Wood product and utilization

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Lecture Schedule

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Lecture 1: Introduction – Need for the study – Characteristics of woody plants

Introduction

At no time in the past has there been as important a challenge and as bright an opportunity for the producers and users of forest products as today. The 1970s was a decade when the realities of the world's fossil fuel limitations became apparent to the public and the governments of industrialized countries. During the 1980s, the limitations of other of the world's non-renewable resources will be more widely recognized. The world is moving from a period of energy problems to one of materials problems. All types of materials – metals, plastics, cements – will be experiencing difficulties either because of shortages of raw material, large and expensive energy requirements for manufacture, or environmental problems created by production.

The bright future of wood based materials, however, lies not in the problems facing competitive industrial materials but in the inherent advantages of wood. The most important of these are:

1. The renewable nature of forests and wood. This characteristic insures that with proper forest management, industry can be assured of an indefinite supply of raw material.
2. The ability to use a portion of the harvested material as the source of energy to produce the product. Forest products manufacturing industries have the potential of becoming energy self-sufficient, generating from wood and bark all the power and heat energy they consume.
3. Wood's versatility as a material. It can be sawn for lumber, sliced for veneer, cut into particles, or broken down into fiber. The technological opportunities to serve human needs are accordingly great.
4. Multiple use of forest for other purposes. While forests are growing and producing wood they can also provide recreational, watershed and wildlife benefits.

The public has a growing preference for natural materials and a concern for the environment. Environmental considerations favor wood based materials. Although not yet clearly stated or understood, there is evidence that the energy implications of the use of wood and the psychological support to be gained from using a renewable resource are being recognized by the public and will have an impact in the 1980s.

One of the most important challenges ahead is to modify wood product technology to permit use of the type of wood now growing in the forests. Softwoods are in short supply and prices are rapidly escalating, but most regions have many species of hardwoods that are underutilized. The small size and low quality of many of these trees is a problem. However, technological developments have made possible the utilization of more and more of this material.

Those using wood material for their products are going to face some problems in the 1980s. At least three major difficulties seem likely. First, the short term supply of timber will become more uncertain and will shift more from public lands of the U.S. Forest Service and the Bureau of Land Management to private lands. In areas where private and industry owned forestlands are limited, means must be found for intensifying the level of management on public lands to provide the raw materials needed, or regional shifts in production will occur. It is possible, using currently available technology, to double and in some areas to triple the amount of wood being produced on the average forest acre. Levels of production could be raised even higher than this through more intensive management, use of genetically improved stock, and short rotation.

Need for the study

- Utilization of wood requires basic knowledge of structure and properties of wood.
- Wood is the renewable energy
- Versatile
- Fit into the concept of multiple use forests
- Environmental friendly

Characteristics of woody plants

- Vascular tissues
- Persistent and aerial stem
- Secondary thickening
- Lignification

Lecture 2: Classification of woody plants – Varied and versatile characteristics of wood

Classification of Woody Plants

Woods, and the trees that produce them, are divided into two categories: hardwoods and softwoods. Hardwood and softwood trees are botanically quite different. Both are included in the botanical division spermatophytes, meaning they produce seeds. They are, however, in different botanical subdivisions. Hardwoods are in the subdivision angiospermae and softwoods are in the gymnospermae subdivision. Angiosperms are characterized by production of seeds within ovaries, whereas gymnosperms produce seeds that are largely unprotected.

Needlelike leaves characterize softwood trees. Such trees are known commonly as evergreens, since most remain green the year around, annually losing only a portion of their needles. Most softwood also bears scaly cones (inside which seeds are produced) and is therefore often referred to as conifers. Included in the softwood family in the Northern Hemisphere are the genera *Pinus* (pine), *Picea* (spruce), *Larix* (larch), *Abies* (fir), *Tsuga* (hemlock), *Sequoia* (redwood), *Taxus* (yew), *Taxodium* (cypress) and *Pseudotsuga* (Douglas-fir) and the genera of those woods known commonly as cedars (*Juniperus, Thuja, Chamaecyparis, Libocedrus*).

In contrast to softwoods, hardwoods are angiosperms that bear broad leaves (which generally change color and drop in the fall in temperate zones) and produce seeds within acorns, pods or other fruiting bodies. Hardwood producing species fall within the dicotyledon class. Hardwood genera of the Northern Hemisphere include *Quercus* (oak), *Fraxinus* (ash), *Ulmus* (elm), *Acer* (maple), *Betula* (birch), *Fagus* (beech) and *Populus* (cottonwood, aspen). Included in the monocotyledon class are the palms and yucca. Many of the roughly 2500 species of palms produce relatively large diameter fibrous stems, which are strong if left in the round condition but tend to fall apart when cut into lumber. Paper can be made from the fiber.

Not only do hardwood and softwood trees differ in external appearance, but the wood formed by them differs structurally or morphologically. The types of cells, their relative numbers, and their arrangement are different, the fundamental difference being that hardwoods contain a type of cell called a vessel element. This cell type is found in virtually all hardwoods but never in softwoods. All hardwoods do not, incidentally, produce hard, dense wood. Despite the implication in the names hardwood and softwood, many softwoods produce wood that is harder and denser than wood produced by some hardwoods. Balsa wood, for example is from hardwood species.

Characteristics of wood

- Ø Cellular in structure
- Ø Hygroscopic
- Ø Biodegradable
- Ø Chemically stable
- Ø Insulatable
- Ø Combustable

Lecture 3: Basic process in tree growth – Vascular cambium – Expansion of cambium layer – Duration of cambial activities

Distribution of Hardwoods and Softwoods

Hardwood species occur in every major region of the United States. They predominate in the East, forming an almost unbroken forest from the Appalachians westward to the Great Plains. Across the plains, the trees that line rivers, streams and ponds are hardwoods. Further west, the perpetually green softwoods that cover the Rockies are frequently interrupted by patches of white-stemmed aspen and other hardwoods. In the far West, hardwoods grow in valleys below softwood-covered mountains. On a worldwide basis also, hardwoods predominate. They are found in most areas of the world. Tropical forests are almost exclusively hardwoods. In total, hardwood growing stock has been estimated to exist in volumes almost double that of softwoods.

Wood – A collection of small cells

A close look at wood shows it to be made up of tiny cells or fibers that are so small they generally cannot be seen without a magnifying glass or microscope. A type of cell that makes up most of the volume of a softwood such as white fir, the cell has a hollow center (lumen), is closed at the ends, and is perforated with openings in the sidewall.

Unmagnified, this block would occupy only about 1/50,000 cm^3. Rays, which are composed of a number of individual ray cells and provide for horizontal movement of moisture in a standing tree, can be seen cutting across the near left (radial) surface; rays in an end view can be seen on the right vertical (tangential) surface.

The three different surfaces of the block labeled transverse (cross section), radial and tangential – look quite different. A cross sectional surface is formed by cutting a log or piece of lumber to length, while radial and tangential surfaces result from cutting along the grain. A radial surface is made by cutting longitudinally along the radius of a round cross section. Tangential surfaces result from cutting perpendicular to a radius. The names transverse, radial and tangential are frequently encountered in the study of wood science.

Basic processes in tree growth

Production of wood and bark – Wood (xylem) is found inside a covering of bark, which is composed of an inner layer (phloem) and an outer protective layer (outer bark). As a tree grows, it adds new wood, increasing the diameter of its main stem and branches. Bark is also added in the process of growth to replace that, which cracks and flakes off as the stem grows larger.

Like all green plants, a tree can manufacture its own food through the process of photosynthesis, which takes place in the leaves. It needs, only water (from the soil), carbon dioxide (from the atmosphere), and light (from the sun) to do this. Water along with nutrients, is taken up by the roots and moved through the outer part of the xylem up to the leaves. Carbon dioxide is taken in through tiny openings in leaf surfaces. With the help of the sun, water and air are combined in the presence of chlorophyll to make sugars that provide energy to the growing tree. Some sugars are used in making new leaves, some in making new shoots, and some in making new wood. A part of the sugar moves to special locations in the wood or to the roots where it is stored for later use, and part is consumed through respiration. Sugars used in making new wood move down a tree through the phloem.

Sugar is transported throughout the tree in the form of sap, a solution containing various sugars and water as well as growth regulators and other substances. The term sap is also used to refer to the mineral rich water that is taken up by roots and moved upward through the outer portion of the xylem. A thin layer between the xylem and phloem produces new xylem and phloem tissue. This layer, called the cambium, completely sheaths the twigs, branches, trunk and roots, meaning that a season of growth results in a new continuous layer of wood throughout the tree.

Since sap moves down the tree through the phloem but is necessary for food in the cambium, a way is needed for it to travel horizontally toward the center of the tree. Wood rays provide for this horizontal movement. Rays also function in storing carbohydrates and may serve as avenues of horizontal transport for stored materials from near the center of the tree outward following periods of dormancy. Careful examination should help in gaining an understanding of the relationship between various layers of tissue.

Development of a young stem – To begin a study of the development process, growth of a young pine seedling will be considered. The seedling shown has a well-developed root system and crown typical of a 5 to 6 year old tree. With the beginning of growth in early spring, buds at the tip of each branch (and root) swell as tissue expands through formation and expansion of cells. These regions in which cells divide repeatedly to form new cells are called meristematic regions. Buds of similar appearance occur at the tip of each branch. The meristematic zone at the apex of the main stem is of special significance since it controls to some extent the development of branches and shoots; it is called the apical meristem.

The process of change continues. A second protective layer, the endodermis, forms beneath the epidermis. The procambium reaches a maximum size (lower edge of section II), then cells that make it up undergo further differentiation. As depicted in section III, inner cells of the procambium continue to undergo change to become similar to xylem, which will form later. Cells of the outer portion of the procambium assume characteristics similar to phloem, formation of which will also follow. These two new tissue layers are called primary xylem and primary phloem. The transformation to primary xylem or primary phloem continues until eventually a ring of procambium tissue only one to several cells in width remains (sections IV – V).

Vascular cambium

Composition – In the previous section, the vascular cambium was described as consisting of a one to several cell width ring of meristematic cells. An artist's conception of cambium layer that has been isolated from surrounding wood and bark tissue. Two kinds of cells can be seen to make up the cambium layer. The long slender cells are called fusiform initials; these divide repeatedly to form either new cambial initials or new xylem and phloem cells. Division parallel to the stem surface in a tangential plane that result in formation of either xylem or phloem cells is called periclinal division. Production of new initials by radial partitioning is termed anticlinal division.

Development and growth of xylem and phloem – Periclinal division of a fusiform initial results in formation of two cells, one of which remains meristematic and part of the cambium. The other cell becomes either a xylem or phloem mother cells. The mother cell immediately begins to expand radially and may it divide one or more times before developing into mature xylem or phloem element. Maturation of new xylem cells involves growth in diameter and length, with growth accompanied by thickening of the cell walls and finally lignification.

It should be noted that not all types of cells grow in both diameter and length. For example, longitudinal cells formed in late summer by pines, spruces, and other softwoods grow considerably in length but little in diameter. Vessel elements that characterize hardwood (broadleaf) species grow little or may even shrink slightly in length but may expand up to 50 times in diameter.

Expansion of the Cambial Layer

As a tree expands in diameter, the cambium is pushed progressively outward. Thus the cambium must expand in circumference to remain an unbroken layer around the stem. Such growth of the cambium is achieved in several ways, the most important of which is anticlinal division of fusiform initials.

Anticlinal division of fusiform initial results in two cells, both of which remain in the cambium. Assuming that the new cells survive, they begin to grow in length almost immediately, becoming about the same length as the originating initial. After a short rest, the new meristematic cells may divide again, either periclinally or anticlinally.

Duration of cambial activity in temperate regions – During cold winter months the vascular cambium is inactive. In the spring, reactivation occurs, apparently in response to hormonal signals at the stem tips and possibly in the roots as well. An increase in average temperature to about $7^{o}C$ (the precise temperature varying by species) or higher is apparently the most important of several factors leading to the onset of cell division.

Since IAA and GA are produced at the stem tips and movement is downward from that point, cambial growth begins in the spring at the top of a stem and moves toward the base. In large softwood, cambial activity may begin at the top of the tree 2-6 weeks before the cambium is reactivated at the base of the trunk (Digby and Wareing, 1966). Hardwoods are classified as ring or diffuse porous depending upon the distribution of vessels in a cross section. Woods that form very large diameter vessels part of a year and smaller ones thereafter are called ring porous. Woods forming vessels of the same size throughout the year are classed as diffuse porous.

Lecture 4: Macroscopic structure of wood – Three distinct surfaces of wood – Growth rings – Discontinuous rings – False rings

Three distinct surfaces of wood

The macro features of the cross-sectional, radial and tangential surfaces appear quite different. Wood differs not only in appearance, depending upon the direction from which it is viewed, but (as will be explained a bit later) in physical properties as well. Thus in a solid wood product such as lumber, boards are classified by the surface of wood that corresponds to the widest face.

GROWTH RINGS

Annual Rings

Appearance – Growth in temperate zones was characterized as proceeding rapidly in early spring and slowing in late summer before ceasing in the fall. For reasons explained in succeeding paragraphs, this kind of growth pattern results in different kinds of wood being formed in various seasons of the year; alternating bands of wood formed early and late in a growing season mark annual growth limits.

Magnification is easy to see why wood formed in the latter part of a growing season appears different to the unaided eye than that formed early in the year. The latewood tissue is of greater density, being composed of cells of relatively small radial diameter, with thick walls and small lumens. It is this tissue that forms the darker colored portion of the growth ring.

Ring Porous Hardwood

Annual growth rings do not always appear as distinct alternating bands of earlywood and latewood. Some hardwood, for example, form large diameter pores early in a growing season and much smaller and usually fewer pores later in the year; such woods are called ring porous. Other woods exhibit little variation in cell structure across a growth increment, thus forming rings that are difficult to detect. Since the pores are about the same size throughout the growth ring, these woods are termed diffuse porous.

Formation – Scientists have sought to explain the causes of earlywood and latewood formation for over 100 years and the riddle is not completely solved. Strong evidence does exist, however, indicating that earlywood and latewood formation is related to photosynthate availability and presence of auxins.

A number of investigators have concluded that two major characteristics of latewood – relatively small radial diameter and thick cell walls – develop independently of one another. The formation of large diameter cells, characteristic of earlywood, is apparently dependent upon an abundance of auxin. Development of thick cell walls, on the other hand, is related to a plentiful supply of photosynthate.

The effect of late-season abundance of photosynthate is less obvious in hardwoods than in softwoods. In ring-porous hardwoods, formation of large-diameter vessels early in the season is commonly followed by production of a more compact latewood having fewer and smaller diameter vessels and of more thick-walled fibers. Diffuse-porous hardwoods likewise often produce a higher proportion of fibers late in a growing season, and these are sometimes radially flattened as well.

Discontinuous rings – Growth rings sometimes fail to form around the complete cross section. This is a result of the cambium remaining dormant in one or more places around the stem. Such dormancy has been reported to be caused by delayed availability of auxins to a portion of the cambium and localized deficiency of food. Discontinuous rings are occasionally found in trees having one-sided crowns and in heavily defoliated, suppressed and over mature trees. The fact that the discontinuous rings do occur indicates that caution should be used when using increment borings to determine tree age; borings from several locations around a stem could be used where presence of discontinuous rings is suspected.

False rings – Occasionally, normal seasonal growth is interrupted by events such as drought, late frosts, or defoliation by insects or hail. If this results in slowing or cessation of terminal growth, auxin production will be reduced and may cause latewood type cells to be produced. If events causing slow growth are followed in the same growing season by conditions favorable to growth, normal growth patterns may be resumed, accompanied by production of large and thin-walled earlywood cells. Casual observation of an annual ring formed under such circumstances will show two rings to have formed in a single year. The ring thus created is called a false ring. It is possible for several of these to form in a given year. Such rings may form throughout the length of a stem, but more commonly they are restricted to upper regions of the crowns.

Lecture 5: Heartwood and Sapwood – Formation - Properties

Some of them are frequently described as being nature's oldest living creations as well. Indeed, one bristlecone pine growing in the White Mountains of California is estimated to be earth's oldest living resident at a ripe old age of about 4600 years.

An estimate that living organisms is almost 5000 years old is impressive, but it can also be misleading. Plant tissue seldom remains alive longer than several years, even when part of an old bristlecone pine. This apparent contradiction is explained by the fact that new cells are continually being produced while others cease functioning. Even cambial initials are periodically replaced. It has been estimated that living cells of a tree may compose as little as one per cent of its total bulk. The longevity of trees such as the bristlecone provides evidence that wood will last indefinitely if conditions are favorable.

Examination of a stem cross section often reveals a dark-colored center portion surrounded by a lighter colored outer zone. The dark center area is known as heartwood, the lighter tissue as sapwood. It is in the sapwood that the living cells are found. Sapwood tissue also serves to conduct water upward in a living tree. Heartwood no longer functions physiological but provides mechanical support to the tree.

Formation of heartwood – Perhaps no term relating to wood has more mystery associated with it than the word heartwood. A typical belief is that because heartwood is older than sapwood, having aged and seasoned more slowly, it is better. Heartwood is reputed to be heavier, stronger, more highly figured and more resistant to decay than sapwood. Some of these notions are true, but others are not. Before an understanding can be gained of what properties heartwood does and does not have, and why, it is first necessary to know what heartwood is.

When a tree or tree art is young and growing vigorously it often contains no heartwood. After the passage of a few seasons, however, heartwood typically begins to form near the center of a stem. In some species many seasons may pass before development of heartwood. For instance, the onset of heartwood formation is typically delayed in southern yellow pine until an age of 15-20 years. Once initiated, the production of heartwood proceeds at a rate greater than that of diameter growth. This situation later stabilizes, however, and the volume of heartwood formed each year is roughly equal to the volume added by new growth. The boundary between heartwood and sapwood does not necessarily follow the growth rings.

The precise cause of heartwood formation continues to be debated, but death of cells is known to be related to at least two events: accumulation of a variety of polyphenolic substances in cell walls and lumens and reduction of water content of such cells. A polyphenolic compound is an organic aromatic compound derived from the six-carbon compound benzene; in such compounds at least one hydroxyl group is attached directly to each benzene ring.

Properties of Heartwood

The various chemical compounds that are products of the decomposition of starches and sugars include fats, waxes, oils, resins, gums, tannins and aromatic and coloring materials. Most decomposition products can be removed or extracted from heartwood by soaking or boiling in water or alcohol or by other extraction processes. Because of this and the fact that the number of individual components is great, these various compounds are commonly collectively referred to as extractives.

As the differences between heartwood and sapwood are almost totally chemical, the presence of these chemicals is primarily responsible for giving heartwood its unique properties, a number of which are discussed below:

1. Heartwood may be darker in color than sapwood. This occurs when some extractable compounds are dark in color. In some woods, heartwood and sapwood show no color difference, this does not necessarily mean an absence of heartwood but may simply indicate that no dark-colored extractives have formed. Hardwoods exhibit a wider range of heartwood coloration than softwoods.
2. Heartwood may be highly decay and insect resistant. When woods are naturally resistant to decay and insects, it is because some of the extractives are toxic or at least repellent to decay fungi and insects; this is the case in woods like cypress, redwood, and most cedars. The heartwood of many in woods does not contain fungus-repelling extractives and such heartwood is no more decay resistant than sapwood. Because decay resistance is imparted by chemicals that occur only in heartwood, sapwood of all species is readily susceptible to decay.

3. Heartwood may be difficult to penetrate with liquids (such as chemicals used to help preserve it). When this is the case, it is the result of (a) the presence of extractable oils, waxes, and gums that may serve to plug tiny passages in cell walls; (b) closure of cell-to-cell passageways in softwoods through slight rearrangement of tiny membranes in passageways (called pit aspiration) or (c) blocking of pores in hardwoods by movement of parenchyma cell sacs into vessel lumens (called tyloses). When a wood is both susceptible to decay and difficult to penetrate, its usefulness for certain applications is limited. Doughlas-fir is an example of a wood not highly resistant to decay and furthermore with heartwood that is difficult to treat to improve durability.
4. Heartwood may be difficult to dry. Drying difficulties are generally traceable to the same factors that inhibit penetration.
5. Heartwood may have a distinct odor. When it does, this is usually due to the presence of aromatic extraction compounds. Most cedars contain pungent smelling compounds.
6. Heartwood may have slightly higher weight per unit volume than sapwood. When this occurs, it is from the presence of significant amounts of extractives.

