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FR 10

Wood Science and Technology

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Department of Forestry and Environmental Science
School of Earth and Environmental Science

Uttarakhand Open University
Haldwani, Nainital (U.K.)

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Board of Studies

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Unit Structure

1.0 Learning objectives.

After studying this unit you will be able to understand about:

- Introduction to wood
- Definition of wood
- History of Wood use
- Structure and formation of wood
- kinds of wood: hardwood, softwood, bamboos and canes

1.1 Introduction

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

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

1.2 History of Wood Use

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

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

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

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

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

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

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

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

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

Timber or Lumber is nothing but wood used for building and other engineering purposes. It is obtained from the trunk of trees. Trees give different types of timber which can be used for different kinds of works.

1.3 Structure and Formation of Wood

Trees are divided into two broad classes, usually referred to as hardwoods and softwoods. This can be confusing, because the wood of some softwoods are harder than that of many hardwoods. For example, Scots pine and Douglas-fir are softwoods, but their wood is harder than that of poplar or mahogany, which is classed as hardwoods.

Hardwood: Botanically, the hardwoods are angiosperm, which refers to the fact that the seeds are enclosed in the ovary of the flower. Anatomically, hardwoods are porous in that they contain vessel cells (pores in the transverse section) that form tubes for transporting water or sap in the tree. Typically, hardwoods have broad leaves that, in temperate and semi-tropical regions are shed in winter.

Softwood: Botanically, softwoods are gymnosperm, which refers to the fact that the seeds are naked (not enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements. Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years; though a few of them such as the larches drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

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

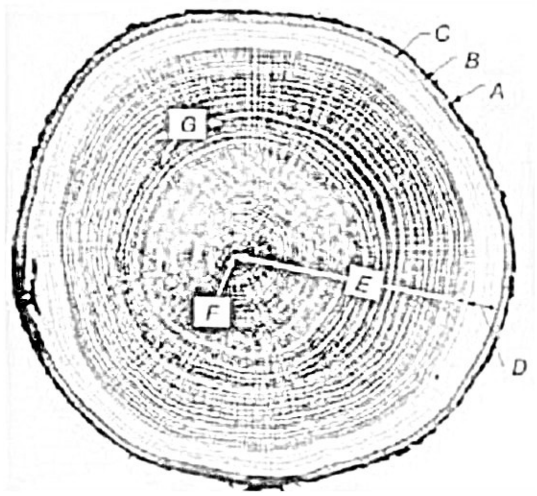

Fig 1. Cross section of white oak tree trunk. A. Outer bark. B. Inner bark. C. Cambium. D. Sapwood. E. Heartwood. F. Pith. G. Wood rays.

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

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis. The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses.

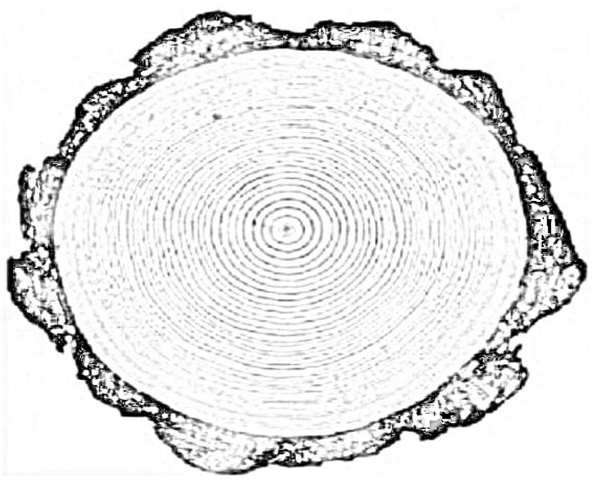

Fig 2. Cross section of ponderosa pine log showing growth rings. Light bands are early wood and dark bands are latewood. A growth ring is composed of an inner earlywood zone and an outer latewood zone. (Forest Products Laboratory).

These components are laid down in layers to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (m) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. During growth of the tree, the cellulose molecules are arranged into ordered strands, called fibrils, which in turn are organized into the larger structural elements that make up the cell walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, low- molecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood (see

Cellulose and Pulp). Hemicelluloses play an important role in fiber-to-fiber bonding in papermaking.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propyl phenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone. The xylem of softwoods is relatively simple, usually comprising only three or four kinds of cells, predominantly fibers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance. Most of the wood of softwoods (90-95%) is comprised of longitudinal tracheids (fibers). These are long, slender cells, about 100 times as long as they are wide, averaging about 3 to 4 mm in length, rectangular in cross section, closed at the ends, with bordered pits primarily on the radial face. A small portion of the wood of softwoods is longitudinal parenchyma, cells shaped like the fibers, but usually divided into short lengths.

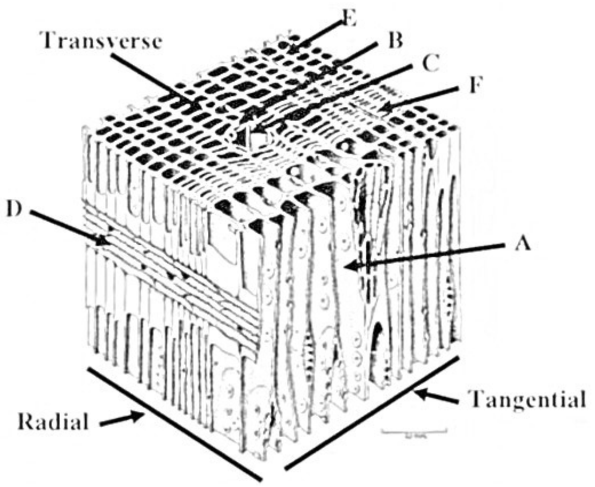

Figure 3. Three-dimensional representation of softwood. A. Longtitudinal tracheid. B. Longtitudinal parenchyma. C. Resin canal. D. Wood ray. E. Earlywood. F. Latewood. (Forest Products Laboratory).

Some softwood (*Pinus, Picea, Larix,* and a few others) contain resin canals, which are intercellular spaces in the longitudinal direction surrounded by specialized cells that secrete resin. Radial structures in softwoods are usually wood rays a few cells thick, composed of either ray tracheids or ray parenchyma. Figure 3 shows a three dimensional representation of softwood illustrating how these structures may be seen on the transverse, radial, and tangential surfaces of the wood.

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

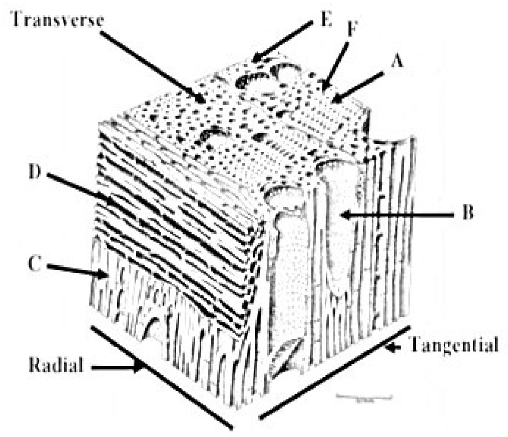

Fig 4. Three-dimensional representation of hardwood. A. Fiber. B. Vessel. C. Longtitudinal parenchyma. D. Ray parenchyma. E. Earlywood. F. Latewood. (Forest Products Laboratory).

1.4 Bamboos

Bamboos are tall arborescent (tree like) woody grasses; belong to the family Graminae. Most of the bamboos are hollow, often gregarious in habit. Growth of bamboos is very fast. Some common characteristics of bamboos – straightness, being light though hard, easy to split, availability in various sizes, easy propagation – have added to their utility. Common uses are in house construction, masts, cart shafts, basket making, furniture etc. Propagation and management practices of bamboo may be seen in Lesson 4 of "Silviculture of Trees and Silviculture Systems".

Bamboo is widely used across the world for everything from food and medicine to furniture and scaffolding. It tends to grow in a "belt" running through tropical, subtropical and temperate climates around the globe, and up to 3500m altitude. There are more than 1000 species of bamboo in total, broken into two "groups": herbaceous and woody. The former tend to be very small-diameter and resemble grasses, while the latter are the more familiar large diameter ones that can be used for construction and will be the focus of this Technical Note Series. Woody bamboos can be broadly divided into two groups: clumping and running (Trujillo, 2007). Clumping species sprout their new shoots close to the base of the existing culm, while running species may send their shoots as far out as 30m from an existing culm. Woody bamboo diameters vary from 10mm to 200mm, wall thicknesses from <10% of the external diameter to completely solid, and culm heights can exceed 30m[3].

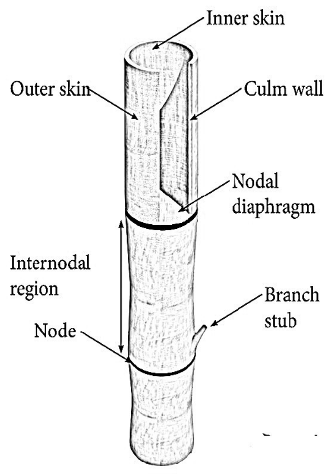

Figure 2: Structure of a bamboo culm.

The stem, or culm, is segmented by nodes, the bands at regular intervals. The node manifests as a diaphragm to the interior of the culm which helps to prevent buckling of the walls. The space between nodes is known as the internode (Figure 2); the internodal spacing varies along the culm and between species. Within the internodes, cellulose fibres and vascular bundles run parallel to the length of the culm (Liese, 1998), while at the nodes they intersect, with some of them crossing into the nodal diaphragm (Trujillo, 2007). For natural efficiency, these fibres are roughly six times more numerous on the outside of the culm compared to the inside making it both denser and stronger towards the outside (Janssen, 2000).

As in timber, a weak matrix called parenchyma (which is primarily made of lignin) holds these strong fibres transversely together (Liese, 1998), and it is this material which normally governs the strength of a bamboo culm, especially in tension perpendicular to the fibres and in shear. Providing a protective shell around the cellulose is a tough silica layer about 0.25mm thick, which is relatively impermeable (Janssen, 2000). The dry density of bamboo is typically about 500-800kg/m^3, although this can vary both along the length of the culm and as noted through the thickness of the wall.

1.5 Canes

Canes (rattans) form one of the most useful forest resources used in manufacture of a wide variety of furniture and handicraft items. In India, canes distributed in Peninsular India, north-eastern parts of India and Andaman and Nicobar Islands are represented by about 60 species under four genera Calamus, Daemonorops, Korthalsia and Plectocomia. Kerala has 15 species of canes belonging to the genus Calamus. A survey conducted with industrial units and artisans in Kerala revealed that there is not enough raw material supply from the forests of Kerala.

