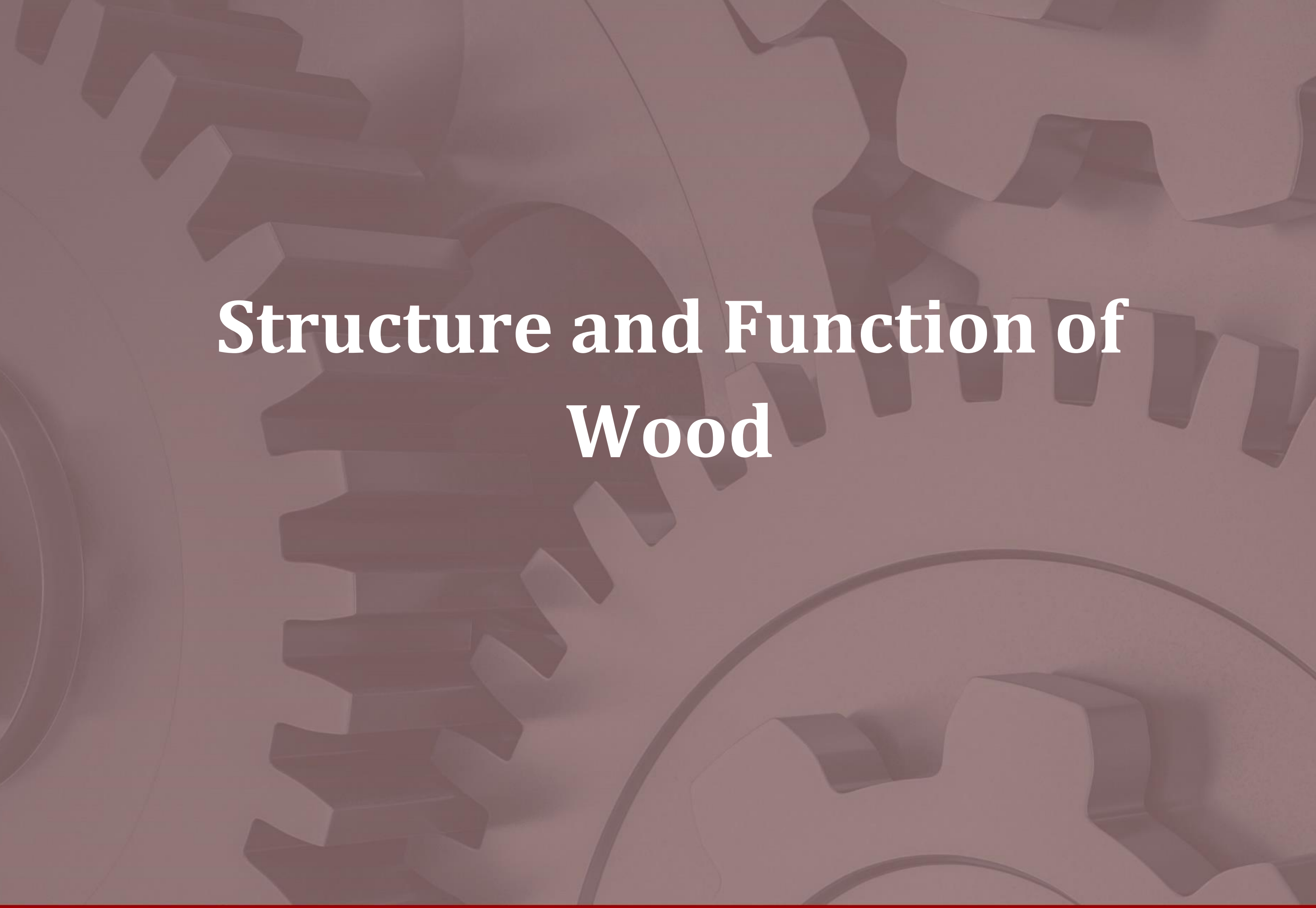

Structure and Function of Wood

An Online Continuing Education Course for Engineers

Course Number: S-2011

Credit: 2 Hours / 2 PDH / 2 CPD

Structure and Function of Wood

Wood is a complex biological structure, a composite of many chemistries and cell types acting together to serve the needs of a living plant. Attempting to understand wood in the context of wood technology, we have often overlooked the key and basic fact that wood evolved over the course of millions of years to serve three main functions in plants— conduction of water from the roots to the leaves, mechanical support of the plant body, and storage of biochemicals. There is no property of wood—physical, mechanical, chemical, biological, or technological—that is not fundamentally derived from the fact that wood is formed to meet the needs of the living tree. To accomplish any of these functions, wood must have cells that are designed and interconnected in ways sufficient to perform these functions. These three functions have influenced the evolution of approximately 20,000 different species of woody plants, each with unique properties, uses, and capabilities, in both plant and human contexts. Understanding the basic requirements dictated by these three functions and identifying the structures in wood that perform them allow insight to the realm of wood as an engineering material (Hoadley 2000). A scientist who understands the interrelationships between form and function can predict the utility of a specific wood in a new context. The objective of this course is to review the basic biological structure of wood and provide a basis for interpreting its properties in an engineering context. By understanding the function of wood in the living tree, we can better understand the strengths and limitations it presents as a material.

The component parts of wood must be defined and delimited at a variety of scales. The wood anatomical expertise necessary for a researcher who is using a solid wood beam is different from that necessary for an engineer designing a glued-laminated beam, which in turn is different from that required for making a wood–resin composite with wood flour. Differences in the kinds of knowledge required in these three cases are related to the scale at which one intends to interact with wood, and in all three cases the properties of these materials are derived from the biological needs of the living tree. For this reason, this course explains the structure of wood at decreasing scales and in ways that demonstrate the biological rationale for a plant to produce wood with such features. This background will permit the reader to understand the biological bases for the properties presented in subsequent courses.

Although shrubs and many vines form wood, the remainder of this course will focus on wood from trees, which are the predominant source of wood for commercial and engineering applications and provide examples of virtually all features that merit discussion.