Lecture 6: Rays – Grain orientation – Knots

Recall that rays provide an avenue by which sap can travel horizontally in either direction from the phloem layer. All woods contain rays. In some hardwoods such as oak, rays are quite large and readily visible in a cross section. In softwoods and a number of hardwoods, rays are very narrow and in some cases difficult to see even with a magnifying glass. Many highly valued hardwoods used for paneling and furniture and in other decorative ways are characterized by distinct ray patterns on radial and tangential surfaces. These are often helpful when identifying wood species.

In addition to contributing to wood figure, rays also have an effect upon wood properties. Rays, for example, restrain dimensional change in the radial direction, and their presence is partially responsible for the fact that upon drying, wood shrinks less radially than it does tangentially. Rays also influence strength properties since they constitute radially oriented planes of weakness. Because of this effect upon strength, splitting may occur along rays in veneer slicing operations if the veneer knife is improperly oriented. Splitting can also develop along rays when wood is dried.

Grain Orientation

The direction parallel to the long axis of most of the long tapered fibers of wood is called the grain direction. Not uncommon, however, is fiber arrangement at a slight angle to the stem axis rather than precisely parallel to it. In fact, angled grain orientation may be the rule rather than the exception. Occasionally, the deviation from parallel is large, resulting in an obvious spiraling grain pattern. This kind of grain orientation can significantly affect wood properties.

Spiral Grain

Trees in which fibers are spirally arranged about the stem axis are said to have spiral grain. This condition is apparently caused by anticline division in which new cambial cell formation occurs in one direction only (i.e. walls formed during fusiform initial division consistently slant the same way). When logs exhibiting spiral grain are sawn, the lumber formed has a grain direction that is not parallel to the board length. Such lumber is said to have diagonal grain; it is typically low in strength and stiffness and may tend to twist as it dries. Planning of such lumber to a high-quality surface may also be difficult.

Interlocked Grain

In some trees, grain may spiral in one direction for several years, then reverse direction to spiral oppositely. Wood produced in this way is said to have interlocked grain. Reversing spiral grain is evidently genetically controlled, occurring very frequently in some species and seldom if at all in others. Woods with interlocked grain, such as elm, are difficult to split and thus are recognized as woods for the do-it-yourself firewood splitter to avoid. Wood with this characteristic may also shrink longitudinally upon drying and/or warp unpredictably. Occurrence of interlocked grain is occasionally considered desirable from an appearance standpoint. Alternating grain directions cause light to reflect in varying patterns across radially cut wood, giving what is known as a ribbon stripe figure. When well developed, this feature can add considerably to the value of veneer.

Knots

The seasonal addition of new wood results in progressive layering over previously produced wood. As new growth increase the diameter of the main stem, branch bases become more and more deeply embedded.

Lecture 7: Chemical composition of wood – Cellulose, hemi cellulose and lignin

As a building material, wood is one of the simplest, most easily used products, it can be cut and shaped with ease and fastened readily. At the same time, wood is one of our most complex materials. It is made up of tiny cells, each of which has a precise structure of tiny openings, membranes and intricately layered walls. The ease with which wood is converted to a product and maintained depends upon practical knowledge of its structure.

Chemical components

Wood is a carbohydrate composed principally of carbon, hydrogen and oxygen. Table details the chemical composition of a typical North American wood and shows carbon to be the dominant element on a weight basis. In addition, wood contains inorganic compounds that remain after high temperature combustion in the presence of abundant oxygen; such residues are known as ash. Ash is traceable to the occurrence of incombustible compounds containing elements such as calcium, potassium, magnesium, manganese and silicon. The fact that domestic woods have a very low ash content, particularly a low silica content, is important from the stand point of utilization, woods having a silica content of greater than about 0.3 per cent dull cutting tools excessively. Silica contents exceeding 0.5 per cent are relatively common in tropical hardwoods and in some species may exceed 2.0 per cent by weight.

Table 1. Elemental composition of wood

Element	% Dry weight
Carbon	49
Hydrogen	6
Oxygen	44
Nitrogen	Slight amounts
Ash	0.1

The elemental constituents of wood are combined into a number of organic compounds: cellulose, hemicellulose and lignin. Table 2 shows the approximate percent of dry weight of each in hardwood and softwood. Cellulose, perhaps the most important component of wood, constituents slightly less than one-half the weight of both hardwoods and softwoods. The proportion of lignin and hemicellulose varies widely among species and between the hardwood and softwood groups.

Table 2. Organic constituents of wood

Type	Cellulose	Hemicellulose (% Dry weight)	Lignin
Hardwood	40-44	15-35	18-25
Softwood	40-44	20-32	25-35

Cellulose

Photosynthesis is the process by which water and carbon dioxide are combined in the presence of sunlight to form glucose and other simple sugars, with oxygen as a by-product.

Cellulose is manufactured directly from units of glucose. As a first step in the process, a tree transports glucose to processing centers located at branch and root tips and to the cambial layer that sheaths the main bole, branches and roots. Then, in a complicated process, the glucose is chemically modified through removal of a molecule of water from each unit, yielding an anhydride of glucose: $C_6H_{12}O_6$ (glucose) – H_2O = $C_6H_{10}O_5$ (glucose anhydride). Glucose anhydride units are next linked end-to-end to form the long-chain polymer, cellulose $(C_6H_{10}O_5)$, w h e re n (the degree of polymerization) equals 5000-10,000.

Cellulose is a material with which people are somewhat familiar. Cotton, for example, is 99 per cent pure cellulose. Fine writing papers are also manufactured largely from the cellulosic fraction of wood. Although it is a carbohydrate, cellulose is not a source of food for humans or most animals. In cellulose, glucose anhydride units are joined by b-type chemical linkages; components of carbohydrates such as starch are linked in a a configuration. Though cellulose in the form of wood or cotton has as much food value as sucrose, cellulose cannot be digested by humans since body fluids can hydrolize a but not b linkages. However, certain animals (ruminants) are able to utilize cellulose as food because they maintain intestinal colonies of microorganisms that produce enzymes known as cellulases, which convert cellulose to metabolically useful glucose.

Hemicellulose

While glucose is the primary sugar produced in the process of photosynthesis, it is not the only one. Other six-carbon sugars such as galactose and mannose and five-carbon sugars such as xylose and arabinose are also manufactured in the leaves. These and other sugars, along with glucose, are used in synthesizing relatively low molecular weight polymers called hemicelluloses. Most of the hemicelluloses are branched-chain polymers, in contrast to the straight-chain polymer cellulose, and generally are made up of 150 or less basic sugar anhydrides (i.e., the degree of polymerization is generally less than 150).

Lignin

Lignin is a complex and high molecular weight polymer built upon phenylpropane units. Although composed of carbon, hydrogen, and oxygen, lignin is not a carbohydrate nor even related to this class of compound. It is instead, essentially phenolic in nature. Lignin is quiet stable and difficult to isolate and occurs, moreover, in a variety of forms; because of this the exact composition as it occurs within wood remains an uncertainty.

Lignin occurs between individual cells and within the cell walls. Between cells, it serves as a binding agent to hold the cells together. Within cell walls lignin is very intimately associated with cellulose and serves in imparting rigidity to the cell. Lignin is also credited with reducing dimensional change with moisture content fluctuation and is said to add to wood’s toxicity, thus making it resistant to decay and insect attack. The rigidity provided by lignin is an important determinant of wood properties. Recollection of the very soft nature of cotton (almost pure cellulose) is an indication of how nonrigid wood would be without a stiffening ingredient.

When a part of wood, lignin is a colorless material. Exposed to air, particularly in the presence of sunlight, it (along with certain carbohydrates) tends to yellow with age. Thus newsprint, which is made of mechanically separated fiber from which lignin has not been removed, has short longevity because of its tendency to yellow. Newsprint is also coarse, bulky, and of low strength because of stiff fibers that have little fiber-to-fiber bond potential.

Lignin is thermoplastic- meaning that it becomes soft and pliable at higher temperatures and hard again as cooling occurs. The thermoplastic character of lignin is basic to the manufacture of hardboard and other densified wood products.

Lecture 8: Cell wall – Chemical structure – Micro fibrils - Layering

Chemical Structure. Recall that a tree is sheathed by a thin cambial layer, which is composed of cells capable of repeated division. New cell produced to the inside of this sheath become new wood, while those moved to the outside become part of the bark.

A newly formed wood cell is encased in a thin, membrane like and pectin-rich wall called a primary wall, and the cell is filled with fluid. (Pectins are complex colloidal substances of high molecular weight that upon hydrolysis usually yield galacturonic acid and small amounts of arabinose and galactose. The precise structure of pectin is not completely understood). In a process than may take several weeks to complete, the cell enlarges and the cell wall is progressively thickened as materials are deposited on the inside (lumen side) of the wall. Eventually, the fluid filling the cell is lost and the cell has a thickened wall and hollow center. Successive deposits cause a gradual thickening of a cell wall. But what is deposited? It is the three organic compounds identified earlier-cellulose, hemicellulose, and lignin.

Deposition of organic materials is not haphazard; it occurs in an amazingly precise fashion. Most cellulose, for example, is not incorporated into the cell wall as individual molecules but rather as intricately arranged clusters of molecules. Prior to becoming a part of the cell wall, long, chainlike molecules of cellulose form into bundles of cellulose molecules laid parallel to one another. These cellulose bundles become surrounded with low molecular weight hemicelluloses to fashion larger units called microfibrils. Cellulose is incorporated in the cell well in the form of microfibrils, which are laid down in layers. Hydrogen (H^+ to OH^-) chemical bounds between adjacent cellulose molecules serve to reinforce the microfibril structure.

In most portions of the microfibril, cellulose molecules are laid in a neat parallel fashion. As such an arrangement is similar to the precise repeating molecular arrangement in a crystal, regions of parallel cellulose molecules are called crystallites. These regions are also sometimes referred to as micelles. These have been termed amorphous regions (without definite form). Crystalline regions are much shorter than cellulose molecules, meaning that an individual cellulose molecule is included in 10 or more such regions. About 60-70% of cellulose in the cell wall crystalline in form.

Layering. The primary wall, described earlier as being pectin rich, is also reinforced with a more or less random network of microfibrils. This random arrangement contrasts with the very organized microfibril pattern in the secondary wall.

The first few microfibrils deposited as the secondary wall starts to form are laid down in a particular way; they are spiraled around the cell interior, with the long axes of the microfibrils nearly perpendicular to (or 50-70º from) the long axis of the cell. After a few layers are laid down in this way, the orientation begins to change; microfibrils are deposited spirally about the cell at a much smaller angle to the axis, varying from 10 to 30º. Just prior to final development of the cell a change in orientation again occurs; with the last several layers arranged similarly to the first few layers (i.e., 60-90º to the long axis). Thus the secondary part of a cell wall has three more or less distinct layers. For purposes of discussion, these layers are numbered according to the order in which they are formed; S-1, S-2, S-3. This intricate structure of the cell wall is the key to the behavior of wood. Note that the S-2 layer is much thicker than the others. The S-1 and S-3 layers in a softwood are on the order of 4-6 layers of clustered microfibrils (lamellae) thick, while the number of lamellae comprising the S-2 may vary from 30 to 40 in thin-walled early wood cells to 150 or more in latewood. In an early wood cell, these proportions would translate to thick nesses of about 0.1 µm for S-1 and S-3 layers and 0.6 µm for the S-2. Because the S-2 layer is much thicker, this wall layer has the greatest effect on how the cell behaves.

Many investigators believe microfibrils to be organized into larger units. These units, called macrofibrils, are thought to be aggregations of several hundred microfibrils. Whether microfibrils actually combine to form macrofibrils or not, it is clear that various layers of the secondary wall are built up as a series of uniformly thick sublayers (lamellae). Moreover, mirofibrill angles in the cell wall change gradually from lamella to lamella.

Lecture 9: Development of cell wall – Sculpturing – Pitting – Aspirated pits – Spiral thickening

Cell Wall Sculpturing. Wood cells that function primarily in the storage and conduction of food materials are known as parenchyma. These cells typically form their secondary wall and are the last to remain functional prior to heartwood formation. Other kinds of cells, in contrast, serve principally as avenues of conduction in the living tree; these often form thick secondary walls and thus are important in providing mechanical support to stems in which they occur.

Pitting. All types of cells are characterized by secondary wall layers that are not continuous. Instead, walls are interrupted by regions in which the secondary portion of the wall is lacing. Known as pits, these regions generally appear quite different in parenchyma as compared to other kinds of cells.

Normally, pit placement in one cell is exactly matched by the position of pits in adjoining cells. Pits thus tend to occur as matched pairs. Since pit regions are areas of the cell wall that lack secondary thickening, they are, in effect, thin spots in the cell wall. As such, these areas are much more readily penetrated by fluids and gases than are unpitted zones; thus pit pairs are the primary avenues of cell lumen-to-lumen transport.

Pits that mark the walls of parenchyma cells are called simple pits. Because both cells in this figure are of the parenchyma type, the pits shown form a simple pit pair. Note that whereas secondary wall material is lacking in the pit zone, the primary walls of the two adjacent cells remain. The primary walls and the thin layer of intercellular material that separates them form the pit membrane.

The type of pit typifying nonparenchyma cell is called a borderea pit, so named because the pit aperture appears to be surrounded by a border when viewed frontally. Rather than a simple gap in the secondary part of the wall, a bordered pit is a conical depression in the secondary wall that is concave toward the middle lamella and has an opening leading to the cell lumen at the depth of the depression.

A pair of this kind of pits, typical of those connecting two conductive cells, secondary walls are seen to overarch the primary wall, forming a pit cavity. As in simple pits, the primary walls of adjacent cells form a pit membrane. When storage (parenchyma) and conductive cells are in contact, each cell usually forms simple and bordered pits respectively. The resulting pit pair is termed half-bordered. In softwood, the pit membrane between two bordered pits differs from that separating a simple or half-bordered pit pair. In the latter two kinds, the pectin-rich and microfibril-reinforced primary wall remains unmodified within the pit zone. The common primary walls separating two softwood-bordered pits are, however, changed considerably as pits are formed.

Bordered pit formation apparently begins prior to the start of S-1 layer formation with the deposition of a ring of cellulose on the primary wall. This ring defines the outer boundary of the fit. Then, as secondary wall formation commences, the pit membrane undergoes modification. The membrane center becomes thickened though accumulation of densely packed and sometimes circularly arranged microfibrils. This thickening is called the torus. The area surrounding the torus is named the Margo, and it too becomes different from the normal primary wall. A net of radially arranged microfibrils may form over the existing primary wall, connecting the torus to the pit exterior. At about the same time, the pectin matrix of the compound middle lamella enzymatically decomposes, leaving a more or less open network. Finally, secondary wall thickening is completed through successive deposits of microfibrils, thus forming the arch or conically shaped wall structure (Wardrop, 1964).

Bordered pits are structurally similar in hardwood and softwood species except that the membranes are quite different. Membrances of all pit combination in hardwoods are similar to those characterizing simple and half-bordered pit pairs in softwoods are similar to those characterizing simple and no dissolution of portions of the primary wall. In such an unmodified wall, it has been reported that no openings are visible even at magnification of X100, 000. In comparison, filtration experiments with softwood bordered pit membranes have shown openings approximating 0.2 nm in size in the reinforced microfibril network.

Spiral thickening. In some woods, formation of the S-3 layer us followed by development of spirally arranged ridges of microfibril bundles on the lumen side of the secondary wall. Such ridges are distinctly separate from the S-3 layer, as evidenced by the fact that they are relatively easily detached from it. (Wardrop, 1964), and they only rarely parallel the S-3 microfibrill orientation. These ridges are termed spiral thickenings.

Lecture 10: Anatomical structure of softwood – Longitudinal tracheids – Cross fields

Softwoods have traditionally been the mainstay of the products industry in North America, and these woods continue to be extremely important today. The homogeneous, straight-grained, and lightweight softwood is preferred for construction lumber and plywood. Tall straightbloled softwoods are also a premium raw typically composed of long fiber, softwoods are also a premium raw material in the manufacture of strong papers. Knowledge of the physical nature of softwood xylem is basic to an understanding of wood products. The structural characteristics of this important group of woods are examined in this chapter.

The xylem of softwoods is simple. Most species have no more than four or five different kinds of wood cells, and only one or two of these occur in appreciable numbers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance.

Longitudinal Tracheids

Configuration. The great majority of softwood volume, 90-95%, is composed of long slender cells called longitudinal tracheids. Such cells are oriented parallel to the stem axis. Longitudinal tracheids are about 100 times greater in length than in diameter and are rectangular in cross. Tracheids have hollow centers (lumens) but are closed at the ends, and their shape is blunt or rounded radially and pointed tangentially. The pits in tracheids are normally bordered. A longitudinal tracheid can be visualized by thinking of soda straw, pinched shut at both ends, the straw being similar in both appearance and relative proportions to a longitudinal tracheid is much smaller, however, averaging only 25-45 µm in diameter and 3-4 mm in length.

The softwood cells formed early in a growing season differ from those formed later in the year. A review of early wood and latewood differences is perhaps best accomplished by looking at one radial file of tracheids representing one year of growth. Thin-walled early wood cells with relativity large radial diameter s are seen to the right in thicker-walled and smaller-diameter cells are seen to the left. The abrupt change from thin- to thick- walled cells depicted in the figure is characteristic of only some softwoods species such as the hard pines, larch, and Douglas fir. In these woods, latewood is sharply delineated from the early wood part of the ring. In order species such as true fir and hemlock, the transition in wall thickness and radial diameter progresses gradually from early-to late-formed wood. Rings in these woods are less clearly defined than in those having abrupt transition. Abrupt and gradual transition in growth rings.

Pitting. Again referring to the numerous pits that marks the radial cell walls are of the bordered type. Such pits typify tracheid-to-tracheid linkages, and thus their location is matched with a pit in an adjacent longitudinal, tracheid.

The characteristics of the softwood bordered pit membrane were outlined. Recall that the softwood pit membrane in most species has a thickened central torus surrounded by a microfibrillar networks known as the Margo. At least one softwood species western red cedar lacks tori in bordered pit membranes.

The typical softwood bordered pits membrane is the source of several significant use- related problems: a shift in the membrane from its normal central position can result in both drying and treating difficulties. Because the membrane is flexible, it can shift to one side of the pit cavity, resulting in the blocking of the aperture by the impenetrable torus. A pit in this condition is said to be aspirated. Wood with aspirated pits is resistant to penetration by protective chemicals such as aspirated pits is resistant to such wood also dries slowly. Drying can, in fact, be the cause of pit aspiration from differences in pressure that may develop on different sides of pit membranes. Once aspiration occurs, it is apparently permanent condition hydrogen bounding between the torus and the overarching secondary wall can fix the position of the membrane.

Pit aspiration occurs as a result of liquid that can occur in standing trees or in processed wood that is being dried. A situation that result in aspiration, for example, is one, which there is closes system of water under tension in the lumen on one side of a bordered pit and an air/water-filled lumen in the other. Evaporation in any part of system or transpiration pull on the closed water system can produced sufficient liquid tension to cause pit aspiration. Hart and Thomas reported that aspiration is always toward the closed water system side of the membrane. Aspiration can also occur in zones characterized by air/water-filled lumens on both sides of pit pairs. In this case, evaporation from one or both lumens can create a pressure differential, causing deflection of pit membrane towards the lower air pressure side.

