late in the growing season (latewood) and this is sufficient to produce clear growth rings (Figure 2). The actual time of formation of earlywood and latewood varies with environmental and growth conditions. Earlywood is characterized by cells with thin walls and large cavities, while latewood cells typically have thicker walls and smaller lumens. In some hardwoods, earlywood may be characterized by the growth of large vessels with pores clearly larger and more numerous (see wood cells). Transition from earlywood to latewood may be gradual or abrupt, depending on the species and conditions of growth. Growth rings, or annual increment, are most readily seen where this transition is abrupt, either due to the thick-walled cells of latewood in softwoods (Figure 2) or the more prominent earlywood vessels of hardwoods (Figure 1). This difference in wood structure causes noticeable differences in physical properties of the wood and proportion of latewood may be used as a rough indication of differences in properties of lumber or other products made from the wood.

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis. The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses. These components are laid down in layers to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (μm) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. 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 walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, low-molecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood (see *Cellulose and Pulp*). Hemicelluloses play an important role in fiber-to-fiber bonding in papermaking.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propyl phenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone.

The xylem of softwoods is relatively simple, usually comprising only three or four kinds of cells, predominantly fibers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance. Most of the wood of softwoods (90-95%) is comprised of longitudinal tracheids (fibers). These are long, slender cells, about 100 times as long as they are wide, averaging about 3 to 4 mm in length, rectangular in cross section, closed at the ends, with bordered pits primarily on the radial face. A small portion of the wood of softwoods is longitudinal parenchyma, cells shaped like the fibers, but usually divided into short lengths. Some softwoods (*Pinus, Picea, Larix*, and a few others) contain resin canals, which are intercellular spaces in the longitudinal direction surrounded by specialized cells that secrete resin. Radial structures in softwoods are usually wood rays a few cells thick, composed of either ray tracheids or ray parenchyma. Figure 3 shows a three dimensional representation of a softwood illustrating how these structures may be seen on the transverse, radial, and tangential surfaces of the wood.

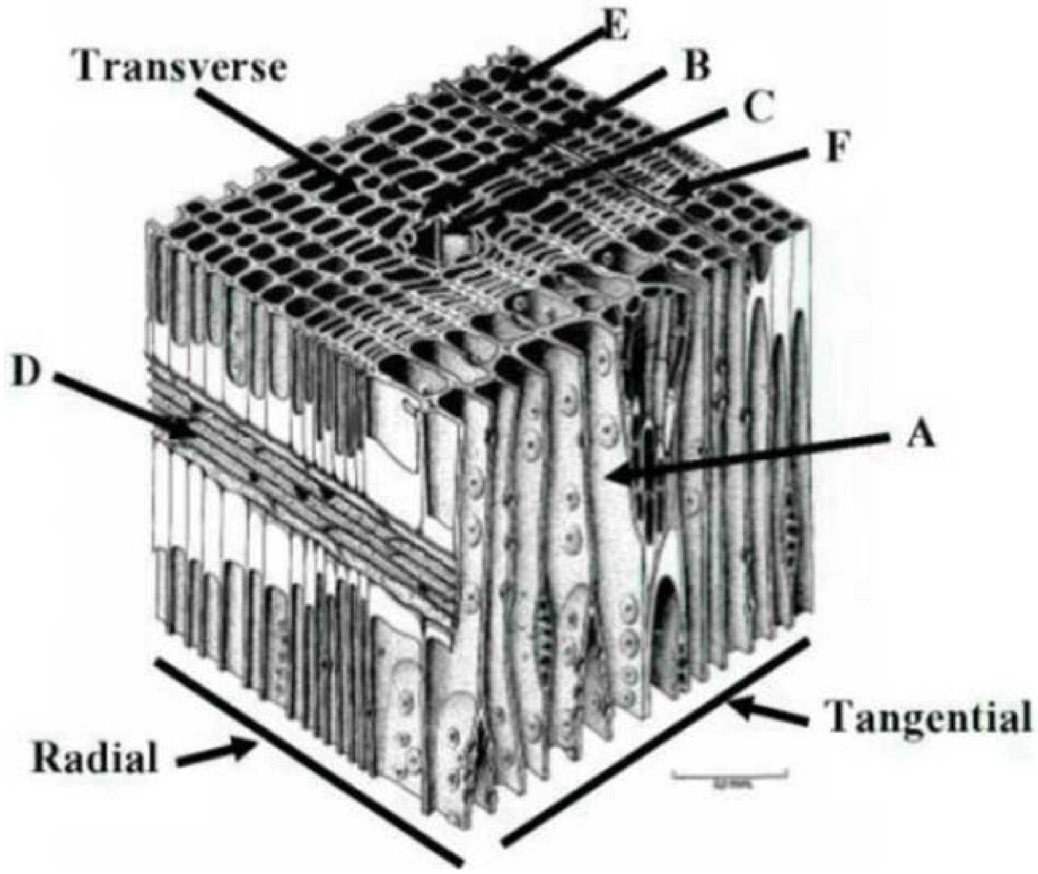

Figure 3. Three-dimensional representation of softwood. A. Longtitudinal tracheid. B. Longtitudinal parenchyma. C. Resin canal. D. Wood ray. E. Earlywood. F. Latewood. (Forest Products Laboratory).