A considerable quantity of the raw material is procured from the north-eastern states and Andaman Nicobar Islands. Hence, resource enhancement is urgently needed for which identification of the species used by industries is essential. The sustainable exploitation of the cane resources also is hindered by the lack of a sound taxonomic base.

Sl No.	Scientific name	Vernacular (Malayalam) name
1.	*Calamus brandisii Becc*	*Cheru-chooral*
2.	*C. delessertianus Becc.*	*Ottamoodan, Pacha chural*
3.	*C. gamblei Becc.*	*Pacha chural, Tannikodi, Narikodi*
4.	*C. hookerianus Becc.*	*Velichural, Kallan, Kakkachural, Vanthal, Chentakara*
5.	*C. pseudotenuis Becc. ex. Becc. & Hook. f.*	*Chural*
6.	*C. rotang Linn*	*Cheruchural*
7.	*C. thwaitesii Becc. & Hook .f.*	*Pannichural, Thadiyanchural, Vandichural, Anachural*
8.	*C. travancoricus Bedd. ex. Becc. & Hook. F.*	*Arichooral*
9.	*C. vattayila Renuka*	*Vattayila, Ottaman*

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3. Janssen, J. (2000) INBAR Technical Report 20: Designing and Building with Bamboo.Beijing: INBAR.

4. Liese, W. (1998) INBAR Technical Report 18: The Anatomy of Bamboo Culms. Beijing, INBAR.

Unit-2: Wood Anatomy I

Unit Structure

2.0 Learning objectives.

After studying this unit you will be able to understand about:

- Introduction to Wood Anatomy
- The plant body
- Plant Cell Organelles
- Endoplasmic reticulum
- Organelles Unique to Plants
- Plant Tissue

2.1 Introduction

Wood is composed mostly of hollow, elongated, Spindle shaped cells that are arranged parallel to each other along the trunk of a tree. The characteristics of these fibrous cells and their arrangement affect strength properties, appearance, resistance to penetration by water and chemicals, resistance to decay and many other properties. All wood is composed of cellulose, lignin, ash-forming minerals, and extractives formed into a cellular structure. The characteristics and amounts of these components and differences in cellular structures result in significant variations. Some woods are heavier, some lighter, some stiffer, some more flexible, some harder, some softer, and some easier to work with than others. It is these differences that make wood such a unique material.

(i) Cellulose: Cellulose is the principal component of the cell walls of trees. It also makes up the cell walls of other plants, includ- ing all the higher plants, most algae, and some fungi. It is the most important component for its effect on the properties of wood. Hemicellulose, composed of shorter molecules than cellulose, makes up a large part of wood. It is also important for some properties of wood.

(ii) Lignin*:* Lignin can be thought of as the glue that holds the wood (cellulose and hemicelluloses) together. Lignin is important because it gives rigidity to the cells so that a tree can grow large and tall.

(iii) Ash: The ash content of wood is made up of inorganic minerals, primarily calcium, potassium, and magnesium. Manganese and silica are two other common minerals. If silica is found in sufficient amounts, (0.5% oven-dry[1] weight), it can dull machining equipment.

(iv) Extractives: Common characteristics that we use to identify different woods with the naked eye come from extractives in the wood. Without extractives, wood would have to be identified solely by its anatomical structure. Extractives are made up of an extremely wide range of organic compounds. These chemical compounds are not part of the wood but accumulate there.

The amounts and types of extractives help to determine the wood's permeability to liquids and influence other wood properties such as density, hardness, and compressive strength. Extractives give certain woods their resistance to insect or fungi attack. (For more information about insect and decay resistance, see FOR-54.) Many useful chemicals are made from the extractives found in trees. They also cause the odors and colors attributed to most woods. In a number of woods, such as cherry, walnut, and mahogany, the extractive colors make these woods very valuable for furniture, wood paneling, and other products.

In general terms, the chemical composition of wood from trees found in the United States, on an oven-dry basis, can be summarized as follows:

Cellulose	40 to 50 percent
Hemicellulose	20 to 35 percent
Lignin	15 to 35 percent
Ash	less than 1 percent
Miscellaneous compounds	usually 1-2 percent

(v) Bark: Bark is an important element in tree growth (Fig 2). The outer bark protects the tree from the outside world and against extreme weather elements. It helps keep moisture in the tree during dry periods. It further protects the tree against diseases and insects. The inner bark or phloem acts as the pipeline through which the food produced in the leaves passes to the rest of the living tree. This section of cells lives for only a short time before it becomes part of the outer bark.

Between the bark and the wood is a thin layer of living cells (those that contain protoplasm) known as the cambial layer or cambium. The cambium represents the growing part of the trunk. Technically speaking, the cambium is only one cell thick. This cell produces bark on one side and wood on the other. Hormones, known as auxins, are produced in leaf buds in the spring. These auxins are transported through the phloem to the cambium. The auxins cause the cambium cells annually to produce new bark on one side and new wood on the other. Eight to ten times more wood is produced than bark.

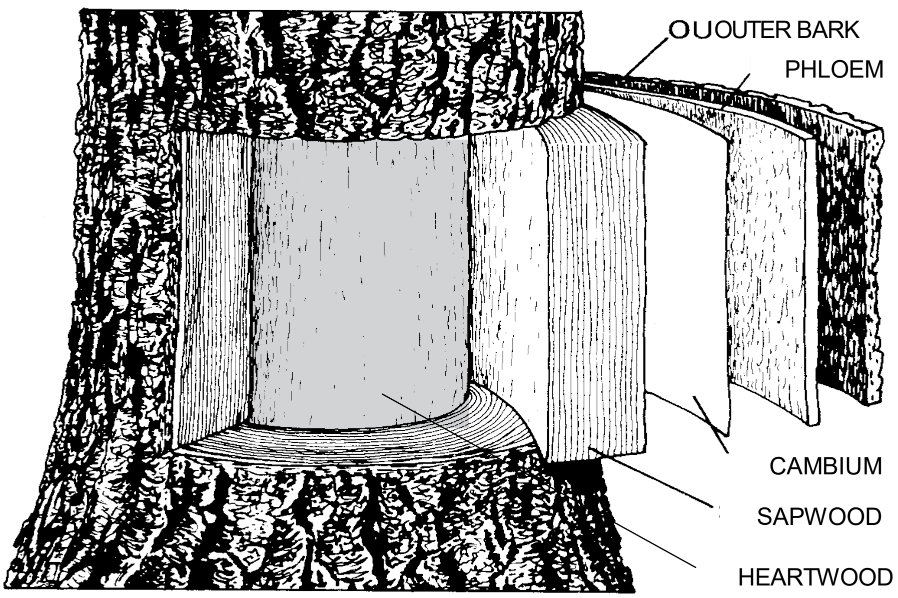


Fig 2. Parts of a tree system

(vi) **Sapwood:** Sapwood, or new wood, provides a pipeline for the movement of water and nutrients through the trunk and into the leaves, where the process of photosynthesis occurs. In this process, oxygen is released into the air and carbon dioxide is taken up. Sunlight and chlorophyll, the chemical that causes leaves to have a green color, are two other important components for photosynthesis. During this process, sugars are made that the tree uses for food. The sap, made up of water and dissolved nutrients, carries the sugars from the leaves through the phloem to the cambium layer where the energy is used to produce new bark and wood. As new rings of sapwood are laid on top, the older sapwood loses its vitality and turns into heartwood.

(vii) **Heartwood:** Heartwood forms the central support of the tree. Although it is made up of dead cells, it will never decay or lose strength as long as the sapwood and bark remain intact. Accumulation of extractives gives the heartwood of many species a darker color than that of the sapwood.

(viii) **Annual Growth Rings:** In temperate climates, where there is a growing season followed by a dormant season, the seasonal production of new wood produces the annual growth rings that are visible on the cross section of a tree stem. A year's formation of wood begins with larger cells in the spring and ends with smaller cells in the summer. The larger cells, called early- wood or springwood, form as the tree is more actively growing. The smaller cells, called latewood or summerwood, form as the tree is growing more slowly.

Growth rings on the lower portion a tree trunk can be counted to estimate the age of a tree, but false rings can sometimes form because of drought, late frosts, or defoliation by insects or harsh weather. The trauma causes the tree to produce latewood cells. If conditions improve, the tree can produce another ring of earlywood and then latewood cells, thus producing two or more rings in a single year.

(ix) **Wood Rays:** Most transfers of water, nutrients, and chemicals occur up and down in a tree. However, there is some transfer across the tree. Sap moves down the tree through the phloem. The sap, containing water and nutrients, is transported horizon- tally to the cambium through structures called wood rays. Wood rays also act as storage areas for the carbohydrates that the tree uses as food. If you carefully examine a cross section of wood with a 10X hand lens, you can see the wood rays as narrow stripes or lines crossing the growth rings and extending from the bark to the pith or center of the tree. Wood rays of oaks and beech can easily be seen with the naked eye. Wood rays of other kinds of trees, including most softwood, are hard to see even with a 10X hand lens.

(x) Three Primary Surfaces of Wood: Because of the way trees grow, you can generally view three very different surfaces of wood, including transverse, radial, or tangential surfaces (Fig 3).

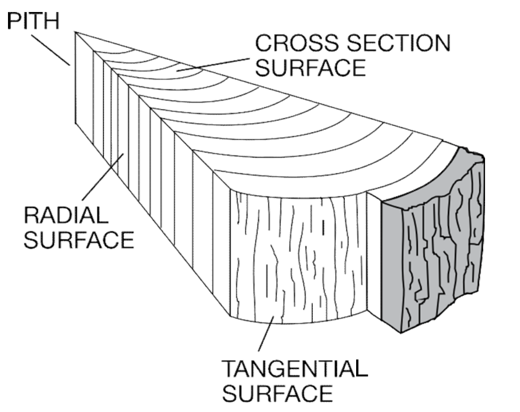


Fig 3. Wood surfaces (radial, tangential and cross-section)

The transverse or cross-sectional surface is what you see when you look at the end of a board or log, and down on a tree trunk.

Growth rings are very apparent and appear as part of a circle on this surface. The radial surface parallels the stem and passes through the pith. If you split a log in half, you will produce two radial surfaces. The tangential surface is named because it is the surface tangent to the growth rings. It is perpendicular to the direction of the wood rays.