Although the kinds of situations described above can occur in functioning sapwood, pit aspiration is much more common during the transition from sapwood to heartwood. This at least partially explains why sapwood of some species such as Douglas-fir, is readily penetrated by treating chemicals, while little or no penetration can be achieved in heartwood of the same piece. No penetrability of heartwood may also result from a buildup of encrusting materials in the Margo, rendering pit membranes progressively less porous over time.

Pit aspiration develops more frequently in early wood than in latewood. This explains why end-grain penetration of treating chemical often extends for some distance along the grain in latewood zones, whereas adjacent early wood zones are free of the chemical.

Cross-fields are areas where longitudinal tracheids contact ray parenchyma. Half-bordered pits form at these locations, and the bordered portion that marks the tracheids is of quite unique form. Cross fields bordered pit apertures when viewed radically vary in shape from lemon drops to cat’s eyes to extended slits to an expansive window like form. The type, size, and number of cross-field pitting is fairly consistent within a species; thus this feature is quite useful in determining the identity of softwood timbers. A microscope is needed to view cross-field pitting.

Lecture 11: Anatomical structure of softwoods – Other longitudinal cells and rays

In some softwood species such as fir and hemlock, the longitudinal tracheid is commonly the only kind of longitudinal cell present. In other species, including redwood, the cedars and the pines, several other kinds of cells make up minor position of the volume.

Longitudinal Parenchyma. A small portion of the volume of some softwood is composed of longitudinally oriented parenchyma cells. When mature, these cells have the same general shape as longitudinal tracheids, although they often subdivide a number of times mature parenchyma usually occur as longitudinal strands of cell butted end- to -end in series. The thin walled and simple pitted parenchyma account for as much as 1 to 2% of the volume of some softwood.

Epithelium. Structure knows as resin canals are found in certain softwood species. They are consistently found in the genera Pinus (pines), Pices (spruce), Larix (larch), and Pseudotsuga menziesii (Douglas-fir); this is one other feature that assists in the identification of softwoods. Normal longitudinal resin canals are always accompanied by horizontals canals, which occur in some of the rays.

A resin canal is an intercellular space surrounded by specialized parenchyma cells that secrete resin into the canal. This is believed to play an important role in the healing of damage tissue and in repelling attack by insects or other would–be an invader. A cut through the wound area and may even be accompanied by production of new resin-producing cells near the wound.

Rays

Uniformly narrow rays characterized softwoods except where horizontal resin canals are present. Viewed tangentially, softwood rays are from one to many cells in height but are usually only one cell wide (uniseriate). Rays of redwood are typically two cells in width (biseriate). In typical softwood ray is shown in contact with the radial raw of cells depicted earlier.

The cells composing softwood rays may be either ray parenchyma or ray tracheids. Ray tracheids are similar to longitudinal tracheids in that they have thick cell walls and bordered pits. In the hard pines, (ponderosa, lodgepole, jack, red, and southern), ray tracheids form secondary walls that are locally thickened in the vicinity of pits, thickened in the thickenings look much like extending into the lumen. Such tracheids are called dentate ray tracheids. Ray cells of the parenchyma type, on the other hand, may be either thin or thick walled. Very thin walled ray perforate the thicker walled variety of ray parenchyma cells. An individual ray may be composed entirely of parenchyma, entirely of tracheids; both ray parenchyma and ray tracheids. A close-up of a uniseriate softwood ray shows it to be composed of both ray parenchyma and ray tracheids. Another uniseriate ray might be entirely of ray parenchyma or ray tracheids. Uniseriate rays that are constructed entirely of ray parenchyma or entirely of ray contains both ray tracheids and ray parenchyma.

Lecture 12: Anatomical structure of hardwoods – Vessels elements – Longitudinal cells

The wood formed by hardwood is much different than produced by softwoods. Softwoods have a uniform arrangement of few cell types and therefore are often without a distinctive appearance. Hardwoods on the other hand are composed of widely varying proportions of markedly different kinds of cells and are thus often uniquely and even spectacularly figured. Because of the unique figure possessed by many hardwood species, such woods are widely used for furniture, paneling, and other decorative purposes.

Longitudinal cells

Although longitudinal cells of hardwood vary considerably in size and general configuration, a single fusiform initial in the cambium can produce all these different cell types. Newly produced cells between types appear quite similar. The differences between types develop during the process of cell maturation.

Vessel elements-unique cells of hardwoods. Several different exist between hardwood and softwood xylem, but the fundamental anatomical difference is that hardwoods contains specialized conducting cells called vessel elements. This cell type is found in virtually all hardwoods but never in softwoods. (The wood of a few dicotyledons does not contain vessels; however, the number and economic importance of species exhibiting this feature are small.)

Vessel elements are generally much larger in diameter than other types of longitudinal cells. Compares the size and shapes of a softwood tracheid, a typical hardwood fiber, and hardwood vessel elements. Note that vessel elements are shorter than hardwood and softwood fiber but larger in diameter. The short length of vessel elements is traceable to the fact that they often do not grow in length during the maturation process and may become even shorter than the cambial initials from which they were produced. Normally, a number of vessel elements links end-to-end along the grain to form long tube like structures known as vessels.

Lecture 13: Vessel arrangements

Because of their large diameter vessel often appear as holes when viewed in cross section; in this view they are often referred to as pores. Both size and arrangement of pores are used to classify hardwoods for purpose of identification. Only the vessels and rays are illustrated. Vessel of large diameter is concentrated in the early wood, with vessels of much smaller diameter in the latewood. This wood is called ring porous because the early wood vessels form a visible ring in a tree cross-section. The majority of hardwoods are diffusing porous, but in northern temperate regions some of the most valuable wood such as oak, ash, and pecan are ring porous. When hardwoods are sawn into lumber, the lengthwise sectioning surfaces. Sectioning of large early wood vessel in ring-porous wood forms a very deep and sometimes-spectacular pattern of vessel scratches (vessel lines) that is interrupt by latewood regions having little texture. Look ahead to an artist's conception of a three-dimensional diffuse-porous hardwood.

The lake of radial alignment of cells in hardwoods has been mentioned. Recall that all types of longitudinal cells arise from the same fusiform initial in the cambium. Remember also that all longitudinal cells are quite similar in size and shapes immediately after formations. Since nothing occur to disrupt alignment, newly formed hardwood xylem cell tend to be arranged in neat radial files corresponding to initial that produced them. During the maturation process, however, cells begin to change, eventually assuming the characteristics of the mature units. In the case of vessel elements, one of these characterized is large diameter. Thus cells will mature to become vessel begin marked diameter growth, expanding from 2 to 50 times their path of vessel elements pushes cells out of radial alignment. Follow the evident that the meandering ray pattern is caused by vessel growth.

End-to-end connection of vessel elements. Vessels are uniquely suited to serve as avenues of condition. Relatively small and membrane-divided pit pairs connect other cells such as fiber tracheids end-to-end. Common end walls of longitudinally linked vessel elements are, however, perforated by unrestricted holes. To facility discussion about this feature, names are given to the common vessel element end walls (perforation plates) and the holes in them (perforations).

Perforations develop near the end of the cell maturation process. Certain enzymes contains in the protoplast of developing vessel elements (such as cellulase) are apparently responsible for this dissolving of portions of the perforation plates. Some rearrangement of cell wall material may also be involved in formation of perforations. It's interesting to note that perforation do not develop in random fashion; instead they form in one of several definite pattern.

Within a given species, the pattern of perforations is commonly the same in all perforation plates. Because of this, the nature of vessel perforations is often useful as an aid in the identification of hardwood timbers. Perforation plates invariably slope at an angle towards the radial. This surface should be examined microscopically to determine the type of perforation.

Side-to-side connection of vessel. Lateral communications from vessel to vessel is provided by numerous pairs of bordered pits. Closely packed bordered pits are depicted. A third type of inter-vessel pitting can be seen in figure. As is the case with perforation plates, the shape and arrangement of vessel pitting is often consistent within a given species and can be of assistance in wood identification.

Connection between vessels and other cells. Vessel often occur adjacent to fiber trachieds, longitudinal any ray parenchyma, or other kinds of cells. Although fiber tracheids and vessel are sometimes not linked by pitting, other kinds of cells typically form pits where they contact vessel elements.

Vessel elements have large diameter and thin walls and thus very spacious lumen area. Moreover, vessel remain living only a short time, losing the cell nucleus and cytoplasm relatively soon after formation. Parenchyma cells, in contrast, are the last cells to die (their death making heartwood formation), maintaining cell cytoplasm and nucleus for a number of years. Thus where longitudinal or ray parenchyma are in contact with vessel, only the ultra thin membranes of numerous pit pairs prevent the parenchyma cytoplasm and enclosing cell membranes from spilling through the pit pairs into the large empty vessel lumen.

Fibers. The terms fiber is often used in a general way to all wood cells isolated in pulping processes. However in the context of wood morphology, the term fiber refer to a specific cell type. Thus fibers, or fiber tracheids as they are more a properly called, are long, tapered, and usually thick-walled cells of hardwood xylem. A casual long suggests a great similarity to the longitudinal tracheids of softwoods, but closer examination reveals several significant differences.

The softwood tracheids average 3-4 mm in length; hardwood fiber, in contrast has an average length of less than 1 mm. That fact explains why softwood tracheids are often preferred as raw material for paper manufacture. Fibers are a necessary ingredient of Kraft paper used for unbleached paper products such as corrugated cartons and grocery bags. Hardwood fibers tend to be rounded in cross section as compared to the nearly rectangular shapes of softwood tracheids. However, fibers are sometimes flattened radically in last-format latewood in much the same way that latewood tracheids are in softwood. Fibers are also characteristically very thick walled and have bordered pits with less developed bordered than softwood tracheids. The walls of fiber tracheids are marked by pits of the bordered type. Fiber-to-fiber [it pairs are normally bordered, while fiber-to-parenchyma pitting is typically half bordered. A variation of the fiber, known as a fiber occur in considerable numbers in some species. Pit pairs seldom connect fiber and vessels.

Longitudinal Parenchyma. Parenchyma cells are thin-walled storage units. In hardwoods, such cells; short, brick-shaped epithelium around gum canals (in only a few species); and ray cells. The longitudinal form of parenchyma is often divided into a number of smaller cells through the formation of cross walls during the process of cell maturation. Parenchyma cells on occasion are thin walled to the point that no secondary wall forms. Science a pit is defined as a gap in the secondary wall, a cell with an unthickened wall is therefore unpitted. Simple pit pairs connect cells of the parenchyma type. Pitting "rules" are often broken where thickened parenchyma contact vessel or fibers; in this case the pita pairs formed are usually half-bordered but may of the simple or bordered type. Whereas longitudinal parenchyma is relatively rare in softwood species (no more than 1-2% of the volume of those wood in which it does not occur), the longitudinal form of parenchyma is often quite significant in hardwood. Certain species of hardwood may, however, have up to 24% of their volume made up of longitudinal parenchyma cells. In these woods the longitudinal parenchyma is commonly arrangement of longitudinal parenchyma are genetically reproduced, this kind of cell is often of value in the identification of hardwood timbers.

Gum canals occur in a few hardwoods and are similar to resin canals of softwoods. The hardwood canals are sometimes lined with parenchyma type epithetial cells.

Lecture 14: Hardwood – Other kinds of longitudinal cells – Rays – Types of rays

Other kinds of longitudinal cells. In addition to vessel fiber, and longitudinal parenchyma, other kinds of longitudinal cells occur in a few hardwoods, contributing to the variable nature of this group of woods. These other cells are mostly transition elements between major cell types and as such have feature typical of each kind of cell to which they are related.

An example of a transition element is a vascular tracheid; this cell has shapes like a vessel element, but it lacks perforation in the end wall, having instead bordered pits in this location similar to those found in fibers. Another kind of cell known as vasicentric tracheids looks much like parenchyma in cross section, yet it is covered with numerous bordered pits.

Rays

As listed in the summary of hardwood-softwood differences, hardwood rays range in width tangentially from 1-30 or more cells. Softwood rays in comparison are generally one or, rarely, two cells in width. Also unlike softwoods, the cells of hardwood rays are all of the parenchyma type (although two distinct types of ray parenchyma are formed).

Ray Size. Hardwood characterized by very large rays, such as oak, exhibit distinctive ray pattern on both tangential and radial faces; such rays in addition to the wide ones; the seen without magnificent in 5.16 a and C represent only largest of these.

Not all hardwood exhibits wide rays. Wood such as aspen (*Populus tremulodides*) or cottonwood (*Populus deltoides*) has rays that are of the unsieriate type only. These woods totally lack a visible ray pattern unless viewed under high magnification.

Type of ray cells. Although all rays cells are of the parenchyma type, there are, nonetheless, different type of hardwood are sometimes almost square when viewed radically, but mare commonly such cells have a rectangular shape. In most woods these rectangular ray cells lie so that the long dimension is perpendicular to the axes of longitudinal cells. Science ray cells arranged in this way appear to be lying down, they are said to be procumbent. In some hardwood species, part of the rectangular shaped ray cells appear to stand on end with their long axes parallel to the grain direction; these cells are logically called upright ray cells. Upright or square ray cells usually occur along the upper and lower margins of rays

The significant of rays cell configuration is that this feature can be used in wood identification since upright and square rays cells occur as a constant feature in only some species. An example is provided by cottonwood and willow- two easily confuse species. Positive identification is based upon the fact that rays of willow consistency have upright cells along the margins, whereas cottonwood rays do not.

In some hardwood species, they rays tend to be arranged into definite, tangentially oriented tiers. In these woods, rays in each layer are roughly the same height, and all begin and end at about the same levels along the brain. Such woods are said to have storied rays, and they often exhibit a readily visible banded pattern on tangential surfaces. A storied cell arrangement is not restricted to ray cells. Almost any type of hardwood cells can occur in storied arrangement, and the resulting pattern is often similar to that produced by storied rays. This pattern will show on both tangential and radial surfaces, while that from storied rays will be seen only on the tangential. Storing of elements is primarily of interest for wood identification.

Lecture 15: Tyloses and their significance – Arrangement

Just prior to typlosis formation, enzymatic action partially destroy membranes in vessel-to-parenchyma cells begins to expand. The result is a bud or balloon like protrusion of the parenchyma cell membranes into the vessel lumen; this protrusion is called a tylosis. Several studies have indicated that a special membranelike meristematic layer forms in parenchyma cell completely encasing the cytoplasm prior to tylosis. This layer knows as the protective layer, is believed to actually form tyloses. The thin membranes formation the tylosis may remain quit thin, or the walls may in much the same way that they do in developing cells, pits may even form where one tylosis contacts another.

Tyloses are significant in that they partially or often completely block the vessels in which they occur, a situation that can be either detrimental or beneficial depending upon the use to which the wood is put. The existence of tyloses in the heart wood vessel of white oak and the related lack of them in red oak is the reason white oak is preferred for the manufacture of barrels, casks, and tanks for the storage of liquids. White oak heartwood, with its tightly plugged vessels, is example, whereas the open-vesseled red oak is avoided for this use. In contrast to this beneficial feature of tyloses, wood in which they are well developed may be difficult to dry or to impregnate with decay-preventive or stabilizing chemicals.

Lecture 16: Differences between hardwood and softwood xylem

It is mentioned in the introduction that softwoods are uniform in structure whereas hardwood structure is complex. This and other difference are summarized below:

1) Softwoods are composed of a few significant cell types hardwoods of many. Longs cells known ass longitudinal tracheids compose 90-95& of the volume of softwoods. Ray cells constitute the remainder of softwood xylem. Although a few other types of cells may occur, they make up an insignificant part of the volume of softwoods. Hardwoods are composed of at least four major kinds of cells; each of these may constitute 15% or more of the volume of hardwood xylem.

2) Only hardwood contains vessels, a structure composed of vessel elements. Specialized conducting cells known as vessel elements occur in

Major hardwood cell types

Cell type	Proportion of xylem volume accounted for by cell type* (%)
Fiber tracheid+	
Vessel element	15-60
Longitudinal parenchyma	20-60
Ray parenchyma	5-30

*Within a species the relative proportion of various cell types is quite consistent. Among species and groups (genera) the mix of various kinds of cell is pronounced.

+Include in this category are several kinds of cells: variations of true fiber tracheids and transition elements between fibers and vessel elements or between fibers and longitudinal parenchyma.

Significant volumes in most hardwood but are never part of softwood xylem. The nature of vessel elements is discussed in the next section.

3) Wide rays of some hardwoods contrast with the uniformly narrow one cell in width when viewed tangentially. Collectively, the ray cells compose about 5-7% of softwood volume. Hardwood rays range in the width from 1 cell to 30 of the volume hardwood xylem. The average is around 17%.

4) Straight radial rows of cells characterized softwoods; they are not found in hardwoods. Softwood cell are aligned in straight radial rows in parallel, with straight spoke like rays; a single fusiform initial in the cambium forms each rows of cell. Hardwood rays are seldom aligned in straight radial rows, nor are other hardwood rays elements. Distortion from a purely radial orientation occurs in the vicinity of large vessel elements.

It is important to note that summary of hardwood-softwood difference does not include any reference to the relative hardness of the wood produced. Many softwoods produced wood that is harder and denser than wood produced by some hardwoods.

Lecture 17: Juvenile wood – Formation – Characteristics and utilization

The character of wood in young trees, in trees that are learning rather than vertical, and in branches and roots is considerably different from the normal wood of the mature bole. Such wood commonly has properties that affect the ways it may be processed and utilized.

Wood formed in the early (or juvenile) stages of tree's existence is called juvenile wood. That produced in response to tipping of a tree stem is termed reaction wood. It is tempting to characterize juvenile and reaction woods as abnormal; yet one (and usually both) of these types of wood occurs in virtually ever tree.

Brach wood and root wood properties are increasingly important as increased emphasis is being placed on maximizing use of material in a tree. This working knowledge of wood must include an awareness of these variations in wood form.

Juvenile wood

A young tree is somewhat analogous to a young child-it grows vigorously requires a balanced nutritional diet for normal developed, is subject to bring "bullied" or suppressed by its peers if it is week, and tends to heal quickly if injured. And like a child, their characteristics are not always considered desirable in relation to those of adults. In case of a young tree, the wood produced is different (and often viewed less favorably) than that of adult trees.

An undefined mass of tissue known as the pith marked the stem center, and this region is surrounded by a thin layer if primary xylem. Both pith and primary xylem are wholly formed in the first year of the life of a stem, and both types of tissue differ from secondary xylem produced later by the cambium. An important point is that secondary xylem is different from secondary xylem produced after this juvenile period.

Juvenile wood has been defined as secondary xylem produced by cambial regions that are influenced by activity in the apical meristem. This definition serves to explain why there is a gradual transition in wood properties between juvenile and mature woods. Juvenile wood is less likely to form in the outer portion of stem cross sections because as the cambium in a given location continues to cause diameter expansion, it also becomes progressively father from and therefore less subject to the influence of the apical mesistem.

By most measure, juvenile wood is lower in quality than mature wood this is particularly true if the softwoods. In both hardwood and softwoods, for example, juvenile wood cells are shorter than those of mature wood. Mature cells of softwood may be three to four times the length of juvenile wood cells, while the mature fiber of hardwoods are commonly double lengths of these found near the pith. In addition to difference in cell length, cells structure differs as well. There are relatively few latewood cells in the juvenile zone, and a high proportion of cells have thin wall layers. The result is low density and a corresponding low strength in comparison to adult wood. In conifers of the United States, density is typically 1 0 -15% lower in the juvenile core. With strength material reported to range from only slightly lower to commonly 15-30% and as much as 52% less than normal mature wood for some strength properties. These reductions appear mild when composed to finding for plantation-growth Caribbean pine. In this material, density was found to be only about 50% that of wood from forest-grown tree, with stiffness as little as26% of published value for the species.