The structure of hardwoods is much more complex and diverse than that of softwoods with at least four major kinds of cells: fibers, vessels, longitudinal parenchyma, and ray parenchyma. Fibers are shaped something like tracheids of softwoods, but are much shorter (<1 mm) and tend to be rounded in cross section. Their function is primarily mechanical support. Vessel elements are specialized conducting tissue, unique to hardwoods, shorter than fibers, and connected end to end. They appear on the transverse face of the wood as pores. In some species, e.g., oak (*Quercus)*, these large vessels become blocked with tyloses as the sapwood changes to heartwood. Tyloses may also form as a result of injury or drought. Longitudinal parenchyma are thin walled cells whose function is primarily storage of nutrients. Hardwood rays are made up of from 1 to 30 cell wide bands of parenchyma, storage tissue, running radially in the tree. In some species, such as the oaks and beeches, these are clearly visible to the eye, in others they are scarcely visible. Figure 4 is a three-dimensional representation of a hardwood, showing these types of cells on the transverse, radial, and longitudinal faces.

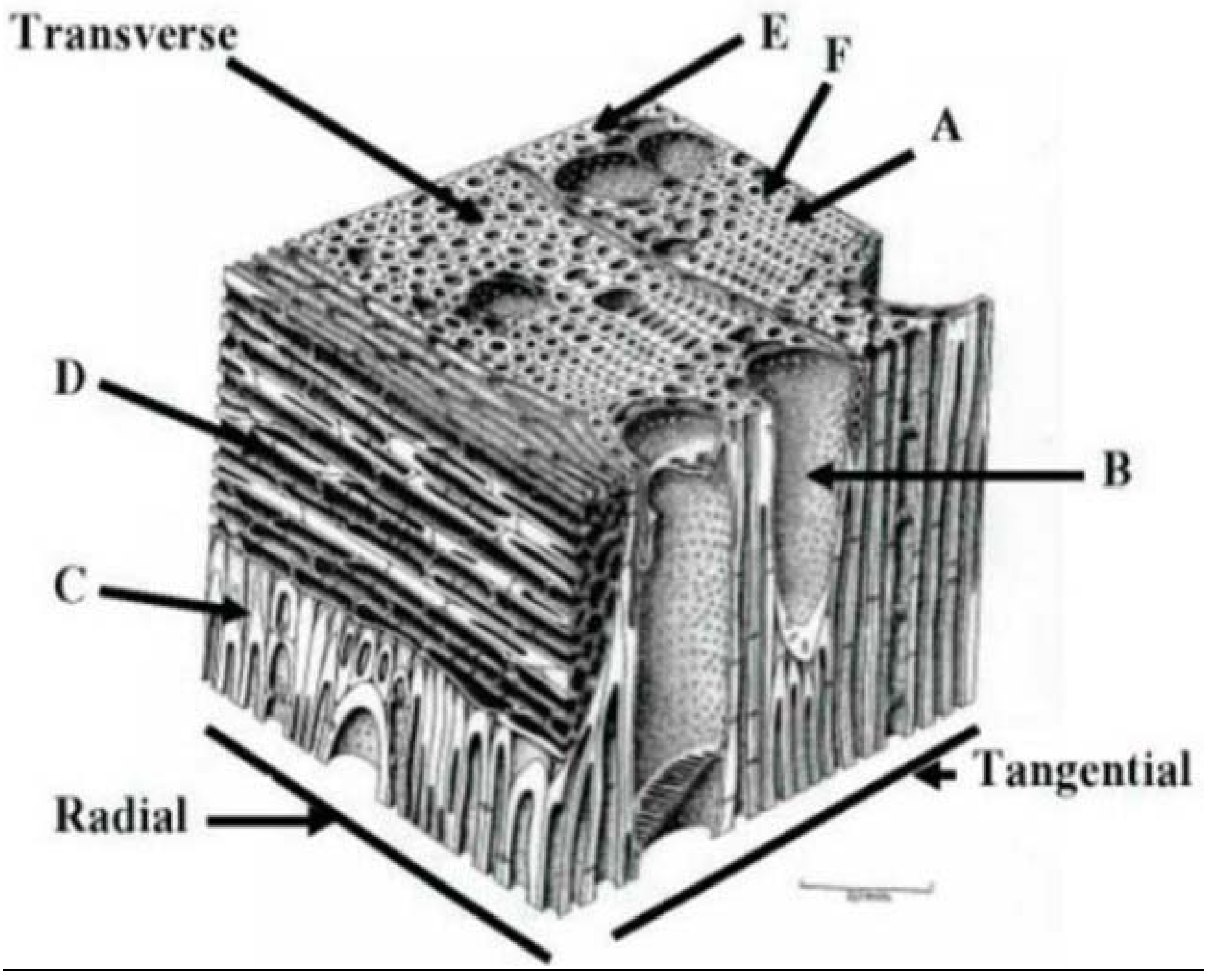

Figure 4. Three-dimensional representation of hardwood. A. Fiber. B. Vessel. C. Longtitudinal parenchyma. D. Ray parenchyma. E. Earlywood. F. Latewood. (Forest Products Laboratory).

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Biographical Sketch

Dr. Robert L. Youngs is Professor Emeritus of Forestry and Forest Products at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA. He was a Professor on that faculty from 1985 to 1995. Previously, he conducted and administered research in forestry and forest products in the Forest Service, US Department of Agriculture from 1951 to 1985. During that time, he served on the research staff of the Forest Products Laboratory, Madison, Wisconsin, as Associate Deputy Chief for Research in Washington, DC, as Director of the Southern Forest Experiment Station and as Director of the Forest Products Laboratory. He is a member of the International Academy of Wood Science and an Honorary Member of the International Union of Forest Research Organizations. He served from 1995 to 2001 as Editor of *Wood and Fiber Science.* He is the author of many publications in wood science and the history of wood use.