The three surfaces of wood are important because wood structures appear very different depending on which surface is being viewed. Wood workers can alter the appearance of their wood projects by working with the different surfaces for the same kinds of wood. Fig 4 illustrates how wood grain in boards can be altered by the way the board is cut from a log.

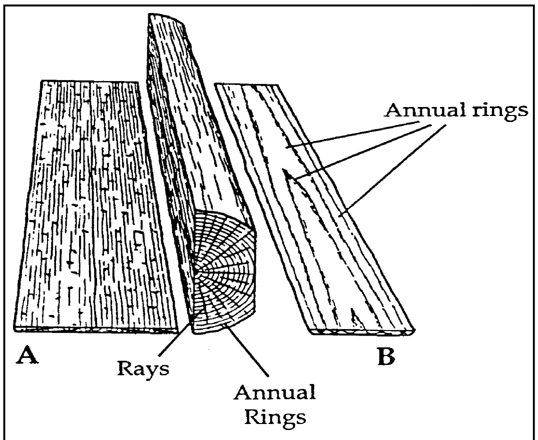


Fig 4. (A) Edgegrained or quartersawn (B) Flatsawn

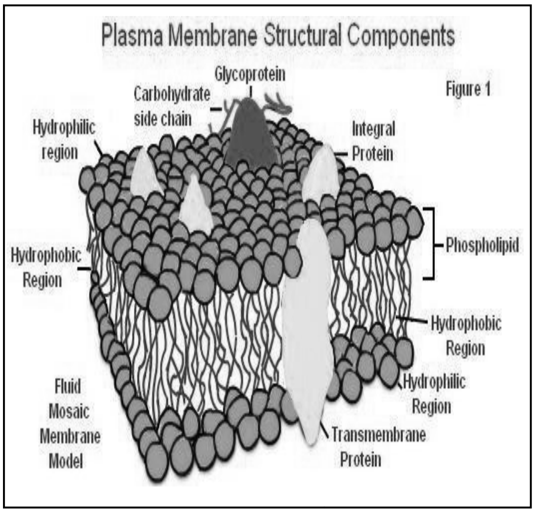
Grain in wood is caused by the annual growth rings, wood rays, and other cell structures in the wood. The grain runs in the direction of height growth. Lumber sawed across the growth rings and parallel with the wood rays exposes the radial surface.

The boards produced are said to be edge- grained or quartersawn. Lumber sawed parallel to the growth rings shows a chevron-shaped pattern. The boards produced are said to flatsawn or plainsawn. For more information on wood anatomy contact your county Cooperative Extension Agent or a specialist at the Department of Forestry at the University of Kentucky.

2.2 Plant Cell Organelles

2.2.1 Plasma or Cell membrane

Cell boundary; selectively permeable; bilayer of phospholipids with inserted protein. Phospholipids are unique molecules they are amphipathic, meaning that they have both hydrophilic and hydrophobic regions. As a result plant phospholipids usually have a higher degree of unsaturation than animals.



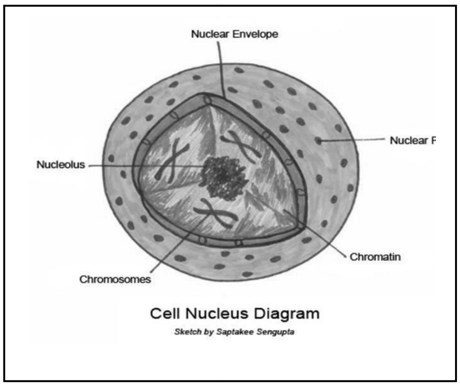
The function of the membrane is to:

Regulate traffic.

- Separate the internal from external environment.
- Serve as a platform on which some reactions can occur
- Participate in some reactions (i.e., the membrane components are important intermediates or enzymes).
- Provide some structural integrity for the cell

2.2.2 Nucleus

The cell "brain". Surrounded by a double membrane (two phospholipids bilayers) - the nuclear membrane.Have pores. The structure of the pores is complex comprised of a more than 100 proteins.



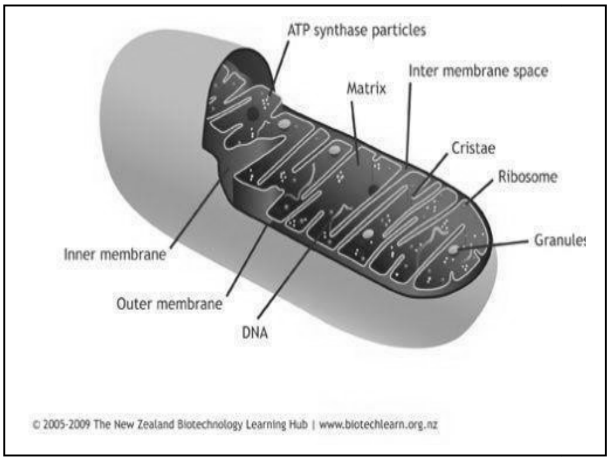
Cell Nucleus Diagram
Sketch by Saptakee Sengupta

2.2.3 Cytoplasm/Cytosol

The cytosol is the gel-like matrix within the cell in which the other structures are embedded. The cytoplasm refers to the cell materials inside the membrane.

2.2.4 Mitochondria

Mitochondria are found in all eukaryotic cells. They are the sites of cellular respiration-process by which energy is released from fuels such as sugar. Mitochondrion is the power plan of the cell. A popular misconception is that "plants have chloroplasts,



animals have mitochondria. Plant cells, at least green plant cells (i.e., leaf cells), and have both. Root cells only have mitochondria. The inner membrane differs from the plasma membrane in that has higher protein content (70 %) and unique phospholipids.

2.2.5 Ribosome

A ribosome is a complex of RNA and protein and is, therefore, known as a ribonucleoprotein. It is composed of two subunits – smaller and larger. The smaller subunit, where the mRNA binds and is decoded, and in the larger subunit, the amino acids get added. Both of the subunits contain both protein and ribonucleic acid components. The two subunits are joined to each other by interactions between the rRNAs in one subunit and proteins in the other subunit. Ribosomes are located inside the cytosol found in the plant cell and animal cell. The ribosome structure includes the following:

- It is located in two areas of cytoplasm.
- Scattered in the cytoplasm.
- Prokaryotes have 70S ribosomes while eukaryotes have 80S ribosomes.
- Around 62% of ribosomes are comprised of RNA, while the rest is proteins.
- The structure of free and bound ribosomes is similar and is associated with protein synthesis.

2.3 Endoplasmic reticulum

It is a series of membranous tubes and sacs (cisternae) that runs throughout the cell. Rough ER has ribosome's while smooth ER lacks ribosome's and is tubular.

The endoplasmic reticulum has several functions including:

- Synthesis of lipids and membranes (smooth ER);
- Serving as a site for the synthesis of proteins by the ribosomes (rough endoplasmic reticulum)
- Transport (a type of cell 'highway system, and Support

2.3.1 Peroxisomes

The membrane sac contains enzymes for metabolizing waste products from photosynthesis, fats and amino acids. A major function of the peroxisome is the breakdown of very long chain fatty acids through beta oxidation.

2.3.2 Golgi apparatus

The Golgi is active in synthesizing many cell components, especially carbohydrates and is involved in tagging proteins with carbohydrates and other side chains for sorting them to their final destination.

2.3.3 Microtubules

Microtubules are involved in the cell cytoskeleton (for support), cell movements and cell division.

2.3.4 Microfilaments

It is protein strands, solid and made from G-actin. They are about 7 nm in diameter. It involved with the cell cytoskeleton. Main function is support.

2.4 Organelles Unique to Plants

An organelle is a tiny cellular structure that performs specific functions within a cell.

2.4.1 Plastids

Plastids are double membrane-bound organelles in plants. They contain their own DNA and ribosomes. They are semi- autonomous and reproduce by fission similar to the division process in prokaryotes. The plastid DNA carries several genes including the large subunit of rubisco and those for resistance to some herbicides.

2.4.2 Vacuoles

This is the large, central cavity containing fluid, called cell sap, found in plant cells. The vacuole is surrounded by a membrane (tonoplast). The vacuole is penetrated by strands of cytoplasm - transvacuolar strands. The tonoplast and plasma membrane have different properties such as thickness (tonoplast thicker) so every plant cell has a large, well-developed vacuole that makes up to 90 % or more of the cell volume.

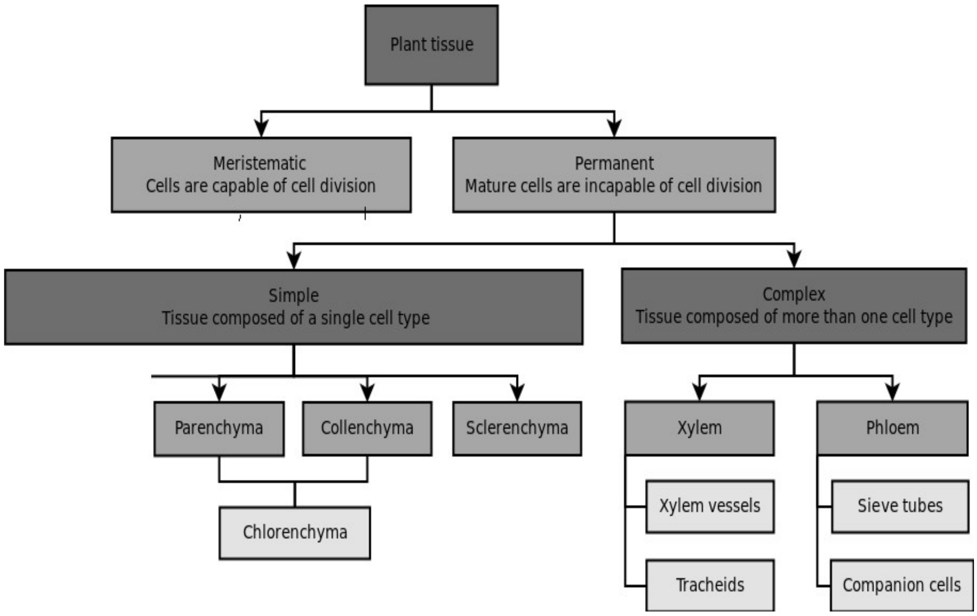
Important roles of the vacuoles are:

- Energetically efficient means to increase surface to volume ratio in the dendritic growth from since 90 % of the cell volume is vacuole, therefore 90% of the cell is water which is relatively cheap in metabolic terms.
- Water storage: - Probably a minor role: mostly in succulent plants.
- Waste disposal: The vacuole can be considered the cell cesspool. It contains many secondary metabolites.