Again comparing juvenile and adult wood, there appears to be a greater tendency for spiral grain in juvenile wood. Within the cell, the micro fibril angle in the S-2 part of the secondary wall is characteristically greater in juvenile wood. This kind of secondary wall micro fibril orientation is also typical of reaction wood that commonly develops in juvenile wood zones. The large S-2 micro fibril angle causes a high degree of longitudinal shrinkage and a corresponding decrease in transverse shrinkage. Large fibril angle are also associated with low tensile strength. Considering all these factor-reduced strength, occurrence of spiral grain, and a high degree of longitudinal shrinkage-juvenile wood is generally undersirable when used in most solid in most solid wood products.

Lecture 18: Reaction wood – Compression wood – Tension wood - Formation

A reaction is a response to a triggering event. Reaction wood was appropriately named. This kind of wood may be formed if the main stem of a tree is tipped from the vertical. It can also arise following the deflection of a lateral stem (or branch) from its normal orientation.

Reaction wood formed in hardwood differs from that formed in softwoods. In softwood it is termed compression wood and in hardwoods tension wood. In both, however, the function of reaction wood is the same: to bring the stem or branch back to the original position.

Compression Wood

If sufficient force is applied to the top of a standing pole, its will bend. The side of the pole towards which the top is bend tends to become shorter as the result of an induced compression stress. Conversely, the other side of the pole is stretched slightly as it is subjected to tension stress. In softwood, reaction wood forms on the compression side (or underside) of a leaning stem. Thus the name compression wood. This name, incidentally, refers only to the position in which softwood reaction is formed and does not imply that it forms as a result of compression stress. Compression wood also forms almost university in branches, where it function to maintain branch angle. An exception is in species with dropping branches, such as spruce, in which there is a conspicuous absence of compression wood (Timell, 1973)

Properties. Compression wood is of interest to the forest products technologist because its properties are considerably different (and in virtually every case less desirable) than those of normal mature wood. Compression wood tracheids, for example, are about 30% shorter than normal (Spur and Hyuarinen, 1954; Dinwoodie, 1961). In addition, compression wood contains about 10% less cellulose and 8-9% more lignin and hemicellulose than normal wood (Cote *et al*., 1966). These factors reduce the desirability of compression wood for plup and paper manufacture. Dad Well and War Drop (1960) indicate that compression wood not only yield less cellulose but produces low strength plup, especially when subjected to the sulfite chemical pulping process. Sulfite plup from compression wood was said by Timel (1973) to be clearly less desirable than normal wood plup, but use of the Kraft (sulfate) process with compression wood was reported to yield an only slightly inferior product. Timell further noted that satisfactory ground wood pulp couldn’t be made from compression wood, apparently because of the high lignin content. Barefoot *et al*. (1964) acknowledged the adverse the effects of compression wood on pulp quality but tempered this observation by pointing out that compression wood fiber vary from a mild to a severe form. Mild forms of compression wood were found to have a detrimental effect upon tear strength but not upon other properties.

Compression wood is highly undersirable in lumen or other solid wood products. A major concern when using compression wood in solid form is the longitudinal shrinkage that occurs upon drying. Longitudinal shrinkage is commonly 1-2% (compared to 0.1-0.2% for normal wood) and may be as great as 6-7%. The results of this extreme longitudinal shrinkage are shown in figure 6.6. Compression wood is about equal in strength to normal mature wood of the same species. However, when comparing wood of similar density, the relatively dense compression wood is inferior in most strength properties compared to normal woods are those having a high strength-to-weight ratio; many products such as tool handles, boat masts, and ladders requires low weight as well as strength. Understandably from the raw material going into most solid wood products.

Identification. Compression wood is relatively conspicuous and can often be identified visually when looking at smooth surfaces. It is especially noticeable in a transverse view. While compression wood may be apparent on a smooth cross section, detection on the rough-cut end of a log (required if this defect is to be identified in a sawmill) is more difficult. One study, in which an expert sawed 680 logs after a visual search foe compression wood showed that visual attempts to identify compression wood in rough-cut logs were unreliable.

Tension Wood. Tension Wood is Reaction Wood of the hardwood species. It forms on the upper or tension side of learning stems.

Lecture 19: Tension wood – Properties – Identification – G layer - Utilization

Properties. Like compression wood, tension wood properties are quite different from those of normal mature wood, tension wood might best be described by a proverbial good news-bad news is that tension wood has long been considered a less desirable raw material than normal wood. It requires a special care in pulping, and pulp containing large amount of tension wood produces weaker paper than normal pulp (Jayme and Harders-Stein Hauser, 1953). Tensile and burst strengths appear to be most affected (Dads well *et al*., 1958). The good news is that tension wood pulp strength compares favorably to that of normal wood after it is subjected to a refining treatment (Isebrands and Parham 1974; Parham *et al*., 1976) the good news gets better, because the cellulose content of tensin wood is higher than normal. The higher cellulose content, together with a 5-10% increase in density over normal wood, result in slightly improved chemical pulp yield (Casperson *et al*., 1968).

Tension wood is especially well suited for both dissolving and mechanical pulps. It is desirable for dissolving pulps because it gives high pulp yields. (Dissolving pulp is a very pure pulp made by removing residual hemicellulose and lignin from a chemical pulp. It is used in making cellulous products such as cellophane, rayon and nitrocellulose.) For this use, individual fiber strength is unimportant. Compared to normal wood, mechanical pulping of tension wood yield higher strength pulp and is easier to accomplish since the proportion of lignin in tension wood is lower (Scaramuzzi and Vecchi, 1968). Recall that compression wood is difficult to pulp mechanically because of high lignin content.

In the manufacture of solid wood products there is little good news associate with the presence of tension wood. Tension wood tends to produce a fuzzy surface upon sawing or surfacing, particularly when processed green. This causes saws to overheat and makes satisfactory finishing difficult. Upon drying, tension wood shows a decided tendency to collapse irreversibly (Collapse is the cave-in or flatting of wood cells during drying, often resulting in severely distorted wood surfaces). Tension wood cells shrinks excessively along the grain, although to a lesser extent than compression wood. Longitudinal shrinkage of tension wood is usually 1% or less. Although this degree of longitudinal shrinkage may seem insignificant, any amount of dimensional change along the grain can create problems. For instance, a change of only 0.5% can mean about 0.25 in. of shrinkage for each 4 ft (or 0.6 cm /0.8m) of length. Warp or twist can also result when tension wood is present along only one side or edge of a board.

Identification. Tension wood is not easy to detect visually, making removal during wood-processing operations difficult. A clue to its presence in log is the shape of the cross section and/ or the arrangement of rings within it. As with compression wood, stem containing tension wood have wider rings in the reaction wood zone than in the opposite side the pith, which often result in an elliptical shape. Other indication of the presence of tension wood is the fuzzy surfaces of some species and a darker color that characterized tension wood of some tropical hardwoods. Unfortunately, none of these are totally reliable indicators of tensin wood. Detection is further complicated because tension wood zones are seldom totally composed of tension wood tissue. Such tissue occur in a mixture with normal cells, with the proportion of tension wood depending upon the degree of lean in a stem. Efforts to find better ways of detecting tension wood continue.

Positive identification of tension wood is possible when laboratory methods are available. Examination under a microscope reveals that tension wood contains fewer and smaller vessel and fewer rays than normal wood. Tension wood fiber walls are often quite thick, with very small lumens, and secondary wall layer are commonly only loosely connected to the primary cell wall.

The thick and loosely attached secondary wall of tension wood fiber is almost pure cellulose of highly crystalline organization. Because this layer contains little lignin, it is soft or gelatin like, rather than stiff like other wall layers, and thus is called a gelatinous (or G) layer. In addition to being almost pure cellulose, the G layer is composed of micro fibrils arranged nearly parallel to the cell axis, varying only about 5^0. A highly cellulose gelatinous layer is the reason for high yield upon chemical pulping of tension wood.

Careful analysis of tension wood fiber walls shows variability in the sequence of layering. In some cells, the S-2 and S-3 portions of the cells wall are missing and the G layer lies to the inside of the primary (P) and S-1 cell wall layer (giving a P, S-1, G configuration). Other tension wood fibers are ordered P, S-1, S-2, G or P, S-1, S-2, S-3,

G. apparently, the cell wall configuration is depending upon the stage of development of a particular cells at the time of stem lean and will shift to G layer development.

Lecture 20: Compression wood – Properties – Identification - Utilization

Compression wood shrinks longitudinal because of the large micro fibril angle in the S-2 wall layer of longitudinal tracheids. This is not the case in tension wood, which exhibits a normal S-2 orientation of micro fibril in the thick G layer. Tension wood shrinks longitudinally because the loosely attached G layer does not provide shrinkage restraint as the S-2 layer in normal wood does. (Wood shrinks when micro fibrils move more closely together as water molecules leave the cell wall. a cell wall layer in which most of the micro fibrils are oriented perpendicular to the cells axis, such as the S-1 layer will tend to shrink longitudinal, as water is lost. This tendency is counteracted in a normal cell by the thick and firmly attached S-2 layer, which does not shrink longitudinally.

Reaction wood has been found in non-leaning stems of loblolly pine, yellow popular, and several species of *Populus.* Tsoumis (1968), explained this by pointing out that very young trees may be tipped, form tension wood, and recover to the vertical position. He also indicated that reaction wood could from in trees that are swayed by wind action but not permanently displaced. Thus gravity appears to play a key role in reaction wood formation even in non-learning to reaction wood formation. Observations of tropical trees suggest that tension reaction wood may serve to direct crowns towards opening in a dense jungle canopy. There is also mounting evidence that reaction wood formation is associated with fast growth (Tsoumis, 1952; Isebrands and Bensend, 1972; Isebrands and Parham, 1974; Crist *et al*., 1977).

What triggers auxin production upon tipping of stems and how these substances move to species locations in the stem are other unsolved riddles. Regardless of the trigger/transport mechanisms, it is clear that the system is sensitive and that events occur quickly. Stem displacements as amall as 2^0 can cause compression wood formation, with the amount of reaction wood formed directly related to the angle of lean.

Lecture 21: Branch wood - Root wood – Properties and utilization

Ever greater demand for wood and wood products has stimulated interest in finding new source of wood. An important development arising from this interest is the total tree concept developed in the 1960s by young, Keatys, Hakkila, Koch, and othes. Whereas traditional methods of harvest involve removal of only the main stem, which is trimmed of the top and branches, total tree harvest is characterized by gathering of main stems, branches, twigs, leaves, and even roots.

Harvesting of all aboveground segments of tree become reality in the late 1960s and early 1970s with the development in the United States of mobile units with capabilities of entire trees. The system provided for collection of chips in semi trailers for movement to processing centers. Tractor-mounted shear devices, developed at about the same time, insured maximum removal of aboveground trees parts; this equipment produced stumps only 2-6 in. (5-15 cm) in height.

Mechanized stump-removal equipment came on the scene in 1973-74, with almost simultaneous development in Finland and the United States. The Finnish system focused upon removal of stumps following harvest of aboveground segments. In contrast, prototype equipment developed for use in southern pine forests of the United States was designed to remove roots at the same time as the main stem.

Although yield can be greatly increased by whole-tree operations, three has been concern about the nature or quality of material harvested. The properties of branch wood and root wood differ from each other and from wood of the main stem, so manufacturing process may need to be modified to accommodate these variable components.

Branch Wood. From utilization viewed point one of the most significant difference have a much higher proportion of bark. This is especially true of that less than 1 in. (25 cm) in diameter. Because bark has markedly different properties than wood and often picks up considerable dirt during harvest, the use of branches for fiber or particle products requires caution. Considered process modification may be necessary. Processes to separate wood and bark are not yet perfected or widely used.

Aside from the bark, branch wood itself differs from of the bole. This can make wood identification as utilization difficult. Some kinds of cells are more abundant in branch wood than they are in the wood of the main stem. In hardwood branches, vessel and rays are more numerous than in the bole, with fibers present in lesser numbers. Softwoods that normally have resin canals also exhibit this character in branch wood, numerous. Softwood branches also characteristically have a higher than normal ray volume.

Narrow growth rings typify both hard wood and soft wood branch material, and longitudinal cells are generally both shorter and of lesser diameter than those in the main stem. In studies of a number of hard woods, fiber length in branch wood was found to average 25-35% less than wood of the main stem. Similar results have been obtained for softwoods.

Early literature indicates that branch wood is generally higher in specific gravity than stem wood. More recent work suggests, however, that this relationship is species dependent. Banches of soft wood tend to be 5-20% lower in specific gravity than bole wood, while specific gravity of hardwood branches ranges from higher in some species.

Products made from branch wood have different properties than those made of main stem wood. Particleboard made of Douglas-fir branch wood was, for example, shown to have lower stiffness and breaking strength in bending and lower strength retention after again than board made from bole wood. (Particleboard is product composed of wood particles that have been sprayed or mixed with an adhesive, 2-8% of the dry weight, and compressed to a desired thickness). Stiffness and breaking strength of boards made entirely of board material were only 30-65% that of controls panels, depending upon whether branches were small less than 1 in. (2.5 cm) diameter or large respectively. Particles board manufactured from logging slash (including branches, twigs, needles, and cones) was found to have considerable lower strength than board made of conventional materials when using the same percent of adhesive.

A number of investigations have assessed the suitability of branch material for wood fiber products. Kraft pulp from branch wood requires less beating time and has lower strength than pulp made from wood of the merchantable bole. One study of western hemlock showed that the paper from kraft branch pulp had 20-25% lower tear strength and 40-45% lower burst and tensile strength than paper made from wood of the main stem. Little work has been done to determine the suitability of branch wood for pulping processes other kraft. Studies do suggest, however, that relatively good quality mechanical or chemi-mechanical pulp can be obtained from this material.

Low pulp strength is not the only reason why branch wood is looked upon with disfavor by paper markers. Branch wood is also a less desirable raw material because of no uniformity of chip size and high proportion of bark. The higher bark fractions result in decrease yield and higher proportion of rejects in the form of oversized material such as slivers, chunks, or uncooked knots that remain after pulp is passed through a series of screen. Although a high bark fraction may partially explain lower pulp yields, lower than normal yield have even been reported from bark free branch wood of conifers. Such observation led to conclude that "the lower yield and strength characteristics of branch pulp can be explained in the part for coniferous species by the high lignin content of compression wood in branches…". Tests of hardwood showed pulp yield from branch material to be virtually the same as yields from bole wood when yield was expressed in terms of pulp weight, divided by the weight of chips entering the digester. Yield from branch material was far lower, however, when unacceptable chips produced in the chopping operation were considered. Over 50% of branch wood chip were a reject, compared to about 22% for chips from the main stem (young and chase 1966). Rejection in this case was upon no uniform chip size.

One wood fiber product for which branch wood appears to be an entirely suitable raw material is hard wood, a high-density product made from mechanically ground pulp by compressing o fiber mat under heat and pressure. A number of U.S. mills currently use branches mixed with normal wood for hardwood manufacture.

In summary, branch wood is an acceptable raw material, although for some products it is less desirable than stem wood. Because of the significant potential for increase yield when tops and branches are used, process modification will probably be made whereas possible to accommodate this material. Utilization of branch material in mixture with traditionally used pulp chips is likely to increase. On the other hand, Keays (1971a) visualized development of system for separating small from large branches. He foresaw the smallest material and foliage being used for chemical extraction processes, possibly for cattle fodder, the medium–sized material being used for fuel or as raw material for chemical extraction, and the largest branches finding use as pulp wood. The current direction of research and development and the rapid increase in the use of wood for energy indicate that some of these predicates developments will soon become reality.

Root Wood. Koch generated interest in utilization of roots as a source of fiber by publicizing the fact that the stump/root system of southern pine contains an amount of fiber equivalent to 20-25% of the fiber volume in the main stem. He also was instrumental in the development of root harvesting equipment designed for use in sandy soils of the southern United State. Wider utilization of roots is likely. However, problem remains to be solved. Roots are dirty and often difficult to clean, and dirt can plug or causes excessive wear of expensive pulp mill equipment. Dirt can also dull knivers or saws when cutting the final product. Another complicating factor is bark, which makes up larger portion of the small-diameter material.

Root wood is structure quite differently from either branch wood or wood of the main stem. Wood of softwood roots exhibits relatively few resin canals, a smaller ray volume than of the main stem and exceptionally large diameter cells. Length of cells is apparently highly variable. Root wood cells are reported by some to be as long or longer than those found in the main stem, while others report that they are shorter, man-willer (1972) student tracheids in stumps and roots of southern pine and found them to be about one-third larger in diameter and one-third longer than tracheids of the stump. Walls of the root tracheids were significantly thinner. Davis and Hurley (1978), in contrast, found tracheids of southern pine roots to be about 10% shorter than tracheids in the stem. Frequent occurrence of compression wood and spiral grain, the lack of well-defined pith, and high fibril angles in cell walls also appear to be characteristic of southern pine roots.

Comparing xylem of hard wood roots to that of the main stem, the vessel and parenchyma of roots occur in greater than normal quantity, while fiber volume is low, cell size varies as well, with abnormally large diameter as compared to stem wood to unusually small. Ring-porous characteristics and tyloses are often lacking in roots.

Specific gravity of root wood of hard wood roots is reported to be low in relation to that of the bole. Several tests of southern pine also show low specific gravity of roots, although experimental with roots of northern soft wood suggests abnormally high specific gravity levels. Chemical analysis of slash pine roots showed the cellulose content lower than in the main stem, with lignin and extractive content corresponding highly.

Lecture 22: Bark – Structure – Chemical composition - Function

Although the focus of this textbook is on wood and utilization, several other components of the tree are both abundant and increasingly valuable. One of these materials is bark, a by-product of wood products manufacture. In 1972 some 46,000,000m^3 (or about 15,000,000 metric tones, dry weight basis) of bark was delivered to U.S. mills as part of sawlogs, pulp wood bolts, and wood chips. Worldwide in 1972 the volume of bark arriving at mill sites was 319,000,000 m^3 to provide an idea of just how much material this is, it has been calculated that this amount of bark would fill a train of rail cars 70,000 km long, which would extend almost twice around the world at the equator. Once considered an expensive and irritating disposal problem, bark is now gaining recognition as an industrial fuel, soil amendment, ground cover, and possible source of chemical feedstock to name but a few uses.

Structure

The term phloem was used interchangeably with bark in earlier chapter. This usage will now be modified slightly in recognition of the fact that problem produced by the vascular cambium compose only the inner part of the layer. As will be explained, the origin of the outer, rough bark is traceable to activity of a second cambium, called phellogen that forms subsequent to and outside the true vascular cambium.

Inner Bark. Secondary phloem is a product of the same cambial initials that divide to form cells of the xylem (wood). Because of the common parentage, several types of phloem cells are quite similar to those in the wood. Other types of cell that form division of these initials are unique to the problem. The anatomical structure of bark is consequently more complex than that of wood.

Sieve cell are similar in shape to longitudinal tracheids of the xylem although somewhat shorter; and like tracheids, these cells are a primary avenue of conduction. The similarity ends there, however, as sieve cells have little structure function because walls seldom lignify or form secondary layer. Moreover, movement of fluids through sieve cells occur only while protoplasm fills the lumens; trachieds lose their protoplasm prior to assuming a conductive role.

Because sieve cells lack secondary wall layer, such cells commonly do not form pits (pits, remember, are defined as gaps in a secondary cell wall). Walls of sieve areas that are perforated by small pores. The pores in adjacent cells are normally aligned, allowing cell-to-cell connection of protoplasm.

Phloem fiber are along, sender, thick-walled, and often heavily lignified cells that resemble latewood tracheids of the xylem. These cells serve as structural elements. From the standpoint of conventional wood products manufacture, phloem fiber appear to constitute the most potentially useful bark fraction. Unfortunately species and are not found at all in the pines.

Outer Bark. A young stem is encased in a layer of primary and secondary phloem, which in turn is covered by a thin epidermis. Because the epidermis is not meristematic and thus cannot grow in size as the tree expands, this layer fractures and peels from the tree, usually in the first year. Before this happens, however, a new meristem forms in the bark and immediately begins to produce a new layer of stem-protecting cells.