Biological Structure of Wood at Decreasing Scales

The Tree

A living, growing tree has two main domains, the shoot and the roots. Roots are the subterranean structures responsible for water and mineral nutrient uptake, mechanical anchoring of the shoot, and storage of biochemicals. The shoot is made up of the trunk or bole, branches, and leaves (Raven and others 1999). The remainder of the course will be concerned with the trunk of the tree.

If one cuts down a tree and looks at the stump, several gross observations can be made. The trunk is composed of various materials present in concentric bands. From the outside of the tree to the inside are outer bark, inner bark, vascular cambium, sapwood, heartwood, and the pith (Fig. 1). Outer bark provides mechanical protection to the softer inner bark and also helps to limit evaporative water loss. Inner bark is the tissue through which sugars (food) produced by photosynthesis are translocated from the leaves to the roots or growing portions of the tree. The vascular cambium is the layer between the bark and the wood that produces both these tissues each year. The sapwood is the active, “living” wood that conducts the water (or sap) from the roots to the leaves. It has not yet accumulated the oftencolored chemicals that set apart the non-conductive heartwood found as a core of darker-colored wood in the middle of most trees. The pith at the very center of the trunk is the remnant of the early growth of the trunk, before wood was formed.

Softwoods and Hardwoods

Despite what one might think based on the names, not all softwoods have soft, lightweight wood, nor do all hardwoods have hard, heavy wood. To define them botanically, softwoods are those woods that come from gymnosperms (mostly conifers), and hardwoods are woods that come from angiosperms (flowering plants). In the temperate portion of the northern hemisphere, softwoods are generally needle-leaved evergreen trees such as pine (*Pinus*) and spruce (*Picea*), whereas hardwoods are typically broadleaf, deciduous trees such as maple (*Acer*), birch (*Betula*), and oak (*Quercus*). Softwoods and hardwoods not only differ in terms of the types of trees from which they are derived, but they also differ in terms of their component cells. Softwoods have a simpler basic structure than do hardwoods because they have only two cell types and relatively little variation in structure within these cell types. Hardwoods have greater structural complexity because they have both a greater number of basic cell types and a far greater degree of variability within the cell types. The single most important distinction between the two general kinds of wood is that hardwoods have a characteristic type of cell called a vessel element (or pore) whereas softwoods lack these (Fig. 2). An important cellular similarity between softwoods and hardwoods is that in both kinds of wood, most of the cells are dead at maturity, even in the sapwood. The cells that are alive at maturity are known as parenchyma cells and can be found in both softwoods and hardwoods.