Organelle	Function
Cell Wall	Supports and protects the cell
Nucleus	Stores heredity information in DNA; Synthesis RNA & Ribosome
Mitochondrion	Transfers energy from organic compounds to ATP
Vacuole	Stores enzymes & waste products
Plastids	Stores food or pigments; one type (Chloroplast) transfers energy form light to organic compounds
Ribosome	Organizes the synthesis of proteins
Endoplasmic	Prepares proteins for export(Rough ER); synthesis steroids, regulates
reticulum (ER)	Calcium level, breaks down toxic substances (Smooth ER)
Golgi Apparatus	Process & Packages substances produced by the cell
Microfilaments & Microtubules	Contribute to the support. Movement, and division of cell
Cilia & Flagella	Propel cells through the environment; move materials over the cell surface

2.5 Plant Tissue

Plant tissue is a group of similar or dissimilar cells having a common origin and performing a similar function.



2.5.1 Meristematic tissue

- The term meristem has been derived from a Greek word meristos- which means divisible or having cell division activity, so meristem is a group of cell which has power of continuous division.
- Meristems are the site of formation of new cells within the plant. eg.: meristem at apex of stem, root and vascular cambium, etc. .
- The term meristem was given by C. Nageli (1858) for group of continuously dividing cells.
- **Characteristics of meristematic cell:**

(i) Living cells found in vegetative regions of the plant 2- They have thin walls of cellulose.

(ii) Cells are normally isodiametric, oval, polygonal or rectangular

(iii) Abundant cytoplasm is present, vacuoles are either absent or very small, large nucleus is present and their plastids are in proplastid stage.

(iv) Cells are compactly arranged and lack intercellular spaces. 6- Cells have the capacity to divide.

- **Classification of merestimatic tissue**

(i) Origin and development

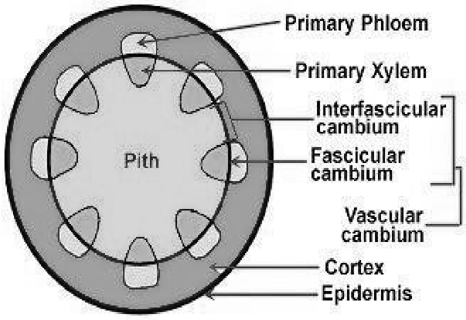
(ii) Position in the plant body

(iii) Plane of division

- **Functions**

2.5.2 Meristems based on origin and development

(A) Promeristem (primordial meristem): A group of cells which represent primary stages of meristematic cells. They are present in a small region at the apices of shoots and roots. They give rise to primary meristems.

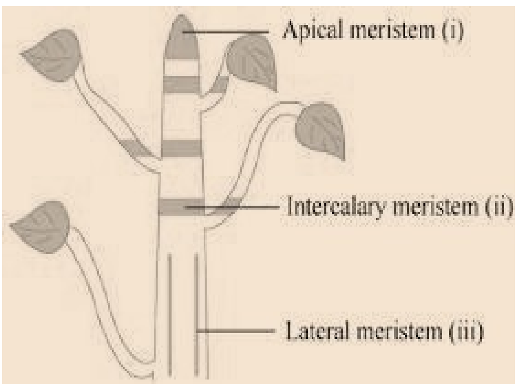


(B) Primary meristem: The meristematic cells that originate from promeristem are primary meristems. In most monocots and herbaceous dicots, only primary meristem is present.

(C) Secondary meristem: They are the meristems developed from primary permanent tissue. They are not present from the very beginning of the formation of an organ but develop at a later stage and give rise to secondary permanent tissues. Examples: Cambium of roots, interfascicular cambium of stem and cork cambium.

2.5.3 Meristems based on position in plant body:

(A) Apical meristem : It is found at the apex of growing points of root and shoot. It divides continuously and brings about growth in length of shoot and root. The apical meristem includes promeristem as well as primary meristem.



(B) Intercalary meristem : It is present away from apical meristem. It is present at the base of internodes e.g.; in grasses and wheat (Gramineae) or at the base of leaves e.g.; in Pinus or at the base of nodes e.g mint or Mentha (Labiatac). It is responsible for increase in length.

(C) **Lateral meristem :** They are located parallel to the long axis of the plant organs. Their activity results in increase of the diameter of the plant organs, e.g.; Cork cambium and Vascular cambium.

2.5.4 Meristems based on plane of division:

It includes three types of meristems:

(i) **Mass meristem:** In this cell division occur in all planes so that an irregular shaped structure is formed e.g. **endosperm**.

(ii) **Plate meristem:** It is consisted of parallel layers of cell which divide anticlinally in two planes so that a plate-like structure formed. This pattern is seen in the development of **leaf lamina**

(iii) **Rib meristem:** In this type, cells divide at right angles in one plane. It is found in the development of **lateral roots**.

2.5.5 Meristems based on function

(i) **Protoderm:** It is the outermost layer of the young growing region which develops the epidermal tissue system

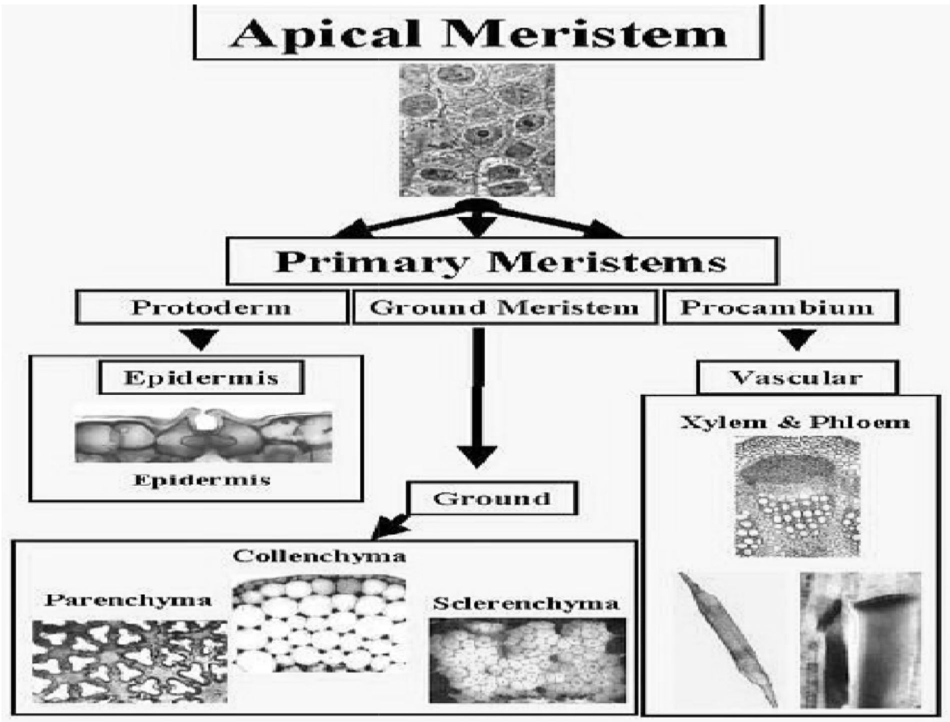
(ii) **Procambium:** It is composed of narrow, elongated cells that give rise to the vascular tissue system that is xylem and phloem.

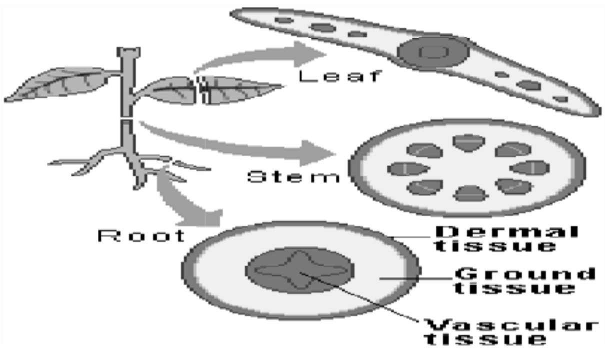
(iii) **Ground meristem**: It consists of large, thin-walled cells which develop to form ground tissue system that is hypodermis, cortex and pith.

Anticlinal and **periclinal** cell division are both different ways of cell division. Now let's understand the difference between the two.

Periclinal cell divisions are the ones that occur parallel to the tissue or organ surface. As a result, we get rows of cells stacked one over the other.

Anticlinal layer of cells. So, what you get is columns of cells adjacent to one another. In simple words, anticlinal division adds more thickness and periclinal division adds length





2.6 Permanent tissues

It is formed due to division and differentiation in meristematic tissue. The cells of this tissue may be living or dead thin-walled or thick-walled. The thin-walled tissues are generally living whereas the thick-walled tissues may be living or dead

Types of permanent tissues

(a) Simple tissue
(b) Complex tissue
(c) Special tissue

A. Simple tissues: These are homogenous in nature and are composed of structurally and functionally similar cells these are of three topes:

(i) Parenchyma (ii) Collenchyma (iii) Sclerenchyma

(i) Parenchyma

- Parenchyma is considered as the precursor of all other living tissues.
- It is also the most primitive tissue from phylogenetic point of view.
- Parenchymatous cells are living thin-walled containing distinct nuclei.
- The cell walls are made up of cellulose hemicellulosic and pectic materials.
- Cells have small or large intercellular spaces. Cells are generally isodiametric (but may also be elongated lobed, columnar, stelate and folded).
- All meristems made up of parenchyma.

Functions:

- Parenctyma cells are the centre of respiration, photosynthesis, storage, secretion etc.
- These cells may have the power of division.
- These cells help in wound-healing and in formation of adventitious buds and roots.
- Parenchymatous cells store water in succulent plants.
- In aquatic plants parenchyma cells store air.
- Parenctyma cells of xylem and phloem help in conduction of water and food materials.

(ii) Chlorenchyma

When parenchyma cell is containing chloroplasts, it is known as chlorenchyma. Examples - leaf mesophyll tissue, outer cortex of young stem, outer cortex of xerophytic stem etc. Its function is to manufacture food material (photosynthesis)

(ii) Aerenchyma

In hydrophytes, the parenchyma develops air spaces and such parenchyma with air cavities is known as aerenchyma. It helps hydrophytes to float and provides O_2, for respiration.