The new bark meristem develops from parenchyma cells of the cortex or occasionally from parenchymatous cells of the epidermis itself. A cylinder of such cells only one cell wide becomes meristematic and begins dividing periclinally (tangentially to form new tissue. this cylinder of cells is called the cork cambium or phellogen. As is the case with the vascular cambium, tissue is produced both toward the outside and the inside (pith side) of the phellogen. The result is a three-layered region, a periderm, near the stem exterior.

Cells composing a periderm are quite unlike cells of the inner bark. Cells of the outer layer (or phellem) are flattened racially; short; and square, hexagonal, or even sprocket shaped tangentially. Walls are thin to very thick, and it is reported that the thin-walled phellem cells tend to be heavily suberized (wax impregnated), whereas the thicker walled elements lignify but lack suberin. This lignified and suberized phellem takes the place of the epidermis in protecting the stem against moisture loss and also serves as a shock-absorbing layer. The innermost layer of the periderm, the phelloderm also contains cells that are square to hexagonally shape in tangential view and usually, but not always, flattened racially. These provide additional protection against moisture loss. Other cells of the phelloderm are thin walled and greatly expanded in cross section; these are though to provide thermal protection. a photograph of a periderm clearly shows the layers described above.

New periderm-producing phellogen layers form from parenchyma cells of the secondary phelloem. Secondary phloem is pushed outward as new phloem is produced by the vascular cambium. At the same time, very thin-walled sieve cells or sieve tube elements become crushed, and some phloem parenchyma cells expand greatly in diameter. This activity results in a rearrangement of bark elements; during this process some parenchyma cells unite into short tangential bands and become meristematic.

Formation of a new periderm cuts off ray contact with the older periderm to the outside. Because the energy supply is cut off, all tissue outside the innermost periderm is dead. The names outer bark and rhytidome are both used to refer to all tissue outside the last-formed (functioning) periderm. Included in the outer bark are old periderms and crushed phloem tissue.

Outer bark ranges from relatively thin (1.3-2.5 cm) in some species such as aspen to quite thick (0.3 m or more) in species such as coast redwood and Douglas fir. Regardless of bark are thicknesses; the bark is never as thick as the pith-to-cambium thickness of xylem beneath it. This because (1) the vascular cambium produces far more xylem than phloem cells (on the order of 3-10 times more xylem than phloem in softwoods and hardwoods respectively), (2) thin-walled and undignified bark cells are crushed during outer bark formation, and (3) outer bark is periodically sloughed from the tree.

Chemical Composition

The lignin content of bark is much higher than that of wood, and the polysaccharide or sugar content is correspondingly lower. The extractive-free cellulose portion of bark is only 20-35%, compared to 40-45% for wood. Because minerals that rare important to physiological functions of the tree tend to become concentrated in bark tissue, the ash content of bark is usually higher than that of wood. (Ash content is defined as the weight of residue remaining, expressed as a percentage of moisture-free weight of wood, after high-temperature burning in the presence of abundant oxygen. Windborne soil or sand particles that may be trapped in rough outer bark contribute to high ash content. The ash content of wood is generally less than 0.5%, while that of the bark of softwood and hardwood averages 2% and 5% respectively. Occasionally, the ash content of bark is quite high; levels up to 20% of dry weight have been reported. Ash levels are significant when considering use of bark as a fuel since high temperature causes formation of slag and clinkers in boilers through melting and fusing of ash.

Extractive content (based on successive extraction with benzene, 95% alcohol, and hot water) of bark is high compared to wood, commonly amounting to 15-26% of unextracted bark weight compared to 2-9% for wood. Bark extractable chemicals, one-fourth to one-half by weight, is tannic acid, a chemical often used as a component of well-drilling mud to help control viscosity and gel strengths. Tannin currently used as a tanning agent in the making of leather and as an important additive in the manufacture of inks and dves. Tannin currently used in most industrial processes such as leather manufacture is chemically synthesized rather than extracted from tree bark. Tannin used in well-drilling mud is, however, often obtained from this source.

pH values ranging from about 3.5 to 6. Barks extract is usually more highly acidic than extract from wood of the same species. The acidic nature of bark may require some modifications in processing methods where it is to be used. For example, Chow (1971) reported that resin used in making particleboard would likely require a change in formulation if significant amounts of highly acidic bark were incorporated. Acidity of bark extractives has been variously reported to pose a problem for use of bark as a potting medium, soil amendment, or ground cover. Studies indicate, however, that poor plant performance in some instance due to nitrogen consumption by bark-destroy by use of supplemental nitrogen.

Moisture content

The moisture content of bark is comparable to that of wood and often exceeds 100% of the oven dry weight. It is calculated by dividing the weight of water present by the moisture-free weight of bark. The difference in moisture content between inner and outer bark is considerable, with an abrupt change between the two layers in some species. Thus the moisture content of whole bark is largely dependent upon the ratio of inner to outer bark. Moisture content is extremely important where use for fuel is considered.

Proportion of the woody stem

Bark Volume. The ability to calculate bark volume has become more important as the value of bark has increased. Estimation of the quantity of phloem fiber that may appear in a given volume of pulp or computation of the likely contribution of a log shipment to bark fuel requirements at the industrial boiler are examples of situations where accurate measurements of volume is needed.

The volume of bark relative to wood is dependent upon species and stem diameter and upon bark thickness. It is possible to estimate bark thickness in standing trees of various diameters buy using regression equations such as those in table. For example, the double bark thickness (DBT) of red oak at a point having a 12-in. diameter outside bark (DOB) can be calculated using the equation:

$$DBT= 0.187 + (0.065\ DOB)=0.187 + (0.06512)=0.967 \text{ in.}$$

Where both DBT and DOB are expressed in inches. (When calculating bark thickness in centimeters, the formula DBT=0.475 + (0.065)(DOB) should be used; DOB should be in centimeters in this case.)

Strength

Bark is low in strength compared to wood. Tests by Murphy and Risheh (1977) show considerable difference in the strength of various barks. The stronger barks, such as hickory, were determined to be very fibrous, whereas low-strength barks tended to have a nonfibrous or conglomerate character. For all species listed in table 7.9, the compressive strength of bark is fat below that of wood stressed parallel to the grain. In some cases, however, values for bark do exceed values for xylem of a different species.

Because bark strength is generally markedly less than that of wood, significant amounts of barks are seldom used for applications in which high strength is important. When whole tree chips or top wood containing bark are used as raw material for manufacture of a structural product, care must be taken to limit the proportion of bark. An indication of the effect of bark upon strength is provided by data for structural panels made of 100% bark, pressed to a density of 40 lb/ ft^3 (640 kg/m^3) and bonded with urea formaldehyde resin. Commercial standards governing similar product made from wood specify a minimum bending strength of 1600 psi ($lb/in.^2$) and minimum standards in may cases by using high resin levels (5-6% resin is normally used) other examples of the effect of bark in various products.

Lecture 23: Wood and water – Location of water in the wood – Nature of wood

Water is natural constituent of all parts of a living tree. In the xylem portion, water (moisture) commonly makes up over half the total weight; that is, the weight of water in green wood is commonly equal to or greater than the weight of dry wood substance. When the tree dies or a log is processed into lumber, veneer, or chips, the wood immediately begins to lose some of its moisture to the surrounding atmosphere of the wood will begin to undergo change.

Some water will remain within the structure of the cells walls even after wood has been manufacture into a lumber, veneer, particle, or fiber product. The physical and mechanical properties, resistance to biological deterioration, and dimensional stability of the product will be affected by the amount of water present and its fluctuation with time. Since almost all properties of wood and wood product are affected by water, it is important to understand the nature of water in wood and how it is associated with the microstructure.

Location of water in wood

Water in green or forestry harvested wood I located within the cell wall and in the cell lumen. The amount of water within the cell wall structure of a living tree remains essentially constant from season to season, although the amount of water in the lumen may vary. The water in the lumen may contain dissolved food materials produced by photosynthesis as well as in organic compounds. This solution is commonly referred to as sap.

When wood is dried during manufacture, all the liquid in the cell lumen is removed. The cell lumen of wood in use will, however, always contain some water vapor. The amount of water remaining in the cell walls of a finished product depends upon the extent of drying during manufacture and the environment into which the product is later placed. After once being removed by drying, water will recur in the lumen only if the product is exposed to liquid water. This could result from placing wood in the ground or using it where rain may come in contact with it.

As long as there is any liquid water remaining in the lumen, the wall of the cell will be saturated; i.e., it will contain as much water as it physically can adsorb. Most physical properties of wood (other than weight) are not affected by difference in the amount of water in the cell lumen. For example, if the same strength as when one-half full. When wood is dried to the extent that all the water in the lumen is removed water begins to leave the cell wall. Almost all wood products used in buildings, or for other applications where there is no contact with the ground.

The point at which all the liquid water in the lumen has been removed but the cell wall is still saturated is termed the fiber saturation point (FSP). This is a critical point, since below this the properties of wood are altered by changes in environments providing no contact with liquid water will always be less than the FSP.

Nature of water in wood

To simplify discussion, the liquid water found in the lumen of wood is often referred to as free water and the water within the cell wall is called bound water. This is an appropriate description, since the free water is relatively easy to remove and so is the to be lost in the drying process. Bound water is held more tightly because of surface adsorption within the wood structure. The lower the moisture content the FSP the more tightly bound is the remaining water.

The water within the cell wall, bound water is held by *adsorption* forces, which are physicochemical in nature. This is not to be confused with the absorption that takes place, for example, when a no cellulose sponge soaks up water. Absorption results from surface tension forces. Adsorption, in contrast, involves the attraction of water molecules to hydrogen bounding sites present in cellulose, hemicelluloses, and lignin. This hydrogen bounding occurs on the chemical elements of wood. The left-hand side of this figure illustrates monomolecular adsorption of water onto the cellulose; the right-hand side shows poly-molecular adsorption. In saturated green wood as many as five or six water molecules may be attracted to each accessible sorption site.

Recall that the grouping of long-chain molecules in the cell wall contains crystalline and amorphous regions. It is believed that the OH groups of adjacent cellulose molecules are mutually boned, or cross-linked. Therefore, there are no sites to hold water within the crystallites.

Lecture 24: Relation of moisture content to the environment – Shrinkage and swelling

Calculating moisture content

The amount of water in wood product is usually expressed as the moisture content. The moisture content (MC) is defined as the weight of the water expressed as a percentage of the moisture-free or oven dry (OD) weight of the wood. (The term weight is used rather than mass throughout this book to conform to general practice.) Thus:

$$\%\ MC = \frac{\text{Weight of water}}{\text{OD weight}} \times 100$$

Because the denominator is dry weight, not the total weight, the moisture content calculated in this way can be over 100%. One of the most common methods of determining the moisture content is to weight the wet sample, dry it in an oven at 103 $\pm\ 2^0$C to drive off all water, and then reweigh. The details of this oven dry method are described in American Society for Testing and Materials (ASTM) Standard D2016. When using the oven dry method, the moisture content is computed as follows:

$$\%MC = \frac{\text{Weight with water – OD weight}}{\text{OD weight}} \times 100$$

Measuring moisture content

The determination of moisture content during manufacture and subsequently to verify conformance to commercial standards is generally accomplished by the oven dry method, described in the preceding section, or by the use of electrical moisture meters which have the advantage of being relatively simple and direct. Other methods of determining moisture content are sometimes used for research purpose where high precision is required.

A variety of electrical meters are available to measure the moisture content of lumen, chips, and particles. Although meters are less precise than other moisture determination methods, their instants readout, ease of operation and non-destructive nature make them well suited for industrial applications.

The most commonly used meters for lumen is the resistance moisture meter, which measure the electrical resistance between pins driven into the wood. His type of meter indicates the moisture content based upon the relationship shown in figure 8.4.

Insulated pins can be used to make it possible to measure the resistance between tips of the pins and therefore to determine the moisture content at different depths. Moisture meters of the resistance type are generally reliable in the 6-30% moisture content range. Since the electrical resistance of wood varies with temperature, correction must be made if the wood temperature is significantly different from the calibration temperature indicated by the manufacture. Also, corrections for species are often necessary, since extractives do influence resistance. Above the FSP, electrical resistance meters give a qualitative rather than a precise measure of the moisture content.

Relation of moisture content to the environment

Because of the adsorptive nature of wood, it has the ability to remove water vapor from the surrounding air until is in moisture equilibrium with the air. Thus wood is called a hygroscopic material. If wood is in equilibrium with the surrounding environment and the air then becomes drier, the wood will lose water (or desorbs) until it again comes into equilibrium. The term sorption is applied to the combined or general phenomena of adsorption and desorption.

Moisture content of green wood

The moisture content of green wood is important because of its direct relation to the weight of logs and green lumber. Therefore, it is of concern to those who design harvesting and transport equipment or purchase wood on a weight basis.

Hardwoods generally have only small differences in moisture content between sapwood and heartwood. This contrast markedly to softwoods, where the moisture content of sapwood is usually much higher than heartwood, often by a factor of three grow older because the percent of sapwood volume declines. If you are lost in the woods and forced to build a fire from green wood, burn the heartwood of softwood, not a hardwood!

Shrinking and Swelling

As wood losses moisture below the FSP i.e., losses bound water, it shrinks. Conversely, as water enters the cell wall structure, the wood will swell. Shrinking and swelling is an exactly reversible process in small pieces of stress-free wood. In wood panel products however, such as fiberboard and particleboard, the process is often not completely reversible. This results in part from the compression that wood fibers or particles undergo during the manufacturing process. In large pieces of solid wood, swelling or shrinking may not be completely reversible as a result of internal drying stresses.

Shrinking of the wall, and therefore of the wood, occurs as bound-water molecules escape from between long-chain cellulose and hemicelluloses molecules. These chain molecules can then move closer together. The amount of shrinking that occurs is generally proportional to the amount of water removed from the cell wall, Swelling is simply the reverse of this process. Since the S-2 layer of the cell wall is generally thicker than the other layers combined, the molecular orientation in this layer large molecules are oriented more or less parallel to the long axis of the cell. Thus both transverse dimension decreases as these molecules move closer together. For the same reason, the length of the cell is not greatly affected as the cell wall substance shrinks or swells.

In reason wood and other abnormal wood the oriented of the micro fibrils in the S-2 layer is often at a significant angle from the cell axis. Therefore, as the wood dries there is a measurable shortening of the cell; consequently, longitudinal shrinking occurs. Longitudinal shrinking in such abnormal wood can be as great as 3% when going from the FSP to the over dry condition. A2 ´ 4-in. stud 8 ft long for the wall of a home would shrink almost 3 in. in length when drying from its FSP to EMC condition if it were manufactured from such material. Fortunately, such lumber is rarely encountered.

Shrinking and swelling are expressed as a percentage of the dimension before the change occurred. Thus:

$$\%\text{Shrinking} = \frac{\text{Decrease in dimension or volume}}{\text{Original dimension or volume}} \times 100$$

$$\%\text{Swelling} = \frac{\text{Decrease in dimension or volume}}{\text{Original dimension or volume}} \times 100$$

The longitudinal shrinking of normal wood is negligible for most practical purposes. This is one the characteristics that maker lumber and lumber product such usable building materials. If this were not so, the change of moisture content during use would be disastrous. Usually, some longitudinal shrinking does occur in drying from the green to the oven dry condition, but this amounts to only 0.1-0.2% for most species and rarely exceeds 0.4%.

From an idealized “soda-straw” concept of wood, one might visualize that the radial and tangential dimension would shrink or swell the same amount. However, tangential shrinking is greater than radial shrinkage by a factor between one and one-half and three to one. Several anatomical characteristics are believed responsible for this differential, including presence of ray tissue, frequent pitting on radial walls, domination of summerwood in the tangential direction, and differences on the amount of cell wall material radically vs. tangentially. The average transverse shrinkage values of a number of domestic and imported species’ are shown in table 8.5. These values are good guidelines to use for estimates; however, the actual shrinkage of individual pieces in service may vary significantly from these averages.

Variation in the shrinkage of different samples of the same species under the same conditions results primarily from three factors:

1. The size and shape of the piece. This affects the grain orientation in the piece and the uniformity of moisture through the thickness.
2. The density of the sample. The higher the density of the sample, the more it will tend to shrink.
3. The rate at which the sample is dried. Under rapid drying conditions, internal stresses are set up because of differential shrinking. This often results in less final shrinkages than would otherwise occur. In contrast, however, some species shrink more then normal when dried rapidly under high-temperature conditions.

Lecture 25: Dimensional changes in veneer – Fibre – Particle and panel products – Means of reducing moisture induced – Dimensional change in wood product

Drying of veneer, particles, and fibers

The major difference in principle between drying veneer and lumber is that veneer, being very thin, develops a limited moisture gradient. Therefore, the drying stresses and impermeable zones that cause problems in the drying of lumber are not the limiting factor in veneer drying how fast veneer can satisfactorily dried.

Veneer driers consist of a means of conveying the veneer through a heated chamber where temperatures range from 150 to 260^{0}C. In older roller driers, air is circulated in a manner similar to that in a dry kiln. This type of drier is still in wide use for hardwood veneer. Most plants built in recent years utilize jet driers. These are also called impingement driers since a curtain of air at velocities of 2000-4000 fpm is directed against the surface of veneer. This eliminates the laminar boundary layer that shows down heat and moisture transfer under ordinary conditions.

Most wood particle- and fiberboard plants utilize a high-speed drying system of some sort because of the large tonnage of material to be dries; one plant in the United States dries 2 million lb wood/day. In common use are driers of two types: drum driers and tube driers. Rotating drum driers make one; two, or three passes from one end of the drier to the other and then are discharged. Inlet temperature of such driers can be as high as 870^{0}C when wet furnish is being dried but is reduced to about 260^{0}C or lower if dry planner shavings are involved.

Drying wood particles at temperatures above the burning point of about 230^{o}C is possible as long as moisture is present in the wood. Drier control systems mist is designed to insure that dried wood is not present in the preliminary high-temperature stages of the drier. The particles, which dry faster, are blown more rapidly through the drum and therefore are exhausted before reaching the combustion point.

The drying of fiber for dry-process fiberboard production can be accomplished in tube driers. The fibers are introduced into a stream of gas heated from 200-320^{0}C. These drivers may have a second stage operating at a lower temperature. Moisture is often flashed off in few seconds; thus effective feed and temperature control systems are critical to avoid fires.

The moisture content to which fiber- or particleboard particles are dried for the manufacture of panel products depends upon the specific product, the amount of water added with the resin and wax size, and the pressing cycle. Generally, the wood furnish is dried to between 4 and 8% MC. Precise control is necessary, since a moisture content 2% higher than desired can causes blows or internal explosions in the panels when the press is opened. Moisture content 2% below the desired level can cause poor bonds and therefore will reduce mechanical properties.

Means of reducing moisture-induced dimension change in wood products

There are several means of reducing dimensional change of woos resulting from changes in moisture content. None of these can entirely eliminate dimensional change, but some come very close. Five approaches to reducing dimensional change are:

1) Preventing moisture sorption by coating the product. This is a common but not completely effective method. Coating includes pigmented paints, clear finished, synthetic resin of other types, and metallic paints. None of these will completely prevent the movement of the water vapor but will slow the rate of diffusion. Some are effective in preventing the pickup of liquid water. Proper in exterior siding and panel materials. Wood, regardless of the coating, can eventually attain the same EMC as uncoated wood.

2) Preventing dimensional change by restraint that makes movement difficult or impossible. The problem with this approach is that internal pressures are built up if wood attempts to swell but is prevented from doing so. These pressures may result in distortion of shape. The buckling of plywood on a roof or wall, which can occur if panels are not properly spaces, is an example of a response to swelling pressure. The restraint method can be used successfully, however, in some situations. For example, particleboard underlayment will exhibit little linear dimensional change if glued to the plywood sub floor beneath it. In case, the swelling stresses in the particleboard are much less then the strength of the plywood.