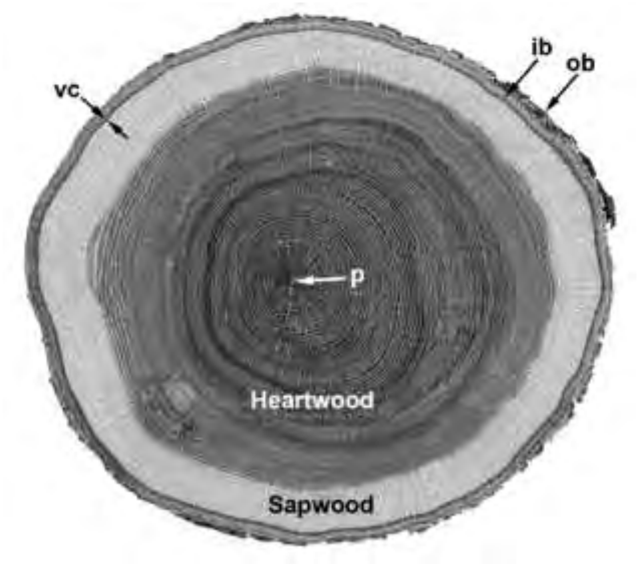

Figure 1. Macroscopic view of a transverse section of a *Quercus alba* trunk. Beginning at the outside of the tree is the outer bark (ob). Next is the inner bark (ib) and then the vascular cambium (vc), which is too narrow to see at this magnification. Interior toward the vascular cambium is the sapwood, which is easily differentiated from the heartwood that lies toward the interior. At the center of the trunk is the pith (p), which is barely discernible in the center of the heartwood.

Sapwood and Heartwood

In both softwoods and hardwoods, the wood in the trunk of the tree is typically divided into two zones, each of which serves an important function distinct from the other. The actively conducting portion of the stem in which parenchyma cells are still alive and metabolically active is referred to as sapwood. A looser, more broadly applied definition is that sapwood is the band of lighter colored wood adjacent to the bark. Heartwood is the darker colored wood found to the interior of the sapwood (Fig. 1).

In the living tree, sapwood is responsible not only for conduction of sap but also for storage and synthesis of biochemicals. An important storage function is the long-term storage of photosynthate. Carbon that must be expended to form a new flush of leaves or needles must be stored somewhere in the tree, and parenchyma cells of the sapwood are often where this material is stored. The primary storage forms of photosynthate are starch and lipids. Starch grains are stored in the parenchyma cells and can be easily seen with a microscope. The starch content of sapwood can have important ramifications in the wood industry. For example, in the tropical tree ceiba (*Ceiba pentandra*), an abundance of starch can lead to growth of anaerobic bacteria that produce ill-smelling compounds that can make the wood commercially unusable (Chudnoff 1984). In southern yellow pines of the United States, a high starch content encourages growth of sap-stain fungi that, though they do not affect the strength of the wood, can nonetheless decrease the lumber value for aesthetic reasons (Simpson 1991).