Unit-3 Wood Anatomy II

Unit Structure

3.0 Learning objectives.

After studying this unit you will be able to understand:

- Primary structure of dicot and monocot stem
- Anatomy of dicot and monocot root

- Secondary Growth and its significance
- Structure and Utility of Wood
- Mechanical Properties of Wood
- Wood Seasoning, Preserving and other treatment

3.1 Introduction

3.1.1 Primary structure of Dicot stem

(i) Epidermis

- It is a protective outermost single layer of parenchymatous cells without intercellular spaces.
- The outer walls of the epidermal cells have a layer called cuticle and multicellular hairs (trichomes).

(ii) Cortex

- Below the epidermis, cortex is differentiated into few layers of collenchyma cells that make hypodermis which gives mechanical strength to the stem.
- A few layers of chlorenchyma cells are present with conspicuous intercellular spaces. Some resin ducts also occur here.
- The third zone is made up of parenchyma cells. These cells store food materials.

(iii) Endodermis:

- The cells of this layer are barrel shaped arranged compactly without intercellular spaces.
- Due to abundant starch grains in these cells, this layer is also known as starch sheath.

(iv) Stele

- It consists of pericycle, vascular bundles and pith.

(v) Pericycle(Bundlecap)

- Pericycle occurs between the endodermis and vascular bundles in the form of a few layers of sclerenchyma cells.

(vi) Vascularbundles

- In dicot stem, vascular bundles are arranged in a ring around the pith.
- Each vascular bundle is conjoint, collateral, open and endarch.

(vii) Pith

- The large central portion called pith composed of parenchyma cells with intercellular spaces.
- The extension of pith between vascular bundles are called as pith ray or medullary rays.
- Function of the pith is storage of food.

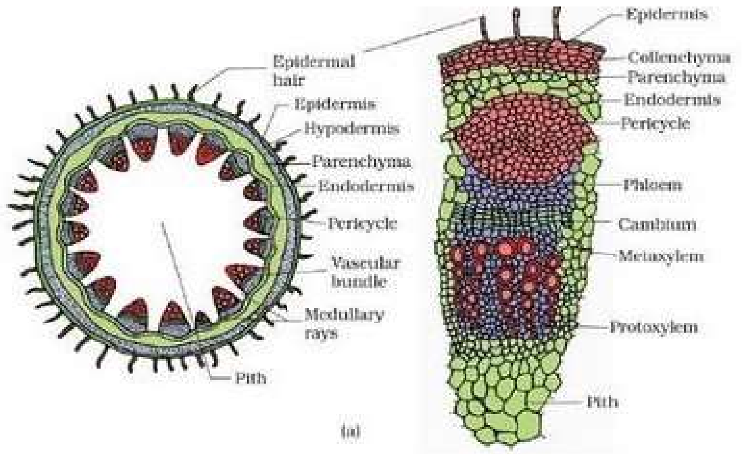


Fig. 1 Anatomy of Dicot Stem

3.1.2 Primary structure of dicot root

(i) Epidermis:

- It is single-layered and composed of thin- walled cells.
- The outer walls of epidermal cells are not cutinised. Many epidermal cells prolong to form long hairy bodies, the typical unicellular hairs of roots.
- Epidermis of root is also called epiblema or piliferous layer (pilus = hair; ferous—bearing).

(ii) Cortex:

- It is quite large and extensive in roots.
- Cortex is made of thin-walled living parenchymatous cells with leucoplasts, which convert sugar into starch grains.
- The last layer of cortex is endodermis. It is of universal occurrence in roots.
- Endodermis is composed of one layer of barrel-shaped cells which are closely arranged without having intercellular spaces.
- The endodermal cells have thickened radial walls, which are called Casparian strips, after the name of Caspary, the gentleman who first noted them.

(iii) Stele or Central Cylinder:

- Next to endodermis there is a single-layered pericycle made up of thin- walled parenchyma cells.

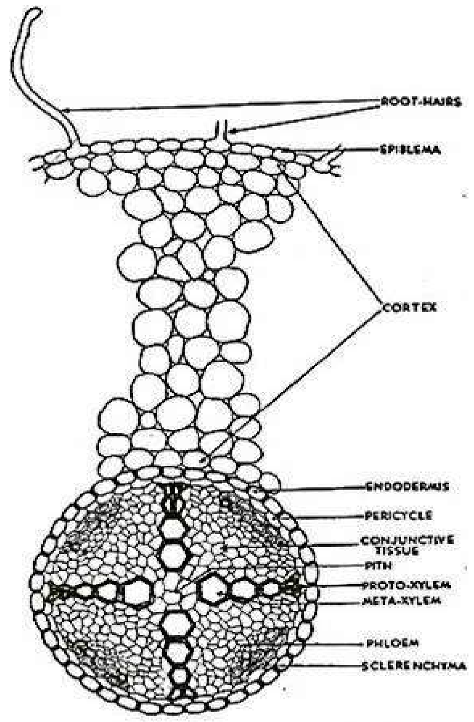


Fig. 2 Portion of TS of Young Dicot root

- Pericycle is the seat of the origin of lateral roots. Vascular bundles are typically radial in roots.
- Xylem and phloem form separate patches and are intervened by non-conducting cells.
- In dicotyledonous roots the number of bundles is limited.
- Xylem has protoxylem towards circumference abutting on pericycle and metaxylem towards centre. This is called exarch arrangement (of endarch arrangement of stems). Phloem with sieve tubes, etc., form patches arranged alternately with xylem.
- A small patch of sclerenchyma cells is present outside every group of phloem.

(iv) Conjunctive Tissue:

- Thin-walled parenchymatous cells lying in between xylem and phloem groups constitute the conjunctive tissue.

(v) Pith:

- At the centre there is small parenchymatous pith. It may be even absent.

3.1.3 Anatomy of monocot stem

(i) Epidermis

- It is the outermost layer made up of single layer of tightly packed parenchymatous cells with thick cuticle.
- There are no epidermal outgrowths.

(ii) Hypodermis

- A few layers of sclerenchymatous cells lying below the epidermis constitute the hypodermis, gives mechanical strength to the plant.

(iii) Ground tissue

- It is not differentiated into cortex, endodermis, pericycle and pith.
- The ground tissue is represented by several layers of loosely arranged parenchyma cells enclosing prominent intercellular spaces.
- The ground tissue is meant for storage of food.

(iv) Vascular bundles

- Vascular bundles are scattered in the parenchymatous ground tissue.
- Vascular bundles are numerous, small and closely arranged in the peripheral portion.

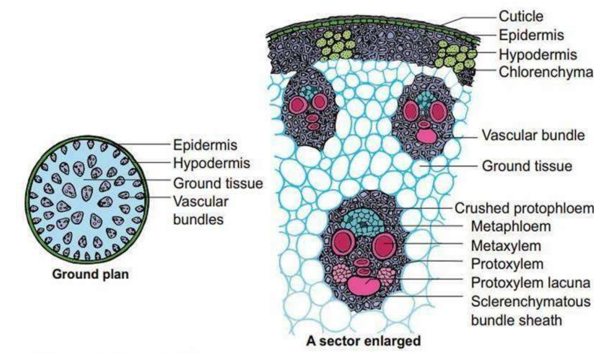


Fig. 3 T.S. of Monocot Stem

- Towards the centre, the bundles are comparatively large in size and loosely arranged.
- Each vascular bundle is surrounded by a sheath of sclerenchymatous fibres called bundle sheath.
- The vascular bundles are conjoint, collateral, endarch and closed.

(v) Phloem

- The phloem in the monocot stem consists of sieve tubes and companion cells.
- Phloem parenchyma and phloem fibres are absent.

(vi) Xylem

- The two metaxylem vessels are located at the upper two arms and one or two protoxylem vessels at the base. (Y shaped)
- In a mature bundle, the lowest protoxylem disintegrates and forms a cavity known as protoxylem lacuna.

3.1.4 Anatomy of monocot root

(i) Epidermis/Epiblema/Rhizodermis:

- It is the outermost layer composed of compact parenchymatous cells having no intercellular spaces and stomata.
- The tubular unicellular root hairs are also present on this layer
- Both epiblema and root hairs are without cuticle.
- In older parts, epiblemma either becomes impervious or is shed.
- Epiblemma and root hairs absorb water and mineral salts.

(ii) Cortex

- It lies just below the epidermis.
- Cortex consists of thin walled multilayered parenchyma cells having sufficiently developed intercellular spaces among them.
- Usually in an old root of *Zea mays,* a few layers of cortex undergo suberization and give rise to a single or multi-layered zone- the exodermis.
- This is a protective layer which protects internal tissues from outer injurious agencies.
- The starch grains are abundantly present in the cortical cells.

(iii) Cortex functions:

- conduction of water and mineral salts from root hairs to inner tissues
- Storage of food
- Protection when exodermis is formed in older parts.

(iv) Endodermis:

- The innermost layer of the cortex is termed as endodermis.
- It is composed of barrel-shaped compact cells that lack intercellular spaces among them.
- Young endodermal cells have an internal strip of suberin and lignin which is called casparian strip.
- The strip is located close to the inner tangential wall.
- There are some unthickened cells opposite to the protoxylem vessels known as passage cells which serve for conducting of fluids.
- The function of endodermis is to regulate the flow of both inward as well as outward.

(v) Pericycle:

- It lies just below the endodermis and is composed of single layered sclerenchymatous cells intermixed with parenchyma.

(vi) Vascular tissue*:*

- The vascular tissue contains alternating strands of xylem and phloem.
- The phloem is visualized in the form of strands near the periphery of the vascular cylinder, beneath the pericycle.
- The xylem forms discrete strands, alternating with phloem strands.
- The center is occupied by large pith which maybe parenchymatous or sclerenchymatous.
- The number of vascular bundles is more than six, hence called as polyarch.
- Xylem is exarch i.e. the protoxylem is located towards the periphery and the metaxylem towards the center.
- Vessels of protoxylem are narrow and the walls possess annular and spiral thickenings in contrast, metaxylem are broad and the walls have reticulate and pitted thickenings.

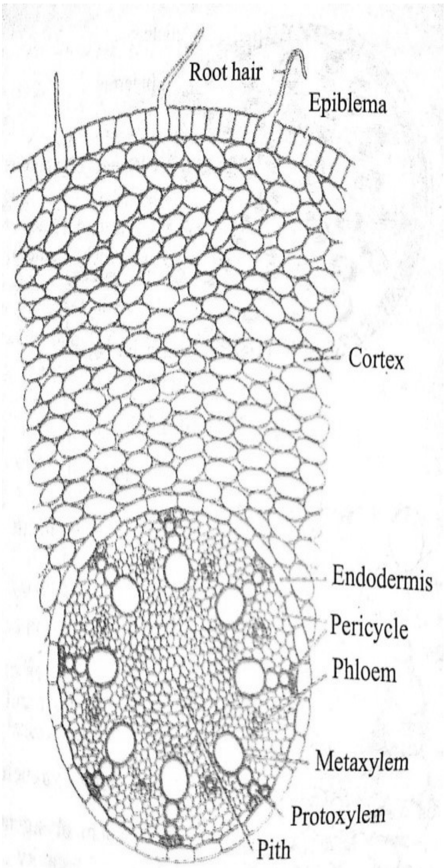


Fig. 4 Monocot Root T. S.