3) Treating wood with material that replaces all or part of the bound water in the cell wall is a commercial means of stabilization. Such treatments are applied to wood when it is still green. The treating material remains it in a partially swollen condition. The

reduction in shrinkage from such treatments varies from about 30 to 90%. These treatments add up to 35% to the weight of the product, are generally expensive, and may adversely affect finishes applied to the final product. Thus they are used only for special products.

Several effective methods of treatment based upon this principle of bulking, i.e., replacing water molecules in the cell wall with other materials, have been developed. One of the first successful applications of this approach utilized phenol formaldehyde resin, which impregnated the cell wall. The resulting product was termed Impreg. Another product, polyethylene glycol (PEG), is used to stabilize a wide variety of wood product-from wood carving to gunstocks. PEG is a waxy substance that, when dissolved in water, can impregnate the wood. A simple soak is ordinarily used to treat with PEG.

4) Treating wood to produce mutual cross-linking of the hydroxyl groups in the cell wall has been used experimentally with success. Cross-linking reduces the hygroscopicity of the wood by reducing the future. Although not being used commercially today, means of accomplishing cross-linking are being studied.

5) Impregnation with plastic monomers such as methyl methacrylate and styrene acrylonitril can improve the stability of wood and increase hardness and wear resistance. These monomers can be polymerized in the wood by radiation or by heating with appropriate catalysts. This technique has been used to produce products such as decorative flooring, novelties, and knife handles. The monomers are generally not as efficient as PEG in eliminating dimensional change, since they only limited access to the cell wall. The appearances of the wood are not significantly changes.

Lecture 26: Moisture movement during the drying process

The movement of water drying takes place as mass movement of liquid water or diffusion of individual water molecules. Diffusion involves both bound water in the cell walls and vapor in the lumen.

Diffusion is a phenomenon that occurs as water moves from an area of higher concentration to one of lower concentration. Thus, to have diffusion occur, there must be a moisture gradient or a vapor pressure gradient across the cell walls. The rate of diffusion is related to the temperature, the steepness of the moisture gradient across cells, and the characteristics of the species that determine the ease with which diffusion can occur. The rate of diffusion in a species can be expressed as the diffusion coefficient. Diffusion through individual cells occurs only below the FSP, since above that level the cell walls are saturated and thus no moisture concentration gradient exists as a driving force. Above the FSP, free water moves out of wood as a result of surface drying and capillary forces. At that stage of drying, wood can be thought of as a series of partially filled tubes, with water evaporating from one side.

The rate at which lumber dries is determined by the rate at which water is removed from the surfaces, the rate of mass movement to the surface, or diffusion. In the initial stages the rate of drying is often controlled by surface evaporation and in later stages by the diffusion characteristics of the species.

In some species the structure of the wood inhibits the mass movement of liquid water. Such woods are referred to as impermeable. Tyloses, aspirated pits, and deposition of extractives on pit membranes are examples of wood characteristics that inhibit movement of water. In woods with these structures, the movement of water must be principally by diffusion; thus drying is an extremely slow process. Redwood, white oak, and walnut are a few of the species having relatively impermeable heartwood. Sapwood is generally permeable in all species. Other species such as western hemlock and aspen contain pockets or localized zones that are impermeable wet areas are subject to drying defects if care is not exercised in the drying process.

Using an analogy between electrical condition and diffusion, Stamm (1964) developed the theoretical transverse drying diffusion coefficients shown in figure 8.14.

Note the over tenfold increase in the rate of diffusion by increasing the temperature from 50 to 120^{0}C. Also note that diffusion is affected much more by the density of wood at high drying temperatures than at low temperatures.

A variety of treatments to increase the movement of water through wood, i.e., increase permeability or diffusion, have been developed, but none has found wide commercial application. Erickson *et al.* (1966) found that freezing redwood lumber prior to drying improved drying performance. Application of hygroscopic chemicals such as urea, sodium chloride, and calcium chloride alters the moisture gradient and permits an increased rate of drying for some species. However, when so treated, the wood retains a hygroscopic surface layer that can cause problems in use. Presteaming of wood has been found to be beneficial in some cases. Unfortunately, a universally effective means of improving liquid water movement and/or diffusion is yet to be found.

Methods of drying lumber and other solid wood products

Most lumber, whether hardwood or softwood, is dried in some type of dry kilns. Modern kilns have controlled temperature and relative humidity; they are also equipped with fans to force air ambient up to about 100^{0}C. High-temperatures kilns designed to provide more rapid drying operate above the boiling points of water. The lumber in a kiln is dried in air that has been heated by steam coils or directly by the addition of combustion gases from a gas-, oil-, or wood residue-fired burner.

Drying in a conventional kiln progresses through a series of temperature and relative humidity steps designed to dry the wood gently while it is at high moisture content. After the free water has been removed, more severe drying conditions are imposed to maintain an adequate rate of drying. The series of temperature and humidity conditions imposed on the lumber during drying is referred to as a kiln schedule. Most hardwood schedules are controlled according to the moisture content of the lumber; i.e., changes in the drying conditions are made when the moisture content drops to predetermined levels. Softwoods are more frequently dried by a time schedules; i.e., drying conditions are changed at predetermine times.

Lecture 27: Specific gravity and density – Effect of moisture content on specific gravity – Porosity – Effect of extractives on specific gravity – Sources of variation on specific gravity

The specific gravity of wood is its single most important physical characteristic. Most mechanical properties of wood are closely correlated to specific gravity and density. In general discussion the term specific gravity and density are often used interchangeably. However, as a will be discussed later, these4 terms have precise and different meaning although they refer to the same concept. The strength of wood as well as the stiffness increases with specific gravity. The yield of pulp per unit volume is directly related to specific gravity. The heat transmission characteristics of wood increase with specific gravity as well as the heat per unit volume produced in combustion. The shrinking and swelling behavior of wood is also affected, although the relationship is not as direct as in the case of strength properties. It is possible to learn more about the nature of a wood sample by determining its specific gravity than by any other single measurement. Perhaps it is for this reason that density was the first wood property to be scientifically investigated.

Wood is a cellular material. The cellular structure gives wood many of its unique properties and characteristics. The density of wood is directly related to its proprosity, i.e., to the proportion of the void volume. A piece of sugar pine with a density of 23.4 lb dry wood substance/ft^3 contains about 25% cell wall material and 75% void (principally lumen space) by volume. In contrast, white oak with a density of 46.8 dry lb/ ft^3 has a void volume of about 50%. When considering the density of wood, it is helpful to visualize the void volume with which it corresponds. One can understand why a block containing 50% void volume will resist crushing to a much greater extent than a block from a different species with 75% void space.

The physicomechanical properties of wood are determined by three characteristics: (1) the porosity or proportion of void volume, which can be estimated by measuring the density; (2) the organization of the cell structure, which includes the microstructure of the cell wall and the variety and proportion of cell types-organization of the cell structure is principally a function of the species; and (3) the moisture content. In the use and engineering of wood materials it is important to keep these three factors in mind. Two physical characteristics, density and specific gravity, are used to describe the mass of a material per unit volume. These characteristics are commonly used in connection with all types of materials. Density is defined as the mass or weight per unit of volume. It is usually expressed in pounds per cubic foot or kilograms per cubic meter. (In the international system of Units the pound is a unit of mass, not force.)

Specific gravity is the ratio of the density of a material to the density of water. With most materials the weight and the volume are determined under the same conditions. However, a dilemma exists when these characteristics are used for a hygroscopic material such as wood. Since both the weight and the volume vary with changes in moisture content, how should density and specific gravity be determined?

The total weight of a wood product is the sum of the weight of the wood substance and the moisture content (MC). This must be taken into account when density id commonly calculated using the total weight, including the weight of water. In the United States it is common practice to use the over dry weight of the wood and the volume at the time of the test to calculate the density. For example, suppose a block of wood has a green volume of 0.50 ft^3, a green weight of 22lb, and weight is $15/0.50=30lb/ft^3$. If the block is dried to 12% MC and then has a volume of 0.45 ft^3 (exhibits 0.05 ft^3 shrinkage), the density on a dry weight basis at that moisture content would be $15/0.45=33lb / ft^3$.

A word of caution is in order when discussing wood density. Although density is often calculated in the United States based upon the moisture-free weight of the wood, this is not always the case. Density is often express in green weight and green volume when the use will be to calculate weights for transportation or construction. Density of particleboard is often calculated from weight and volume without considering moisture. Therefore, when ever wood density is discussed, it is good practice to be sure of the based upon green weight and green volume, dry weight and green volume, or weight and volume at specific moisture content?

The characterization of wood by using gravity rather than density has the major advantage that it is always calculated using oven dry weight or mass. Because of this recognized standard procedure, confusion about the basis of the calculation is avoided. Specific gravity is defined as the ratio of the density of wood (based on oven dry weight at 4^0C. Water has a density of 1 g/cm^3 or 1000 kg/m^3 at that standard temperature.

Therefore, wood with a specific gravity of 0.5 has 0.5 g dry wood substance /cm^3 or 500 kg/m^3. In English system, water has a density of 62.4%lb/ft^3. Therefore, the density of a specific gravity of 0.5 is 0.5 × 62.4 or 31.2lb/ft^3 (oven dry weight per unit volume at the specific moisture content).

Calculation of specific gravity is greater simplified in the metrics system because 1 cm^3 of water precisely 1 g. Specific gravity can thus be calculated directly by dividing the weight in grams by the volume in cubic centimeters. Numerically, the density (D) and specific gravity (SG) are then the same. However, specific gravity has units since it is a relative value.

Common units = /cm^3, kg/m^3, lb/ft^3

$$SG = \frac{\text{OD mass / volume}}{\text{Density of water*}} \quad \text{(* in same units as the numerator)}$$

Density of water=62.4 lb/ft^3, lg/cm^3, 1000 kg/m^3)

Effect of moisture content

As seen in the previous example, density and specific gravity can be calculated at any moisture content desired. Which is preferable depends upon the purpose of the calculation. The specific gravity of a sample increases as the moisture content on which it is based decreases, below the Fiber Saturation Point (FSP). This occurs because dry weight remains constant while the volume decreases during drying. The greater the volumetric shrinkage of a species of wood, the greater the different between the green and the oven dry specific gravity.

Cell wall density and porosity

The direct relationship between of void volume in wood (porosity) and density of dry wood substance is approximately the same for all species. That is, if section of void-free cell wall material were taken from a low-density species like basswood, tested for specific gravity, and compared to result of a similar test from a dense wood such as hickory, the two specific gravity values would be almost identical. For general purposes it can be assumed that the density of dry wood cell walls is approximately 1.5 g/cm^3; i.e., the specific gravity is 1.5. If a wood species contained no cell lumens or other voids, its specific gravity would be 0.75. The approximate void volume of wood can be calculated by the following equation:

$$\%\text{void volume} = (1\text{-}SG_{O\,D}/1.50) \times 100$$

The density of cell wall material has been studied by many wood scientists since the early 1900s. The density values observed are affected by the techniques employed. In determining cell wall density, volume is generally determined by displacement of a fluid. Different fluids vary in their ability to penetrate the voids in the wall and in their physical association with chemical components of wood, so it would be expected that these measurements would vary. In most cases these studies have determined the cell wall specific gravity to be between 1.45 and 1.54.

Effect of extractives and inorganic materials on specific gravity

Wood often contains measurable quantities of extractives and infiltration materials, including terpenes, resin, and polyphones such as tannins, sugars, and oils as well as inorganic compounds such as silicates, carbonates, and phosphates. These materials are located to a large extent within the cell wall, where they are deposited during the maturation of the secondary wall and during heartwood formation. The heartwood has a higher concentration of these materials than the sapwood; therefore, the density of heartwood is often slightly higher than that of sapwood.

The amount of extractives in wood varies from less than 3 to over 30% of the oven dry weight. Obviously, the presence of these materials can have a major effect upon the density. In some species, including pines, it has been shown that the presence of extractives contributes significantly to the variability observed in the specific gravity. In other words, the specific gravity of wood from which extractives is included.

In research work it is often desirable to determine the density of the wood without the extractives. Water and organic solvents are used to extract as much of this material as possible prior to determining the density. When the extractives are removed, a sample will weigh less and will tend to shrink a greater amount when dried because some of the bulking effect is lost.

Methods of determining specific gravity

The volume at given moisture content and the weight of the dry wood are necessary for determination of specific gravity. In most cases, the dry weight is found by oven-drying the sample as would be done when finding the moisture content. However, since this may drive off some of the extractives on addition to the water, it is sometimes desirable to determine the moisture content by a distillation method that involves condensing and weighing the vapor driven off.

The volume of the wood may be obtained in a variety of ways. For a piece that is regular in shape, such as a section of lumber, the simplest methods are it measure the dimensions as accurately as possible and calculate the volume.

Relationship of density to rate of growth

Intuition or common sense might suggest that wood density should decrease if the rate of growth of a tree increases. This is not necessarily or even usually the case. When wood density is related to growth rate, the responds depends on the species and the range of growth involved. Other factors such as age of the tree when the wood was produced and location of wood in the tree are more closely correlated with density than is the rate of growth. However, since rate of growth can be visually determined once a lumber product is cut from a tree, while these other factors cannot, growth rate is sometimes used as in indicator of density.

There are three typical growth rate-density relationships that may be found within species of the following groups.

1. Ring-porous hardwoods. The density tends to increase as the growth rate increases.
2. Softwoods with prominent latewood. Density tends to decreases slightly as the growth rate increases. These correlations neither are weak and do nor appear to exits in some species.
3. Diffuse-porous hardwoods and softwoods without prominent latewood. The density often has little direct correlation to the growth rate.

These general rules are often true for wood within the normal range of growth rates for the species. Wood of exceptionally slow or fast growth, juvenile wood, and reaction wood often do not follow these relationships. These three rules of thumb should always be used with caution. When growth rate is to be used as an indicator of density, a study should be conducted with the species and site conditions involved to establish what relationship in fact exists.

The rate of growth is used to estimate density (and thus strength) in the grading of several types of lumber products. Hickory tools handles are often grading based upon the number of growth rings per inch. The fewer the growth rings per inch the higher the density and therefore the higher the grade. Ash shovel and hoe handles and implement parts can be graded based on the number of growth rings per inch. A handle with 30 or more rings per inch cannot be relied upon to perform satisfactorily under heavy use.

In the grading of softwood lumber a so-called density rule can be applied to southern pine, Douglas-fir, and western larch. Such lumber may be grades as Dense if it averages 6 or more growth rings per inch and if it contains one-third or more latewood. Material graded Dense carries engineering strength values 15-30% higher than for normal lumber. Southern pine structural lumber containing 15% or less latewood is deemed to be exceptionally light and is excluded from the top three grades.

Most research directed to the question of the relationship between growth rate (or rings /inch) and density has been conducted in conjunction with studies on fertilization, irrigation, genetic improvement, or other intensive silvicultural practices.

Variability in wood density

Wood density within a species has been found to vary with a number of factors including location in a tree, location within the range of the species site condition, and genetic sources. However, the user of a wood or lumber product has no control or knowledge of where the particular wood was cut, in what part of the tree it originated, or if the tree was normal or over-mature. The user is concerned primarily with the variability that may be encountered in the density of the product, regardless of its estimating the variability of strength properties, establishing a procedure for purchase of wood on a weight basis, and estimating the amount of pulp to be obtained per unit volume of raw wood.

Generally, the specific gravity of most species in North America has a coefficient of variation (COV) of about 10%. To determine the range of wood densities one might normally expect to encounter in any such species, the COV is multiplied by the average density and by 1.96 (to include 95% of a normally distributed population). This figure is then added and subtracted from the mean. For example, the average green specific gravity of black cherry as indicated in Appendix table A.6 is 0.47. Therefore, the range of density to be expected in black cherry is approximately 0.47± (10% ´ 0.47 ´ 1.96)

=0.47 ± 0.09 = 0.38 to 0.56. Wood users frequently question the quality of material they purchase of it has a specific gravity that differs from the average value published in the wood Handbook (USFPL 1974) or in trade association literature. Such differences are to be expected because of variability.

Sources of variation in specific gravity

Many factors of site, climate, geographic location, and species affect the specific gravity wood. Since many of these occur in combination, it is difficult to separate the independent effects. There is a great deal of scientific literature dealing with these relationships, the inconsistencies of which indicate the complex interactions among these factors.

Site-related factors such as moisture, availability of sunlight and nutrients, wind temperature can affect specific gravity. These are determined to a large extent by elevation, aspect, slop, latitude, soil type, stand composition and spacing. All these factors can affect the size and wall thickness of the cell and thus the density. Species differ greatly, however, in their sensitivity to these factors.

It is common for density to vary significantly within a tree. Figure 9.8 shows the variation found within young yellow poplar in West Virginia. Note that the density was found to vary from 0.36 to 0.42 at various heights in the tree and from 0.37 to 0.40 at different distance from the pith at selected heights. In many species, butt logs tend to have a higher density than normal wood. Generally, in softwood the density decreases with height and increases with distance from the pith. In large softwood logs the density often increases outward from the pith and then reaches a fairly constant level.

Juvenile wood, reaction wood

The density of juvenile wood is usually less than that of moisture wood, and such wood has a correspondingly lower strength. Although this may be of concern of the portion of a log near the pith is utilized for lumber, a more serious problem is the tendency of juvenile wood to exhibit abnormally high longitudinal shrinkage, which frequently result in excessive warp. The specific gravity of compression wood is normally greater than that of normal wood-up to 40% greater. This higher density can often be detected visually from the proportion of summerwood. In some cases, however, the density of compression and normal wood may not differ significantly.

Density its high longitudinal shrinkage and erratic strength properties. The commercial standards for some products such as ladder rails specifically exclude compression wood because of its unreliable strength and the tendency to exhibit failure (splinter-free fracture). Like compression wood, tension wood often possesses higher than normal specific gravity. Some woods, however, including *Populus* spp., often contain scattered groups of gelatinous fiber that could be termed tension wood but in which the density is normal.

Density of forest products

The density of veneer, particle, and fiber products will differ from the density of the raw wood because of the weight of adhesives and other additives and the amount is compression of the wood that occurs during the manufacturing process. Plywood is ordinarily only slightly denser than the wood from which it is produced-usually 5-15%. The pressure used to press plywood is intended only to provide good contact between the veneers and not to density the wood.

Particleboard, by contrast, is usually produced at a density of 1.2-1.6 times the density of the species used. Particleboard densities ranging from 39 to 55 lb/ft^3 are common. Of this weight, 3-12% is the weight of the resin (adhesive) and wax used to impart water repellency.

Fiber products vary widely in density. Insulation board used for wall sheathing is produced at 10-30 lb/ft^3, medium density board at 31-50 lb/ft, and hardboard at 50-70 lb/ft^3. These products may contain from 1 to 30% bounding resin and other additives to improve strength and water resistant properties.

Metric practice

The international system of units (SI), used throughout most of the world, will someday be in the United States. This system is a modern version of the meter-kilogram-second-ampere system that was adopted by international treaty in 1935. SI units are recommended for wood science research, although presently much work is being reported in English measurements. In areas of applied technology such as product sizes, codes and standards, and engineering and structural designs, most work in the United States is still based upon English units. This is expected to change gradually in the next several decades.

During this period of transition wood scientists and technologists need to be able to work and think either in terms of meters and newtons or in feet and pounds. An excellent guide to the proper use of metric units is Standard for Metric Practice, E 380-79, published by the American Society for Testing and Materials. The following comments may aid in understanding metric units commonly encountered in forest products research.

One greater advantages of SI is that only one base unit is used for each physical quantity. Base units include meter (m) for length, second (s) for time, and kilograms (kg) (not gram) for mass. All mechanical properties are than derived from the base units are given special names such as Newton (N) for force, joule (J) for work or energy, and watt (W) for power. The SI units for force, energy, and power are the same regardless of whether the process is mechanical, electrical, chemical, or thermal.