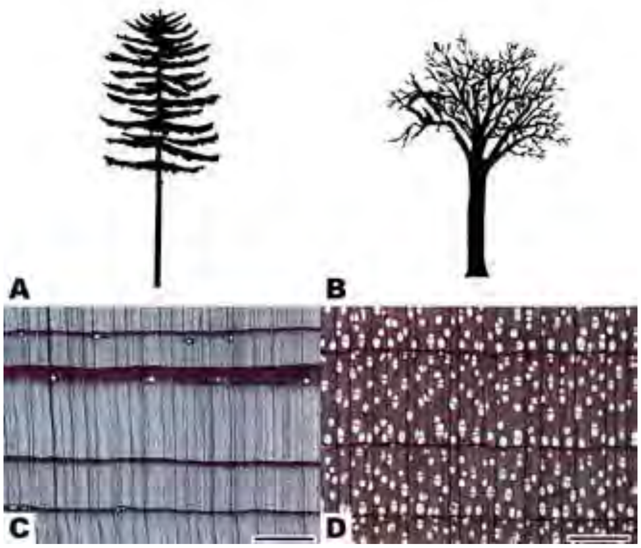

Figure 2. A, the general form of a generic softwood tree. B, the general form of a generic hardwood tree. C, transverse section of *Pseudotsuga mensiezii,* a typical softwood; the thirteen round white spaces are resin canals. D, transverse section of *Betula allegheniensis*, a typical hardwood; the many large, round white structures are vessels or pores, the characteristic feature of a hardwood. Scale bars = 780 µm.

Living cells of the sapwood are also the agents of heartwood formation. Biochemicals must be actively synthesized and translocated by living cells. For this reason, living cells at the border between heartwood and sapwood are responsible for the formation and deposition of heartwood chemicals, one important step leading to heartwood formation (Hillis 1996). Heartwood functions in long-term storage of biochemicals of many varieties depending on the species in question. These chemicals are known collectively as extractives. In the past, heartwood was thought to be a disposal site for harmful byproducts of cellular metabolism, the so-called secondary metabolites. This led to the concept of the heartwood as a dumping ground for chemicals that, to a greater or lesser degree, would harm living cells if not sequestered in a safe place. We now know that extractives are a normal part of the plant's system of protecting its wood. Extractives are formed by parenchyma cells at the heartwood–sapwood boundary and are then exuded through pits into adjacent cells (Hillis 1996). In this way, dead cells can become occluded or infiltrated with extractives despite the fact that these cells lack the ability to synthesize or accumulate these compounds on their own.

Extractives are responsible for imparting several larger-scale characteristics to wood. For example, extractives provide natural durability to timbers that have a resistance to decay fungi. In the case of a wood like teak (*Tectona grandis*), known for its stability and water resistance, these properties are conferred in large part by the waxes and oils formed and deposited in the heartwood. Many woods valued for their colors, such as mahogany (*Swietenia mahagoni*), African blackwood (*Diospyros melanoxylon*), Brazilian rosewood (*Dalbergia nigra*), and others, owe their value to the type and quantity of extractives in the heartwood. For these species, the sapwood has little or no value, because the desirable properties are imparted by heartwood extractives. Gharu wood, or eagle wood (*Aquilaria malaccensis*), has been driven to endangered status due to human harvest of the wood to extract valuable resins used in perfume making (Lagenheim 2003). Sandalwood (*Santalum spicatum*), a wood famed for its use in incenses and perfumes, is valuable only if the heartwood is rich with the desired scented extractives. The utility of a wood for a technological application can be directly affected by extractives. For example, if a wood like western red cedar, high in hydrophilic extractives, is finished with a water-based paint without a stain blocker, extractives may bleed through the paint, ruining the product.

Axial and Radial Syste

The distinction t, is a gross feature that is
often fairly easil e of wood shows that wood is
composed of dis cate and predictable fashion
to form an integr he cells of wood are typically
many times longe arate systems of cells: the
axial system and t ir long axes running parallel
to the long axis of lial system are elongated
perpendicularly to ii in a circle or spokes in a
bicycle wheel, fron l system runs up and
down, functions in lk of the mechanical
strength of the tree. rovides lateral transport
for biochemicals, ar rage function in wood.
These two systems a esence is a defining
characteristic of wo

Planes of Section

Although wood can b any direction for examination, the organization and interrelationship between the axial and radial systems give rise to three main perspectives from which they can be viewed to glean the most information. These three perspectives are the transverse plane of section (the cross section), the radial plane of section, and the tangential plane of section. Radial and tangential sections are referred to as longitudinal sections because they extend parallel to the axial system (along the grain).

The transverse plane of section is the face that is exposed when a tree is cut down. Looking down at the stump one sees the transverse section (as in Fig. 3H); cutting a board across the grain exposes the transverse section. The transverse plane of section provides information about features that vary both in the pith to bark direction (called the radial direction) and also those that vary in the circumferential direction (called the tangential direction). It does not provide information about variations up and down the trunk.