- Phloem strands consist of sieve tubes, companion cells and phloem parenchyma.
- The phloem strands are also exarch having protophloem towards the periphery and metaphloem towards the center.

(vii) Conjunctive tissues:

- In between the xylem and phloem bundles, there is the presence of many layered parenchymatous or sclerenchymatous tissue.
- These help in storage of food and help in mechanical support.

(viii) Pith:

- It is the central portion usually composed of thin-walled parenchymatous cells which appear polygonal or rounded in T.S.
- Intercellular spaces may or may not be present amongst pith cells.
- In some cases pith becomes thick walled and lignified.
- Pith cells serve to store food.

3.2 Secondary Growth

Primary growth produces growth in length and development of lateral appendages and Secondary growth is the formation of secondary tissues from lateral meristems. It increases the diameter of the stem. In woody plants, secondary tissues constitute the bulk of the plant. They take part in providing protection, support and conduction of water and nutrients.

Secondary tissues are formed by two types of lateral meristems, vascular cambium and cork cambium or phellogen. Vascular cambium produces secondary vascular tissues while phellogen forms periderm.

Secondary growth occurs in perennial gymnosperms and dicots such as trees and shrubs. It is also found in the woody stems of some herbs. In such cases, the secondary growth is equivalent to one annual ring, e.g., Sunflower.

3.2.1 Formation of Secondary Vascular Tissues

They are formed by the vascular cambium. Vascular cambium is produced by two types of meristems, fascicular or intra-fascicular and inter-fascicular cambium. Intra-fascicular cambium is a primary meristem which occurs as strips in vascular bundles. Inter-fascicular cambium arises secondarily from the cells of medullary rays which occur at the level of intra- fascicular strips.

These two types of meristematic tissues get connected to form a ring of vascular cambium. Vascular cambium is truly single layered but appears to be a few layers (2-5) in thickness due to presence of its immediate derivatives. Cells of vascular cambium divide periclinally both on the outer and inner sides (bipolar divisions) to form secondary permanent tissues.

The cells of vascular cambium are of two types, elongated spindle-shaped fusiform initials and shorter isodiametric ray initials (Fig.5). Both appear rectangular in T.S. Ray initials give rise to vascular rays. Fusiform initials divide to form secondary phloem on the outer side and secondary xylem on the inner side (Fig. 5 B). With the formation of secondary xylem on the inner side, the vascular cambium moves gradually to the outside by adding new cells.

The phenomenon is called dilation. New ray cells are also added. They form additional rays every year (Fig.5 D). The vascular cambium undergoes two types of divisions—additive (periclinal divisions for formation of secondary tissues) and multiplicative (anticlinal divisions for dilation).

Ray initials produce radial system (= horizontal or transverse system) while fusiform initials form axial system (= vertical system) of secondary vascular tissues.

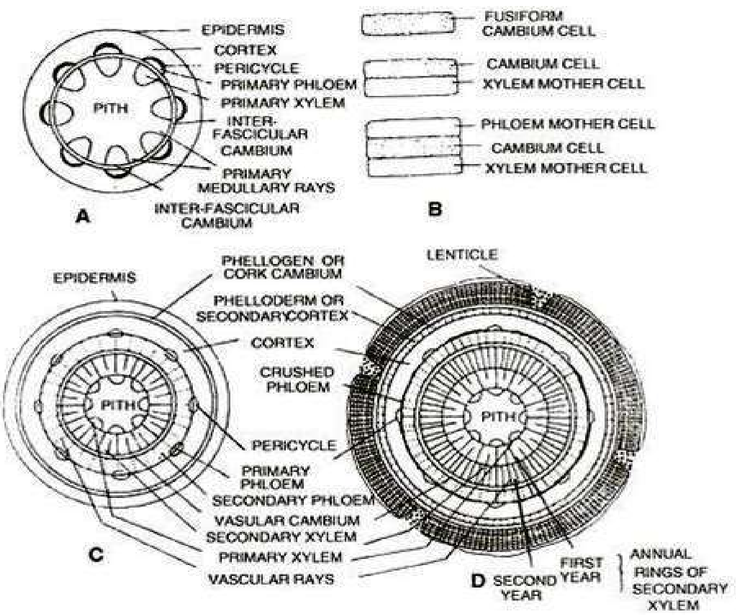


Fig. 5 A. Complete vascular cambium formed by strips of intra-fascicular cambium and inter-fascicular cambium, **B.** Formation of secondary vascular tissue mother cells, **C.** the beginning of secondary growth of dicot stem, **D.** two year stage of secondary growth of dicot stem.

3.2.2 Vascular Rays

The vascular rays or secondary medullary rays are rows of radially arranged cells which are formed in the secondary vascular tissues. They are a few cells in height.

Depending upon their breadth, the vascular rays are uniseriate (one cell in breadth) or multiseriate (two or more cells in breadth). Vascular rays may be homo-cellular (having one type of cells) or hetero-cellular (with more than one type of cells). The cells of the vascular rays enclose intercellular spaces.

The part of the vascular ray present in the secondary xylem is called wood or xylem ray while the part present in the secondary phloem is known as phloem ray. The vascular rays conduct water and organic food and permit diffusion of gases in the radial direction. Besides, their cells store food.

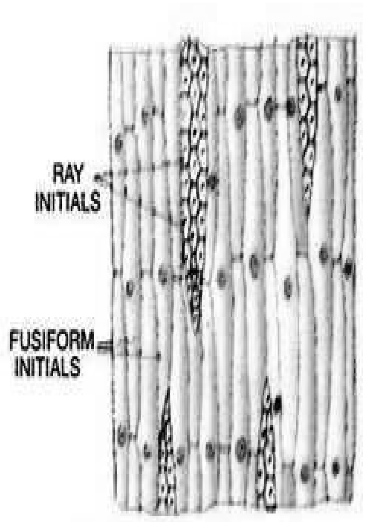


Fig. 6 L. S. vascular cambium

3.2.3 Secondary Phloem (Bast)

It forms a narrow circle on the outer side of vascular cambium. Secondary phloem does not grow in thickness because the primary and the older secondary phloem present on the outer side gets crushed with the development of new functional phloem (Fig.5 D). Therefore, rings (annual rings) are not produced in secondary phloem. The crushed or non-functioning phloem may, however, have fibres and sclereids.

(i) **Secondary phloem is made up of the same type of cells as are found in the primary phloem (metaphloem)-** sieve tubes, companion cells, phloem fibres and phloem parenchyma.

(ii) **Phloem pairenchyma is of two types-** axial phloem parenchyma made up of longitudinally arranged cells and phloem ray parenchyma formed of radially arranged parenchyma cells that constitute the part of the vascular ray present in the phloem. Elements of secondary phloem show a more regular arrangement. Sieve tubes are comparatively more numerous but are shorter and broader. Sclerenchyma fibres occur either in patches or bands. Sclereids are found in many cases. In such cases secondary phloem is differentiated into soft bast (secondary phloem without fibres) and hard bast (part of phloem with abundant fibres).

3.2.4 Secondary Xylem

It forms the bulk of the stem and is commonly called wood. The secondary xylem consists of vessels, tracheids (both tracheary elements), wood fibres and wood parenchyma. Wood parenchyma may contain tannins and crystals besides storing food. It is of two types— axial parenchyma cells arranged longitudinally and radial ray parenchyma cells arranged in radial or horizontal fashion. The latter is part of vascular ray present in secondary xylem.

Secondary xylem does not show distinction into protoxylem and meta-xylem elements. Therefore, vessels and tracheids with annular and spiral thickenings are absent. The tracheary elements of secondary xylem are similar to those of meta-xylem of the primary xylem with minor differences. They are comparatively shorter and more thick-walled. Pitted thickenings are more common. Fibres are abundant.

Width of secondary xylem grows with the age of the plant. The primary xylem persists as conical projection on its inner side. Pith may become narrow and ultimately get crushed. The yearly growth of secondary xylem is distinct in the areas which experience two seasons, one favourable spring or rainy season) and the other un-favourable (autumn, winter or dry summer).

In favourable season the temperature is optimum. There is a good sunshine and humidity. At this time the newly formed leaves produce hormones which stimulate cambial activity. The activity decreases and stops towards the approach of un-favourable season. Hence the annual or yearly growth appears in the form of distinct rings which are called annual rings (Fig.9).

Annual rings are formed due to sequence of rapid growth (favourable season, e.g., spring), slow growth (before the onset of un-favourable period, e.g., autumn) and no growth (un- favourable season, e.g., winter). Annual rings are not distinct in tropical areas which do not have long dry periods.

3.3 Significance of Secondary Growth:

(i) Secondary growth adds to the girth of the plant. It provides support to increasing weight of the aerial growth.

(ii) Secondary growth produces a corky bark around the tree trunk that protects the interior from abrasion, heat, cold and infection.

(iii) It adds new conducting tissues for replacing old non-functioning ones as well as for meeting increased demand for long distance transport of sap and organic nutrients.

3.4 Anomalous Secondary Growth:

It is abnormal type of secondary growth that occurs in some arborescent monocots (e.g., *Dracaena, Yucca, Agave*) and storage roots (e.g., *Beet, Sweet Potato*). In arborescent monocot stems, a secondary cambium grows in hypodermal region. The latter forms conjunctive tissue and patches of meristematic cells. The meristematic patches grow into sec- ondary vascular bundles.

Anomalous vascular bundles also occur in cortex (cortical bundles, e.g., *Nyctanthes*) and pith (e.g., *Boerhaavia*). In storage roots (e.g., Beet), accessory cambial rings appear on the outside of endodermis. They produce less secondary xylem but more secondary phloem. The secondary phloem contains abundant storage parenchyma.

3.5 Importance of Secondary Growth:

(i) It is a means of replacement of old non-functional tissues with new active tissues.

(ii) The plants showing secondary growth can grow and live longer as compared to other plants.

(iii) It provides a fire proof, insect proof and insulating cover around the older plant parts.