Lecture 28: Mechanical properties – Concepts of stress, strain and flexure; shear – An isotropic nature of wood

The strength and resistance to deformation of a material are referred to as its mechanical properties. Strength is the ability of a material to carry applied loads or forces. Resistance to deformation determines the amount a material is compressed, distorted, or bent under an applied load. Changes in shape that take place instantaneously as a load is applied and are recoverable when the load is removed are termed elastic deformation. If the deformation, on the other hand, develops slowly after the load is applied, it is termed a rheological or time-dependent property.

Mechanical properties are usually the most important characteristics of wood products to be used for structural building materials. Structural application may be defined as any use where mechanical properties are the primary criteria for selection of the material. Structural uses of wood products include floor joists and rafters in wood-frame homes, power line transmission poles, plywood roof sheathing and sub flooring, glue-laminated beams in commercial buildings, particleboard flooring in mobile homes, laminated roof decking in commercial buildings, rails of wood ladders, sailboat masts, and frames of upholstered furniture.

The term strength is often used in a general sense to refer to all mechanical properties. This can lead to confusion, since there are many different types of strength and elastic properties. It is important to be very specific about the type of mechanical property being discussed. To appreciate properties of wood of the various strength properties of woos it is necessary to understand some basic definitions of engineering mechanics.

Concepts of stress, strain, and flexure

Two basic terms used throughout the study of mechanics are stress and strain. Stress is a distributed force or transfer load, such as a column supporting a beam. Stress also occurs internally within a body. Stress is usually expressed in psi (pounds per square inch) or in Pascal (Newtons square meter). One psi equals 6895 Pascal.

When an external force is applied to a member (body), internal stresses result. These stresses distort or deform the shape and size of the body. The change in length per unit of length in the direction of the stress is called the strain. Since strain is expressed in units of length divided by the length, it has no dimensions.

When a load of 8000 lb is applied to the specimen, an internal parallel to the grain stress of 2000 psi is created throughout. The stress is uniformly distributed at all distances from the end; therefore, the total deformation of 0.0072 in. (6.0000-5.9928) is distributed uniformly along the 6-in length. Strain is change in length per unit of length, so in this example, strain is 0.0072 in./6 in. or 0.0012.

Strain will result whenever stress is applied to any solid body. If the stress applied does not exceed a level called the proportional limit, there is a linear relationship between the amount of stress and the resulting strain. Below the proportional limit the ratio of stress to strain, i.e., the slope of the line is a constant value called the modulus of elasticity (MOE). In compression and tensile tests this ratio is sometimes termed Young's Modulus to differentiate it from the MOE as determined by a bending test. Notice that the greater the stress required producing a given strain, i.e., the greater the resistance to deformation, the higher the MOE of the material.

The concept of stress and strain, quit simple in uniaxial tension and compression, is more complex in abeam (bending member). When a beam such as a wood floor joist is bent, the top half is stressed in compression and the bottom half is stressed in tension. The maximum stresses develop at the top and bottom surface of the beam. (Since the tensile and compressive properties of wood are not exactly the same, this assumption is nor strictly true, but it is adequate for engineering purposes. Clear straight-grained wood is stronger in tension than in compression, but lumber containing knots and grain deviation is usually stronger in compression.) No tension or compression stresses occur at the center of a rectangular beam. This center plane, free of compression or tension, is termed the neutral axis.

Since no tensile or compressive stresses develop at the neutral axis of the beam, the length of the neutral axis remains the same when the beam is bent. The top surface of the beam is compressed and the bottom surface is lengthened. The amount of bending at the result of these tensile and compressive strains. The deflection that occurs when a beam is loade4d depends upon the location and magnitude of the load, the length and size of the beam, and the MOE of the material. The higher the MOE the less a beam of a certain size will deflect under a given load.

It is normal to determine the MOE of wood materials by use of a bending test. To do so, the beam is loaded while the load and deflection are measured. From this data the MOE can be calculated by use of the known relationship between the MOE, beam size, span, load, and deflection. This procedure is commonly used to determine the MOE of solid wood, particle, and fiber products. It is a simpler test to conduct and more closely related to most use situations than the MOE (Young's Modulus) as determined from a tensile or compressive test.

For a test specimen loaded by a concentrated load at the center of its span and supported at its ends, the MOE can be calculated from the following formula:

MOE = PL^3 / 48 *ID* (psi)

Where

P = the load in pounds (below the proportional limit)

D = the deflection at midspan in inches resulting from *P*

L = moment of inertia, a function of beam size

= (Width ´ $depth^3$) / 12 for beam with a rectangular cross section; units are $inches^4$.

If the MOE of the beam were known, this same equation could be solved for D to predict the amount of deflection that would result from a concentrated load applied at midspan.

The MOD for wood ranges from about 0.5 ´ 10^6 psi to 2.8 ´ 10^6 psi. The engineer or designer of a structure must balance the MOE against the span, load to be carried, and size of beam to use, and deflection considered to be acceptable. Several examples may better illustrate how the MOE can be calculated from the results of a bending test and how knowledge of it can be useful to the engineer and structural designer.

Shear stress and strain

Shear stress differs from tensile or compression stress in that it tends to make one part of a material slip past the material adjacent to it. Wood is low in shear strength parallel to the grain but extremely high in shear strength across the grain. If an attempt is made to shear wood across the grain, using the device illustrated in figure 10.6 the wood will be crushed rather than sheared.

Shear strength parallel to the grain is important when designing connections between structural elements in a building. Shear stresses also develop internally in wood beams under load. In that situation the various levels or layers in a beam tend to slip horizontally past each other as the beam bends. As this composite beam bends, the ends of the boards slip with respect to each other. If these boards were glued together to form a laminated beam, the slipping would be resisted and the beam would be much stiffer, but as a result shear stresses would develop internally in the beam. Such shear stresses are usually not high enough to be a factor in the engineering of light-frame wood beams such as rafters and floor joists. In larger solid timber beams and laminated beams, however, the shear strength may be the limiting factor in how much load can be safety carried. As for calculating bending stresses, there is a standard formula the designer can use to determine shear stress for a given loading situation.

Another type of shear stress, sometimes termed rolling shear, is important plywood components where veneers of wood are glued with the grain direction in adjacent pieces perpendicular to one another. Rolling shear is a stress that acts in the plane of the plywood panel. It is important in the engineering design of plywood-wood components such as stress-skin floor panels and box beams. In such products, rolling shear is developed at the point that the solid wood member is glued to the plywood.

The wood cells at the glue line tend to roll (or so it can be visualized) when the stress is applied. This must be considered when engineering the components, because the rolling shear strength of wood is less than shear strength parallel to the grain.

Anisotropic nature of wood

A material that has the same mechanical properties in each direction is termed isotropic. Most metals, plastic, and cement products are isotropic. Wood has drastically different properties parallel to the grain as contrasted to the transverse direction, and thus is termed anisotropic (not isotropic). More specifically, wood can be considered as an orthotropic material, i.e., one that exhibits different properties in the direction of three mutually perpendicular axes.

The strength and elastic properties of wood are different in the longitudinal, tangential, and radial directions. However, the properties in the radial and tangential directions usually do not differ greatly. Since it is not possible to predict what the radial-tangential grain orientation of lumber may be when in place (i.e., whether flat-swan or edge grain lumber will be used), a common strength value for the tangential and radial direction is used for engineering purposes. It is referred to as the perpendicular to grain property.

Relationship of strength to specific gravity

The strength of wood is closely correlated with specific gravity (SG). Its possible to make a reasonable good estimate of strength based only upon specific gravity without knowing the species. In some tropical countries, where grading rules for lumber are not highly developed and many species are sawn and used interchangeably, the grading of structural lumber is based primarily upon specific gravity.

Comparative strength of important species

Although it is possible to estimate the strength of wood knowing only the specific gravity, more precise information can be obtained by referring to data collected for the particular species. One of the most widely used sources of such information is a table from the wood handbook (USFPL 1974). Another source of information on properties of U.S. and Canadian species is ASTM D 2555.

Allowable stresses

Although knowledge of the properties of clear defect-free wood may be sufficient to answer many questions, the engineer and wood scientist are more frequently involved in the use of structural lumber and laminated lumber products. These forest products contain knots, slope of grain, and other defects that reduce strength. These strength-reducing characteristics must be reflected in the strength values used for the design of buildings and other wood structures. In addition, the weakening effect of continuous loading (long-term loading), natural variability within the species, effect of temporary overloading, and other uncertainties involved in manufacture and application must also considered. Strength values that have been adjusted to consider all these factors are referred to as allowable stresses.

Lecture 29: Factors affecting strength of clear wood and lumber products

Variability of clear wood strength properties

Strength varies widely within and among species. There is a wide overlapping range of mechanical properties between hardwoods and softwoods used in the United Sates.

Within a species there is variability in clear wood strength, which corresponds to the natural variation in density and to the density-strength relationships for that property. The coefficient of variation of selected strength properties is illustrated in table. These coefficients were derived from tests conducts at the U.S. forest products Laboratory on green specimen.

Factors affecting the strength of clear wood

Moisture Content. As wood dries below the fiber saturation point, most strength and elastic properties increase. It might be expected that this would occur since, as water is removed from the cell wall, the long –chain molecules move closer together and become more tightly bounded. The increase in strength generally begins to be apparent slightly below the fiber saturation point-usually around 25% MC. The relationship between the moisture content and strength properties of white ash as related to green strength.

Time. Aging of wood alone without the deterious effects of microorganisms, high temperature, or continuous loading has little effect on its properties. After centuries, changes do occur, but these are usually the result of environmental factors and not aging *per se*.

Temperature. Most mechanical properties decrease when wood is heated and increases when it is cooled. As long as temperatures do not exceed about 100^0C, there is little permanent loss is strength in the wood. Exposure to high temperatures for long periods can cause a permanent loss of strength. Generally, the high temperature. This point should be considered when extremely high kiln temperatures are used to dry critical structural members.

Fatigue. The fatigue strength of a material is its ability to retain its strength when subjected to repeated severe loading. The beams in a railroad bridge are an example of an application where fatigue strength is important. In this casa the beam are cyclically loaded each time the wheels of a rail car pass. This could occur millions of times in life of a bridge. According to the wood handbook (USFPL 1974), clear straight-grained wood subjected to 2 million cycles of bending will retain 60% of its static strength. Such cycling of the stresses may have a more severe effect when defects such as knots are present in the product. This is particularly true when slope of grain is involved. Most types of materials are subject to fatigue if used under situation of repetitive loading. Only rarely, however, is the fatigue characteristic of wood an important factor in structural design, because most structural wood member are not frequently loaded to the level assumed in the design of the structure.

Exposure to chemicals. The strength of wood may be reduced by exposure to severe acidic or alkaline environments. However, wood is more resistant than steel to acidic conditions. Chemical fertilizer and highway salt storage buildings are often built from wood because of its ability to withstand corrosion and deterioration when in contact with chemicals.

Factors affecting the strength of lumber products

The strength of wood varies continuously with the moisture content below about 25%. It would be very difficult, however, for designers to consider the variable moisture content and the induced variation of strength of wood products in the design of a wood structure. To avoid this complication, the allowable stresses ate established at fixed moisture content. Therefore, the allowable stresses (strength) of lumber, glue-laminated beams, and plywood are considered to be constant below some limiting moisture content. This limits (maximum moisture content) is 19% for softwood lumber and 16% for plywood and glue-laminated beams. Allowable stresses must be reduced when the moisture content limit is exceeded. The reduction made when these moisture content limits are exceeded depends upon the product and the specific strength property involved. Reductions range from 3 to 40%.

In addition to the factors that affect the strength of the clear wood itself, three tree or growth characteristics are very important to the strength of lumber. The effect if these defects are considered when deriving allowable stresses.

Knots. Knots are the most common defect that reduces the strength of lumber. The effect of a knot may in many cases be considered equivalent to that of a hole. In other cases the knot may have a greater effect than a drilled hole because of the distortion in the grain that accompanies it. The amount that a knot reduces strength depends not only upon the size of the knot but on its location in the piece. A knot on the top or bottom edge of a beam is much more severe than the same knot located near the centerline. Recall that the maximum bending stresses occur on the top and bottom edges of a beam. Knots on the bottom edge of a beam are more serious than if placed on compressive strength. A good carpenter will inspect floor joists and place the largest knots on the top edge, not on the bottom.

Decay. Decay is generally prohibited in grades of lumber used for structural purpose (some localized types are permitted) because it is impossible with many types to estimate by visual inspection the extent to which decay has weakened the piece. By the time it is apparent, the loss in strength may static strength. Figure 10.14 shows the zone of fracture from two toughness specimen on the left is normal, and the heartwood specimen on the right has a slight amount of decay. The splinter-free fracture on the right (brash failure) is typical of decay wood. In this case the scaffold plank from which the specimen on the right was cut had its toughness reduced 85% by decay but looked normal to the user until failure occurred. It is important to be alert decay is occasionally encountered.

Some grades of dimension lumber permit blue stein to be present. Blue stain fungi do not cause a weakening of the wood, since they live upon the food materials in the cell lumber, not upon the cell wall substance. One problem encountered with stain, however, is that it can occur in combination with decay and make the decay difficult to detect.

Slope of the grain. Slope of the grain in lumber is express as the length in inches through which there is a 1-in deviation in the grain. The first two examples show how slope of the grain can result from the way the lumber is cut from the log. Slope of the grain of this type is fairly easy to detect in a species that has distinct growth rings. Slope can also result from logs containing spiral grain. In this case, even though the may be quit serious. The best way to visually detect this type of grain derivation is to look at resin checks, mineral stains, or other minor defects that tend to be oriented with the cells.

Lecture 30: Silvicultural practices and wood quality

The practice of caring for and cultivating forest trees is known as silviculture; this activity is one of the responsibilities of the forester, whose objective is usually to accelerate growth. One method of increasing growth rate involves reduction of competition for available sunlight, nutrients and water, which can be achieved through such practices as control of under story vegetation, thinning, or control of spacing between seedlings at the time of planting. Another approach is to add nutrients and water by fertilizing and irrigating. Growth rate of new forest stands can also be stimulated through genetic selection of seed or planting stock. Tremendous increases over natural growth rates are possible. Tables contain data representative of a number of trials conducted to determine the effect of silvicultural treatments upon yield.

Growth manipulation and wood quality

The amount of space in which a tree grows is an extremely important determinate of growth rate and thus of wood properties. The spacing is tween trees and the extent of surrounding vegetation defines the degree of competition for such critical growth elements as nutrients, water, and sunlight. When competition is slight, crowns and root systems can develop fully because critical elements are not limiting factors. On the other hand, when crowding occurs, trees must compete intensely for element needed for growth. For example, considered sunlight-tolerant seedlings that have taken root in a clear-cut area. They first must compete with weeds and shrubs. Young trees that develop quickly have the best chance for survival. Others may remain stunted and eventually die. Trees that do become established face a new battle-with each other. If a large number of trees survive the first stage of competition with other vegetation, crown development will quickly fill the open space between trees. As competition for sunlight, nutrient, and moisture intensifies, growth of the entire stand slows. Despite the slow growth, slight differences in the rate of height extension will eventually begin to favor a few trees, giving them a significant advantage over their neighbors. The slight advantage is magnified as success in competition for sunlight improves growth rate even more. Suppressed trees are left further and further behind, and the weakest will fail. Even the trees that grow fastest lose branches through natural pruning caused by limited light from lateral crowding; such crowding may even diminish the capacity for wood production.

The scenario described above serves to illustrate one role of the forester, who can manage the forest to minimize the effects of competition and thus maximize the rate of growth. For example, fertilization and irrigation can be applied so that critical elements are present even in densely stocked stands. Another approach to control of competition levels is manipulation of the stand to ensure that it is in balance with naturally occurring growth elements.

Spacing trees at planting time. Assuming that nutrient and water availability limited and maximum sunlight is desirable for the growth, widely spaced trees will grow faster than crowded ones. When this relationship is combined with the knowledge that growth rate in some tree species is related to wood density, and properties such as strength and dimensional stability are closely correlated with wood density, it is easy to see how spacing of trees can affect wood properties.

Thinning. Tree released when surround trees are removed by thinning or partial cutting respond to the more open environment by stimulated crown development and formation of wider growth rings along the bole. Effects upon growth are often dramatic. Only study of slash pine in Georgia indicated the benefits of thinning. A yield of 28 cords / ace (251 m^3 / ha) was obtained at age 23 for a plot that had been thinned at age 3, as compared to a yield of less than 5 cords / acre (45 m^3 / ha) in an adjacent plot. In addition to increased yield at harvest, another benefit of periodic thinning is that material normally lost through natural mortality is salvaged.

Fertilization and irrigation. Forestry practices discussed thus far-spacing tree at planting time, thinning, and control of under story vegetation-are designed t o maximize potential for growth, given the limitations of a particular site. Another strategy that can be used to achieve increased rates of growth involves modification of the site through such cultural practices as fertilization, irrigation, and combinations of the two. The objective here is to improve site quality. Thinning, for example, reduce competition for available nutrients, water, and sunlight and concentrates growth n fewer stems. Application of fertilizer, on the other hand, simulates growth by increasing the availability of nutrients generally, thereby stimulating crown development and the size of photosynthesizing surfaces. Both the size and number of leaves in the crown are affected. Because growth of all vegetation on the site is stimulated, it is usually necessary to employ thinning and/ or under story control in conjunction with a fertilization program. Use of fertilizer may serve to improve the growth potential of an already production site of bring a nonproductive or nutrient-deficient site into productivity. Similarly, irrigation can be used on moisture-deficient sites to improve growth potential. An example of the effects of fertilization and irrigation is presented in table.

Effects of fertilization on wood quality. Foresters and users of wood have long been concerned over the effects of fertilizer and water application upon wood quality. Larson (1973) lent some perspective to this concern, pointing out that these techniques simply improve the site. He went on to say that all too often, fast-growth trees from the better sites are readily accepted whereas the quality of similar wood produced by improved growth conditions is questioned.

Changes in wood properties resulting from fertilization or irrigation induced fast growth are similar to those occurring as a result of increased growth rate associated to the general rules given earlier: fast growth may cause a density increase in ring-porous hardwoods, and a variable effect upon density in other woods.

Effects of fast growth on product properties. A major consideration in the use of intensively growth wood is how this material affects properties of products. In solid wood products, strength is important. Rapidly grown wood has been evaluated for this quality by several investigators. They found that although some aspects are diminished by accelerated growth, others are improved.

Pruning. Pruning is the practice of trimming branches from chosen portion s of standing trees to reduce the occurrence of knots in subsequently produced wood. When a branch is removed from the bole of a tree, the sheath of new growth will eventually cover the stub, producing knot-free wood thereafter. Such wood has markedly higher value than knotty wood for solid wood products and veneer because of increased strength and improved appearance. Considered improvements in lumber grade and veneer grade yield can result from pruning. It is employed only on a limited basis, however, because of the high cost.

Genetic improvement and wood quality

The field of genetics offers perhaps the greatest potential for improvement of wood yield and quality in the future. Over the past several decades, efforts in this area have concentrated on identifying trees in the natural forest that exhibit superior growth or form. Seeds have been collected from these trees ad planted in nurseries to raise new generations of trees having many of the same characteristics. Vegetative propagation has also been employed in reproducing clones of certain species. A relatively recent development is the perfection of the technique of tissue culture, whereby a medium and grown to a small plantlet, which is then transferred to a nursery. Recent selection work has involved crossbreeding of selected tree progeny to develop trees that combine the best features of several superior trees. Wood quality characteristics are among the feature upon which selection is based.

Genetic selection of both hardwoods and softwoods has resulted in development of fast-growing trees that produce wood of normal to higher than normal density. It has been shows to be possible to breed for log fibers, high proportions of fibers relative to vessels, uniform density, and amount of heartwood extractives, low proportions of lignin and juvenile wood, and minimal branch development. Even the tendency to produce spiral grain has been shown to be heritable. It also been demonstrated that genetic selection can be used to reduce bark thickness, the number of stone cells, and other undesirable elements in the bark.