(iv) Commercial cork is a product of secondary growth. It is obtained from Quercus suber (Cork Oak).

(v) Wood is a very important product of secondary growth. It represents secondary xylem.

3.6 Structure and Utility of Wood

Sapwood white and small; the heartwood when cut green, has a pleasant and strong aromatic fragrance and a beautiful dark golden yellow colour, which on seasoning soon darkens into brown, mottled with darker streaks. The timber retains its fragrance to a great age, the characteristic odour being apparent whenever a fresh cut is made.

It is moderately hard, exceedingly durable and strong, does not split, crack, warp, shrink or alter its shape when once seasoned; it works easily, takes a good polish.

Teak owes its chief value to its great durability, which is ascribed, probably with justice, to the circumstance that it contains a large quantity of fluid resinous matter which fills up the pores and resists the action of water. (At the Karli caves near Poona the teak-wood-work, two thousand years old, seems perfectly good at the present day).The many uses of teak are well known. In India it is highly prized for construction, ship building, and for making sleepers and furniture.

Wood is very durable and resistant to fungi. It is used for poles, beams, trusses, columns, roofs, doors, window frames, flooring, planking, panelling, stair cases, and other constructional work. It is one of the best timbers for furniture and cabinet making, wagons and railway carriages. Due to its better shape-retention ability, teak is popular in marine constructions and is a class by itself for boat and ship-building, particularly for decking. On account of its resistance to chemicals, teak articles are used in chemical industries and for making laboratory bench-tops; suitable for casks and vats for shipping corrosive liquids and for storing vegetable oils, fruit syrups, chutneys, etc. Teak is employed for sound-boards of musical instruments, keys, etc., and for different grades of plywood. Wood waste in the form of wood-shavings and sawdust is used for chip- boards, fibre-boards and plastic-boards.

3.6.1 Chemical composition

Look at some freshly cut wood under a microscope and you'll see it's made up of cells, like any other plant. The cells are made of three substances called cellulose (about 50 percent), lignin (which makes up a fifth to a quarter of hardwoods but a quarter to a third of softwoods), and hemicellulose (the remainder). Broadly speaking, cellulose is the fibrous bulk of a tree, while lignin is the adhesive that holds the fibers together. The inner structure of a tree makes wood what it is—what it looks like, how it behaves, and what we can use it for. There are actually hundreds of different species of trees, so making generalizations about something called "wood" isn't always that helpful: balsa wood is different from oak, which isn't quite the same as hazel, which is different again from walnut. Having said that, different types of wood have more in common with one another than with, say, metals, ceramics, and plastics.

3.6.2 The more important diagnostic features are mentioned here:

3.6.2.1 Porous and Nonporous Woods:

The presence or absence, and the nature and arrangement of pores, serve as a ready means of classifying woods. The coniferous woods do not possess pores, and are known as nonporous woods, whereas the angiospermic woods possess numerous pores and are termed as porous woods. On the basis of the distribution of pores, the woods may be of two types—ring porous and diffuse porous woods.

In ring porous woods (e.g., ash, elm, oak, etc.) the pores are found to be arranged in concentric circles, the outer and inner portions of which differ with regard to the number and size of the pores. In diffuse porous woods (e.g., beech maple, walnut, etc.) the pores are small and nearly of the same size and are found to be scattered uniformly throughout the wood.

3.6.2.2 Early Wood and Late Wood:

In temperate regions, every year new wood is formed in a limited growing season, with the result definite growth layers develop, which shows two distinct areas within each layer.

The wood thus formed in the spring is called the spring wood or early wood, and that formed in winter is called the autumn wood or late wood. There is a sharp contrast between the late autumn wood and the early spring wood, and this makes the successive rings distinct.

The growth ring of a single year is called an annual ring and the number of these annual rings gives an indication of the age of tree. Annual rings of successive years may vary greatly in width. Wide rings are formed under favourable conditions of growth of the tree, and narrow ones are formed when conditions are unfavourable.

3.6.2.3 Sapwood and Heartwood

The wood of the older stems (*Dalbergia, Acacia*) gets differentiated into two zones, the outer light coloured and functional sapwood or alburnum and the inner darker and nonfunctional heartwood or duramen (Fig.7). The tracheids and vessels of the heart wood get plugged by the in growth of the adjacent parenchyma cells into their cavities through the pits. These ingrowths are called tyloses (Fig. 8). Ultimately, the parenchyma cells become lignified and dead. Various types of plant products like oils, resins, gums, aromatic substances, essential oils and tannins are deposited in the cells of the heartwood. These substances are collectively called extractives. They provide colour

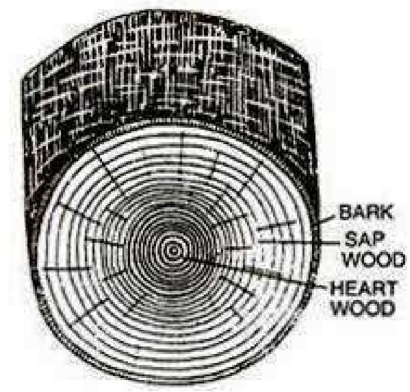


Fig. 7 Sapwood and heart wood in T.S. of trunk

to the heartwood. They are also antiseptic. The heartwood is, therefore, stronger and more durable than the sapwood. It is resistant to attack of insects and microbes.

Heart wood is commercial source of Cutch (*Acacia catechu*), Haematoxylin (*Haematoxylon campechianum), Brasilin (Caesalpinia sappan) and Santalin (Pterocarpus santalinus*). Heartwood is, however, liable to be attacked by wood rotting fungi. Hollow tree trunks are due to their activity.

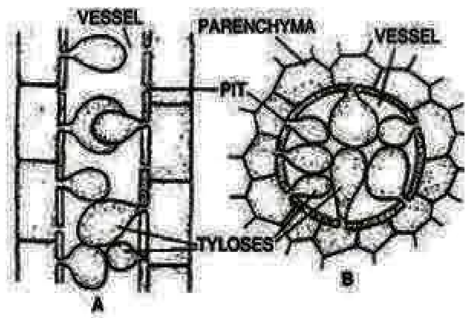


Fig. 8 Formation of tyloses in heartwood.
A: L.S. vessel showing tyloses
B: T.S. versel showing tyloses

3.6.2.4 Softwood and Hardwood

Softwood is the technical name of gymnosperm wood because it is devoid of vessels. Several of the softwoods are very easy to work with (e.g., Cedrus, Pinus species). However, all of them are not 'soft'. The softness depends upon the content of fibres and vascular rays. 90- 95% of wood is made of tracheids and fibres. Vascular rays constitute 5-10% of the wood. Hardwood is the name of dicot wood which possesses abundant vessels. Due to the presence of vessels, the hardwoods are also called porous woods. In Cassia fistula and Dalbergia sisso the vessels are comparatively very broad in the spring wood while they are quite narrow in the autumn wood. Such a secondary xylem or wood is called ring porous. In others (e.g., *Syzygium cumini*) larger sized vessels are distributed throughout spring wood and autumn wood. This type of secondary xylem or wood is known as diffuse porous. Ring porous wood is more advanced than diffuse porous wood as it provides for better translocation when the requirement of the plant is high.

3.6.2.5 Texture, Grain and Figure:

Texture refers to the relative size and quality of the various woods, while gram refers to their structural arrangement. Figure is applied to the design or pattern which appears on the surface of wood.

3.6.2.6 Rays

The rays are made of parenchyma cells that are oriented at right angles to the main axis of the stem. They vary greatly in width, height and arrangement.

3.7 Annual Rings (Growth Rings).

It is the wood formed in a single year. It consists of two types of wood, spring wood and autumn wood (Fig. 9). The spring or early wood is much wider than the autumn or late wood. It is lighter in colour and of lower density. Spring wood consists of larger and wider xylem elements.The autumn or late wood is dark coloured and of higher density. It contains compactly arranged smaller and narrower elements which have comparatively thicker walls. In autumn wood, tracheids and fibres are more abundant than those found in the spring wood. The transition from spring to autumn wood in an annual ring is gradual but the transition from autumn wood to the spring wood of the next year is sudden. Therefore, each year's growth is quite distinct. The number of annual rings corresponds to the age of that part of the stem. (They can be counted by increment borer). Besides giving the age of the plant, the annual rings also give some clue about the climatic conditions of the past through which the plant has passed. Dendrochronology is the science of counting and analysing annual growth rings of trees.

Fig. 9 Part of old stem T.S showing annual rings

3.8 Formation of Periderm

In order to provide for increase in girth and prevent harm on the rupturing of the outer ground tissues due to the formation of secondary vascular tissues, dicot stems produce a cork cambium or phellogen in the outer cortical cells. Rarely it may arise from the epidermis (e.g., Teak, Oleander), hypodermis (e.g., Pear) or phloem parenchyma.

Phellogen cells divide on both the outer side as well as the inner side (bipolar) to form secondary tissues. The secondary tissue produced on the inner side of the phellogen is parenchymatous or collenchymatous. It is called secondary cortex or phelloderm. Its cells show radial arrangement.

Phellogen produces cork or phellem on the outer side. It consists of dead and compactly arranged rectangular cells that possess suberised cell walls. The cork cells contain tannins. Hence, they appear brown or dark brown in colour. The cork cells of some plants are filled with air e.g., *Quercus suber* (Cork Oak or Bottle Cork). The phelloderm, phellogen and phellem together constitute the periderm (Fig.7).

Cork prevents the loss of water by evaporation. It also protects the interior against entry of harmful micro-organisms, mechanical injury and extremes of temperature. Cork is light, compressible, nonreactive and sufficiently resistant to fire.

It is used as stopper for bottles, shock absorption and insulation. At places phellogen produces aerating pores instead of cork. These pores are called lenticels. Each lenticel is filled by a mass of somewhat loosely arranged suberised cells called complementary cells.

3.9 Lenticels

Lenticels are aerating pores in the bark of plants. They appear on the surface of the bark as raised scars containing oval, rounded or oblong depressions (Fig. 10 A). They occur in woody trees but not in climbers. Normally they are formed in areas with underlying rays for facilitating gas exchange. Lenticels may occur scattered or form longitudinal rows.

A lenticel is commonly produced beneath a former stomata or stoma of the epidermis. Its margin is raised and is formed by surrounding cork cells. The lenticel is filled up by loosely arranged thin walled rounded and suberised (e.g., Prunus) or un-suberised cells called complementary cells (Fig. 10 B).