Lecture 32, 33 and 34: Plywood, particle board, hard board, fibre board and composite products

Plywood

Plywood consists of thin sheets or veneers of wood which are glued together in a way that the grain of each veneer is at right angles to that of the adjacent veneer. This is also referred to as cross-banding and can be differentiated from laminated wood in which the grains of successive layers of veneers are parallel.

The art of producing and using veneers is not new to the human race with the first one having being produced in Egypt around 3000BC. They were relatively small pieces of valuable wood that were selected for the manufacture of costly and decorative furniture for the royalty. The small veneers produced by hand were combined with inferior wood on the inside and used for special items. The adhesives used by them have not been fully understood.

During the centuries that followed the technique of making and using plywood was lost to be started again in the eighteenth century by the Germans. Machine production of veneers began in 1834 in France though it took considerable time to develop it for commercial use. Plywood has now come to be widely used in the modern world.

Parts

Various parts of plywood are:

a) Faces: Faces of face and back is the term used for denoting the outer piles or members in a plywood panel.

b) Core: The centre ply or member is known as the core. It may comprise of veneer, timber or various combinations of veneer and timer.

c) Cross bands: In its simplest form, plywood consists of an odd number of piles. In it are panels having more than three piles the layers between the core and face or back are referred to as cross bands.

Benefits

The main advantages of plywood over other forms of woods and even solid wood are many. These have been outlined in brief in the following points:

1. It has dimensional stability or in other words, its shape and size will not usually change with time. Even if there is shrinkage or swelling, these will be less than the radial or tangential changes in solid wood.
2. The strength properties of plywood are distributed in both directions.
3. It has little or more less no tendency to split.
4. It is also possible to make plywood in large sizes.
5. Special glues are used for making plywood resistant to the action of water even if it is soaked or exposed for considerable periods of time.
6. Plywood can be moulded into different shapes and it will retain these shapes for long periods of time.

Manufacture

The process involved in the manufacture of plywood is long and involves many stages. This is usually done in plywood manufacturing units which function as large industries. Veneering or the manufacture of veneers is the first step involved in the manufacture of plywood. Veneers are also used for other specialized purpose than for the manufacture of plywood. These include blackboard, flush door, veneered particle board and laminated, compregnated and impregnated woods. Various processes involved in the manufacture of plywood including veneering have been discussed in the following text:

1. Manufacture of veneers

Veneers can be manufactured on a commercial scale from as many as 87 species which include a large number of hardwoods and a limited number of softwoods. These include both for making plywood and also decorative veneers. The properties of logs suited for conversion into veneers are

- Ø cylindrical
- Ø straight grained
- Ø of suitable dimensions

Different stages in the manufacture of veneers are:

a) Log conditioning

The log is conditioned or softened. It is brought to the manufacturing unit in a green condition and is maintained as such spray stacking or immersion under water in log ponds. This helps in the following manner:

(i) The logs are protected from drying degrades.

(ii) The risk of attack by fungi, particularly staining fungi is minimized.

(iii) It facilitates the steaming of the logs before peeling or slicing.

(iv) The logs are cleaned and dust is removed from them.

(v) The colour of the wood is improved and this is desirable particularly when the veneers are to the used for decorative end uses.

(vi) Moisture is uniformly distributed throughout the log.

Softening is the next phase in conditioning of the log for the manufacture of veneers. This is done by boiling or steaming. The optimum temperatures for boiling or steaming depends on

Ø Quality of the cutting desired.

Ø Species

Ø Specific gravity, presence of hard knots, tendency for end splitting.

Ø Colour changes in the wood.

The duration of softening treatment is influenced by species, diameter and length of the log, moisture content and other properties of the wood before steaming. The

logs are boiled or steamed in pits or vats either directly or indirectly. The former is not preferred as it increases the development of cracks and checks. In indirect steaming, these risks are avoided though it is costly the cost of veneer manufacture increases.

b) Cutting

This is the phase in the manufacture of veneers and it brings about the first major change in the form of the wood. It involves the following:

(i) Rotary peeling

In rotary peeling, the log is mounted on the veneer lathe and revolved against the knife fixed over the entire length of the log. During this process, two actions may take place either separately or simultaneously

- Ø Cutting
- Ø Splitting

They usually occur together and the latter causes under able effects on the veneer. The wood tends to split along the grain as soon as the cutting action begins. Splitting may take place in advance of the knife edge. In this way, vertical cracks may form which reduce the smoothness of the veneer. These are known as lathe checks.

As rotary peeling proceeds, the veneer is peeled from the round log in a tangential direction in a spiral with equidistant windings. The distance between the singular windings is equal to the thickness of the veneers.

(ii) Slicing

Strips of veneer are cut in a straight line action in this process. The slicers may either be horizontally or vertically oriented. Proper positioning and alignment of the knife and nose bar on either of these slicers is important for cutting veneers of good quality.

The quality of veneer obtained from slicing depends on:

- Ø Species
- Ø Horizontal openings or gap.

(iii) Semi-rotary cutting

Semi-rotary cutting machines are also used for the production of sliced veneer. Semi-rotary veneer is produced on a rotary veneer lathe. It is a combination of clicing and rotary peeling and is primarily used for producing decorative veneers with figures varying from quarter to tangential cut throughout the one veneer strip.

c) Clipping

This process involves jointing and splicing of the veneers. The defects are cut out and joined by gluing on a splicer. Some too narrow or small veneers may be produced and these may be used by trimming them accurately on a jointer. They are glued perfectly together.

d) Drying

Veneers which have been freshly cut are usually very wet and not fit for gluing into plywood. Many glues are ineffective if the veneers are wet. In that condition, they are also prone to attack by fungi and insect pests.

Various types of dryers in common use are

- Ø Drying sheds.
- Ø Drying kilns
- Ø Channel dryers.
- Ø Roller dryers.
- Ø Endless belt dryers.
- Ø High frequency dryers

The jet dryer is the most effective dryer in use on a commercial basis. It involves air at very high temperatures which is blasted on the surface of the veneer at high velocities. Its advantages are

- Ø The rate of drying is faster
- Ø Operation are simple
- Ø Less energy is consumed.
- Ø The material is saved due to less shrinkage. The

moisture content of the dried veneer is between 8 to 12%

e) Glue spreading

After the veneers have been dried the processes involved in the manufacture of plywood begin. When the commercial manufacture of plywood on a commercial scale first began, the adhesive or glue was applied with brushes. The method was both cumbersome and the quality of the product was not very high. In later years, as the demand for plywood went up, mechanical spreaders for gluing were introduced. These consist 2 to 4 rollers which aid in distributing the adhesive evenly over the surface of the veneer. Pressure is applied on the veneers by the mechanical roller.

Incase of three veneer ply, the glue is applied and spread only on the core while in multi-ply, each alternate ply is glued on both sides. Glue is not applied to the core and face plies. Precautions need to be taken while applying and spreading the adhesive or glue. These include:

- Ø The veneers should be fully dry, carefully peeled and all impurities removed from their surface.
- Ø The adhesive must be of the correct concentration and viscosity for proper gluing and spreading.
- Ø The pressure applied in the mechanical rollers must be of the desired level.

- Ø The glue that has been spread should not harden before full pressure has been applied.

f) Assembly

After the glue has been spread, the veneers are assembled into a pack of the required thickness. The number of plies in the plywood may be 3, 5, 7, 9, 11 etc. with the grains of the adjacent veneers being perpendicular to each other.

When only three plies are being assembled, the central ply is best made equal in thickness to the combined thickness of the two oute plies. In this way, the plywood would more or less be of the same tensile strength in the longitudinal and transverse directions. The plywood is stiffer in bending when the bending stress is applied normal to the surface and width of the span length is parallel to the face plies.

Plywood of three plies of equal thickness may be assembled when it has to be used for aircraft and some other structural uses. This assemble increases the flexibility obtained transverse to the grain of the outer plies. In this way, the plywood can be bent to fit curved surfaces without unduly stressing the sheet which would otherwise be liable to crack.

The general guidelines for assembling plywood are:

(i) The thickness of any one veneer should not be more than three times the thickness for any other veneer.

(ii) The sum of the thickness of the veneers in one direction is more or less equal to the thickness of the veneers at right angles to all.

(iii) Veneers equidistant from the centre or core veneer should be of equal thickness and of the same thickness

g) Pressing

After the plies have been assembled as per the desired specification, the plywood is pressed. Pressing is affected by the following

- Ø Type of adhesive that has been used.
- Ø Thickness of the pack or assembly.
- Ø Species of wood.

The following two types of pressing may be done:

i) Hot pressing

The plywood assembly is placed between the heated plates of the hot press under atmospheric conditions. Hot pressing helps in the following functions

- Ø The adhesive is also spread to the un spread portions of the veneers.
- Ø Developing strength in the individual panels.
- Ø Decreasing the degree of degrade.

The time required for hot pressing depends on the thickness of the panels. The usual temperature of which pressing is done is 100 degrees C while higher temperatures may be needed in some cases

Density of wood	Pressure in kg per square cms
Low	10.5
Medium	14.0
High	17.5

(ii) Cold pressing

In this form of pressing, the assembled plywood is pressed without any heat being applied. This is done in a cold press and best results are obtained when they are pressed immediately after the glue has been spread. A number of assemblies are piled with flat caulk boards separating into small groups. Rigid and smooth press boards are put on the top and bottom of this stack of panels and then the assembly is place under pressure. The application of pressure is done by hydraulic press and the panels being pressed are clamped in position. The level of pressure required for hot pressing is also enough for cold pressing.

h) Conditioning

Pressing is likely to disturb the distribution of moisture in the plywood. Moisture may be produced near the glue lines as t result of the reaction between the adhesive and wood as the former is absorbed. In the process, the veneers are heated to above the boiling point of water and this changes the distribution of moisture. Some of the moisture originally present in the veneer may be given off as steam when the hot pressure is released. This disbalance in the moisture may lead to problems like

- Ø Cracking and splitting of the face veneers.
- Ø Buckling of the panels.

It is thus necessary that the pressed plywood is conditioned or reasoned with regards to its moisture distribution. This may be done by adding surface moisture and allowing time for the moisture locked up near the glue line to adequately rediffuse.

After pressing the sheets of plywood are sprayed or dipped for a few seconds in water and then close piled for diffusion of moisture. This brings the moisture distribution in the plywood to equilibrium and problems of splitting, cracking and buckling are avoided.

i) Sizing or trimming

The plywood prepared from the above process is allowed to cool in pack. It is brought to equilibrium with regard to temperature and moisture content. Then are trimmed to standard sizes.

Double circular saws which trim two parallel edges in a single operation are used for trimming. The same machine is used for trimming the third and fourth edges by adjusting the distance between the saws. Heavy duty machines may be used for trimming and sizing products such as batten boards, flush boards etc.

j) Sanding or scraping

This process involves the sanding or scraping of surface imperfections on the plywood. The plywood is passed through machines known as sanders or scrapers. They remove the surface imperfections and give the desired finish to the product. The following machines may be used for this purpose:

- Ø Drum sander
- Ø Belt sander
- Ø Wide belt sander
- Ø Scraper

USES

The main uses of plywood are:

1. Interior walls partitions in buildings, shops, offices and factories.
2. Floors, doors, kitchen fitting, cabinets and fitments.
3. Shuttering for concrete works.

4. Interior fittings of railway carriages and even aircraft.
5. Cabinets of radios and television sets.
6. Sports goods such as table tennis bats and laminated skis.
7. Tea chests and packing cases.
8. Parts of furniture.

LAMINATED WOOD

Laminated wood is made up of layers of wood that are laid in a way that the grains of successive layers are parallel. These are glued or otherwise fixed in a way that they function as a specific unit. The individual layers are known as laminate and may vary with

- Ø Species
- Ø Number
- Ø Size, shape and thickness

BENEFITS

The main advantages or benefits of laminated wood are:

a) They do not vary in dimensions under normal conditions of dry use.

b) It is easy to produce laminated structural members in a short time as compared to solid wood.

c) The utilization of all sizes of laminated wood can be readily done.

d) Laminated wood can be produced in curved and other special shapes.

e) Mixed grades and species can be used in the same structural member.

LIMITATIONS

On the other hand there are a number of limiting factors in the widespread use of laminated wood. These are:

a) The cost of production of laminated wood is fairly high as compared to solid wood.

b) It is difficult to transport laminated wood in bulk and in large sizes over long distances as it has to be manufactured in factories

MANUFACTURE

The following process is involved in the manufacture of laminated wood:

1) The laminates are in the form of thin veneers or boards depending on the purpose for which the material is to be used. These are cut into uniform width and length. Those having short lengths are end joined and glued to the desired length. Machines may also be used for cutting.
2) The laminate are properly cleaned and then arranged in the required order after which they are fed into a machine for spreading the glue. This is known as the glue spreader and it spreads the adhesive properly.
3) After the glue has been spread, the assembly is placed on a jig and pressure is applied with the help of clamps that are fitted at regular intervals.
4) These are held in place till the glue has set and is cured. Curved assembles may be made on the appropriate jig.
5) The quantum to pressure applied should be such that there is close contact of the wood surfaces and they can be held in position till the glue has set.

Gluing is much more advantageous than other methods of fastening. It is possible to obtain cent per strength of clear, straight grained lumber through gluing as compared to a maximum of 85% in the case of other methods of fastenings.

USES

The main uses to which laminated wood may be put are:

a) Parts of furniture.
b) Cores of veneered panels.
c) In construction of special buildings such as aircraft hangars auditoria, exhibition halls, gymnasiums, theatres and warehouses.
d) Sports goods, skis and diving boards.
e) Boards
f) Flooring
g) Fittings in ships, boats and even aircraft
h) Propellers of aeroplanes

COREBOARDS

Core boards are made up of a core formed by strips of wood of various dimensions that are bonded together by glues between veneers. They are light in weight and their cost is relatively less than other forms of composite wood given the same functions and requisites.

TYPES

Different types of core boards that may be used for special purposes are:

1. Batten board

In this type of core board, the core is comprised of strips of wood, each having a width of less than 7.5 cms. They are assembled in a way that they form a slab which in turn is glued between two or more strips with the direction of the grains of the core strips being at right angles to that of the adjacent veneers.

2. Block board

In this type of core board, the core is comprised of strips of wood, each having a width of less than 2.5 cms. They are assembled or laid in a way that they form a slab. This is turn is glued between two or more outer veneers with the direction of the grains of the core strips running at right angles to that of the adjacent veneers.

3. Lamin board

In this type of core board, the core is comprised of strips of wood, each having a width of less than 7mm. They are glued together face to face in a way that they form a slab. The slab in turn is glued between two or more outer veneers in a way that the direction of the grains of the core strips is at right angles to that of the adjacent veneers.

USES

Core boards are finding wide use due to their low weight, better stability, good, acoustics and heat insulating properties. They are used for:

a) Doors

b) Partitions

c) Ceilings

SANDWICH BOARDS

These are built up boards in which the core is of a light material being faced on both sides with a relatively thin layer of mater with high strength properties.

CONSTITUENTS

Composites of different materials are bonded together to form sandwich boards. In this way they combine together to have properties that individual they would not posses. Their constituents are

1. Skins

These are the two thin facings made up of a strong and dense material. They are the main load bearing constituents of sandwich boards. Their constitution determines the stiffness, stability and strength of the sandwich board. The materials used for facings include plywood, single veneers or plywood overlaid with a resinous treated paper, hard words or even metal.

2. Core

The core is made up of weaker and lighter material. Its function is to

- Separate and stabilize the thin facings.
- Carry shearing loads.

The assembly of core and skins combines to have fairly high strength. Proper selection of material for the core and strips can provide sandwich boards of specifically desired properties. Light weight materials are used as the core. These include balsa wood, rubber or plastic foams and formed sheets of cloth, metal or paper.

USES

Properties of the facings and core and also the ratio of the thickness of the core to that of the facings have a bearing on the structural properties of the sandwich boards. The main uses of these boards are:

- In aircraft parts.
- Motor boats
- Table tops
- Flush doors
- Containers
- Landing mats

FIBREBOARDS

Fibre boards are made from the fibres of wood or other lingo-cellulosic materials. It involves the difrabration or depulping of the fibrous material. They are then interfelted into a mat and then consolidated into a board by application of pressure and heat. Some mechanical properties of such boards may be improved by using bonding agents like adhesives.

TYPES

On basis of their density and the specific purpose for which they may be used, fibre boards may be of the following types

1. Hardboard
   - Ø Semi-hardboard
   - Ø Hardboard
   - Ø Super hardboard
2. Wallboard
3. Soft board
4. Insulation board
5. Medium density board

MANUFACTURE

The following is a brief description of various processes involved in the manufacture of fibreboards. While selecting the raw material for the manufacture of fibreboards, the aim is to use cheap and otherwise worthless fibrous residues. Different raw materials that may be used for the production of fibreboards are:

a) Pulpwood and fuelwood
b) Inferior quality wood
c) Wood that is not even used by saw mills, veneer plants and pulp factories.
d) Thinnings or small logs
e) Residues from saw mills and veneer plants
f) Agricultural wastes
g) Waste paper
h) Pulp from saw dust
i) Bark, if it is not detrimental to the manufacture of fibreboards.

j) Grasses and shrubs

Preparation of raw material:

The raw material is prepared for production of these boards by the following steps:

(i) The raw material which may be in the form of solid wood may be converted into small chips. For this purpose, disc chippers are brought into use.

(ii) The raw material is screened and the larger sizes are further chipped for obtaining chips of more or less the same size.

(iii) The chips are passed through a magnetic field for removing any iron particles that may be mixed in it.

PARTICLE BOARDS

These are boards comprised of fragments of woods or other lignocellulosic materials that are bonded by organic binders with the help of heat and pressure. They differ from fibreboards as the basic material used to make particle boards is small chips or flakes or splinters that are held together by organic bonding material. On the other hand, pulp or fibrous material is used for making fibreboards.

TYPES

Various types of particle boards are:

1. Based on density:
    a) Low density boards with specific gravity varying from 0.2 to 0.4
    b) Medium density boards with specific gravity varying from 0.4 to 0.8
    c) High density boards with specific gravity varying from 0.8 to 1.2
2. Based on constituents:
    a) Chip board made primarily form chips.
    b) Flake board made mainly from flakes of wood.
    c) Shaving board made primarily form wood shavings.
3. Based on end use:
    a) Building board
    b) Insulating board
    c) Wall board

MANUFACTURE

The following is a brief discussion on the manufacture of particle boards.

Raw material

Wood and/or other lingo-cellulosic materials are the main raw materials for the manufacture of particle boards. They may be in the following forms

a) Chips
b) Flakes
c) Saw dust
d) Shavings
e) Splinter

(i) Wood waste, residues from saw mills, wood working factories and plywood factories
(ii) Lops and tops of felled trees
(iii) Fuelwood
(iv) Secondary species of low economic value.
(v) Agricultural residues

Processes

Various processes involved in the manufacture of particle boards are:

1) Debarking: The bark of wood that is being used for particle boards manufacture is removes, usually manually or with the help of hydraulic or mechanical debarking machines.
2) Particle preparation: The raw material is converted into particles of the desired dimensions. The particles may be flakes, granules, shaving or splinters.
3) Screening: The particles are screened so that only those of uniform size are used in preparation of the particle board.
4) Drying: The particles are dried before further processing is done.
5) Resin blending: Resins are added to the particles in a resin blender. Some other additives which may be added include paraffin wax emulsion.
6) Formation: After resin blending, the particle board is formed into a mat like structure. This may be done by:

a) Batch formation

b) Continuous formation

7. Pressing: This involves pressing the particle boards. Pre pressing is generally done in a single opening cold press. It makes the particle mat more compact. After this hot pressing is carried out by:

   a) Flat platen process

   b) Extrusion pressing

8. Finishing: This is the last stage in the particle board manufacturing process. It includes:

   a) Sanding

   b) Painting, varnishing, polishing and printing

USES

Particle boards are used for the following purposes:

a) Interior fittings in buildings

b) Furniture

c) Ceilings