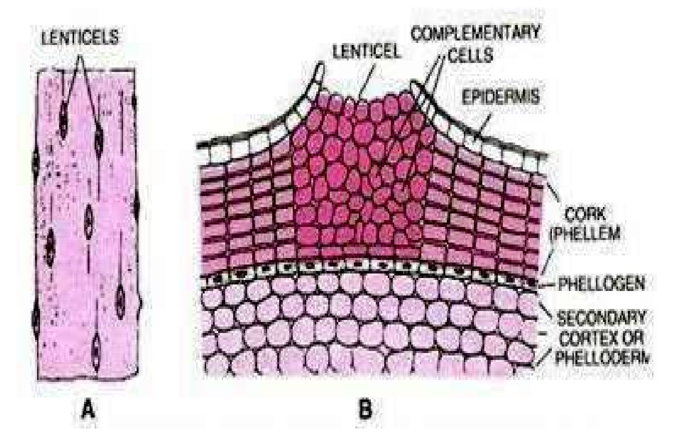


Fig. 10 Lenticels. A: external view of lenticles, B: T.S. lenticel

They enclose intercellular spaces for gaseous exchange. The complementary cells are formed from loosely arranged phellogen cells and division of sub-stomatal parenchyma cells. The suberised nature of complementary cells checks excessive evaporation of water.

In temperate plants the lenticels get closed during the winter by the formation of compactly arranged closing cells over the complementary cells.

3.10 Bark

In common language and economic botany, all the dead cells lying outside phellogen are collectively called bark. The outer layers of the bark are being constantly peeled off on account of the formation of new secondary vascular tissues in the interior. The peeling of the bark may occur in sheets (sheets or ring bark, e.g., Eucalyptus) or in irregular strips (scaly bark).

The scaly bark is formed when the phellogen arises in strips instead of rings, e.g., Acacia (vem. Kikar). Bark formed in early growing season is early or soft bark. The one formed towards end of growing season is late or hard bark.

Bark is insect repellent, decay proof, fire-proof and acts as a heat screen. Commercially it is employed in tanning (e.g., Acacia), drugs (e.g.*, Cinchona*— quinine) or as spice (e.g., *Cannamon, vem. Dalchini)*. The cork of *Quercus suber* is employed in the manufacture of bottle stoppers, insulators, floats, sound proofing and linoleum.

3.11 Mechanical Properties of Wood

Wood possesses some important mechanical properties which either alone or in combination, determine its usefulness and suitability for various purposes. These properties may differ in different species. The mechanical properties enable the wood to resist various external forces which tend to change its shape and size and produce deformations. The important mechanical properties of wood are mentioned as follows:

(i) **Strength**: Physically, wood is strong and stiff but, compared to a material like steel, it's also light and flexible. It has another interesting property too. Metals, plastics, and ceramics tend to have a fairly uniform inner structure and that makes them isotropic: they behave exactly the same way in all directions. Wood is different due to its annual-ring-and-grain structure. You can usually bend and snap a small, dead, tree branch with your bare hands, but you'll find it almost impossible to stretch or compress the same branch if you try pulling or pushing it in the opposite direction. The same holds when you're cutting wood. If you've ever chopped wood with an axe, you'll know it splits really easily if you slice with the blade along the grain, but it's much harder to chop the opposite way (through the grain). We say wood is anisotropic, which means a lump of wood has different properties in different directions. That's not just important to someone chopping away in the woodshed: it also matters when you're using wood in construction. Traditional wooden buildings are supported by huge vertical poles that transmit forces down into the ground along their length, parallel to the grain. Wooden poles are much weaker placed horizontally; they need plenty of support to stop them bending and snapping. That's because they have lower tensile strength (resistance to bending or pulling forces across the grain). Not all woods are the same, however. Oak has much higher tensile strength than many other woods, which is why it was traditionally used to make the heavy, horizontal beams in old buildings. Other factors such as how well seasoned (dry) a piece of wood is (as discussed below) and how dense it is also affect its strength. The strength is restricted to the ability to resist certain definite forces which may be termed— crushing strength, tensile strength, shearing strength and cross-breaking strength.

(a) **Crushing Strength:** It is the resistance offered to forces that tend to crush wood.

(b) **Tensile Strength:** It is the resistance to forces that tend to pull wood apart.

(c) **Shearing Strength:** It is resistance to those forces which tend to make the fibers slide past one another.

(d) **Cross-Breaking Strength:** This is the resistance to forces which cause the beams to break, and all the above-mentioned forces are involved.

The strength of wood is the most important property in determining the value of any species for structural purposes. It is a very variable property, and is influenced by the density of the wood, the moisture content, the presence of defects and many other factors. Suitability figures for eight different properties have been calculated by taking into consideration the various strength functions of both green and seasoned timber as shown in the following table.

Suitability	*Strength and other properties of wood*
1. **Weight**	Specific gravity based on weight oven dry and the volume of seasoned timber (approximately 12%) moisture content.
2. **Strength as a beam**	Modulus of rupture and fibre stress as the elastic limit in static bending. Fibre stress at the elastic limit in impact bending.
3. **Stiffiness as a beam**	Modulus of elasticity in static bending. Modulus of elasticity in impact bending.

Suitability	Strength and other properties of wood
4. Suitability as a post	Maximum crushing strength and strength at the elastic limit in compression parallel to grain. Modulus of elasticity in static bending.
5. Shock-resisting ability	Work to maximum load and total work in static bending.
6. Retention of shape	Shrinkage green to oven dry in volume and in the radial and tangential directions.
7. Shear	Shearing strength in the radial and tangential directions.
8. Hardness	Fibre stress at the elastic limit in compression perpendicular to the grain. Radial, tangential and end hardness.

(ii) Stiffness: It is the measure of the ability of wood to resist forces that tend to change its shape.

(iii) Toughness: It is referred to the ability of wood to absorb a large amount of energy, and so resist repeated, sudden sharp blows or shock.

(iv) Hardness: It is the measure of the power of wood to resist indentations, abrasion and wear.

(v) Cleavability: It is an expression of the ease with which wood can be split.

(vi) Durability: One of the best things about wood is how long it lasts. Browsing through the daily news, you'll often read that archeologists have unearthed the buried remains of some ancient wooden article—a wooden tool, perhaps, or a simple rowboat or the remnants of a huge building—that are hundreds or even thousands of years old. Providing a wooden object is properly preserved (something else we discuss later), it will easily outlast the person who made it. But just like that person, a wooden object was once a *living* thing—and it's a natural material. Like other natural materials, it's subject to the natural forces of decay through a process known as rotting, in which organisms such as fungi and insects such as termites and beetles gradually nibble away the cellulose and lignin and reduce wood to dust and memories.

3.12 Wood and water

Wood has many other interesting characteristics. It's hygroscopic, which means that, just like a sponge, it absorbs water and swells up in damp conditions, giving out the water again when the air dries and the temperature rises. If, like mine, your home has wooden windows, you'll probably notice that they open much more easily in summer than in winter, when the damp outdoor conditions make them swell into the frames (not necessarily such a bad thing, since it helps to keep out the cold). Why does wood absorb water? Remember that the trunk of a tree is designed to carry water from the roots to the leaves: it's pretty much a water superhighway. A freshly cut piece of "green" wood typically contains a huge amount of hidden water, making it very difficult to burn as firewood without a great deal of smoking and spitting. Some kinds of wood can soak up several times their own weight of water, which is absorbed inside the wood by the very same structures that transported water from the roots of the tree to the leaves when the tree was a living, growing plant.

3.13 Wood and energy

What other properties does wood have? It's a relatively good heat insulator (which comes in handy in building construction), but dry wood does burn quite easily and produces a great deal of heat energy if you heat it up beyond its ignition temperature (the point at which it catches fire, anywhere from around 200–400°C, 400–750°F). Although wood can absorb sound very effectively (another useful property in buildings, where people value sound insulation shutting out their neighbors), wooden objects can also be designed to transmit and amplify sounds—that's how musical instruments work. Wood is generally a poor conductor of electricity but, interestingly, it's piezoelectric (an electric charge will build up on wood if you squeeze it the right way).

3.14 Environmentally friendly

Wood was one of the first natural materials people learned to use, and it's never lost its popularity. These days, it's particularly prized for being a natural and environmentally friendly product. Forestry is a rare example of something that has the potential to be completely sustainable: in theory, if you plant a new tree for every old tree you cut down, you can go on using wood forever without damaging the planet. In practice, you need to replace like with like and forestry is not automatically sustainable, whatever papermakers like us to believe. A brand new tree has much less ecological value than a mature tree that's hundreds of years old so planting a thousand saplings may be no replacement for felling just a handful of ancient trees. Logging can be hugely environmentally damaging, whether it involves clear cutting a tropical rainforest or selectively felling mature trees in old-growth temperate woodland. Some of the processes and chemicals used in forestry and woodworking are also environmentally damaging; chlorine, used to bleach wood fibers to make paper, can cause water pollution in rivers, for example. But on the positive side, growing trees remove carbon dioxide from the atmosphere and planting more of them is one way to reduce the effects of climate change. Trees also provide important habitats for many other species and help to increase biodiversity (the wide range of living organisms on Earth). Practiced the right way, forestry is a good example of how people can live in perfect harmony with the planet.

3.15 Using wood

How does wood get from the tree to the roof of your house, your bookshelf, or the chair you're sitting on? It's a longer and more complex journey than you might think that takes in harvesting, seasoning, preserving and other treatment, and cutting. Here's a brief guide.

3.16 Harvesting

Growing plants for food is called agriculture; growing trees for human use is silviculture and the two things have a great deal in common. Wood is a plant crop that must be harvested just like any other, but the difference is how long trees take to grow, often many years or even decades. How wood is harvested depends on whether trees are growing in plantations (where there are hundreds or thousands of the same species, generally of similar age) or in mature forests (where there's a mixture of different species and trees of widely differing ages).

Planted trees may be grown according to a precise plan and clear-cut (the entire forest is felled) when they reach maturity. A drastic approach like that makes sense if the trees are a fast-growing species planted specifically for use as biomass fuel, for example. Individual trees can also be selectively felled from mixed forests and either dragged away by machine or animal or even (if it makes economic and environmental sense) hauled upward by helicopter, which avoids damaging other nearby trees. Sometimes trees have their bark and small branches removed in the forest before being hauled away to a lumber yard for further processing, though they can also be removed intact, with the entire processing done offsite. It all depends on the value of the tree, the growing conditions, how far away the lumber yard is, and how easy the tree is to transport. Another interesting form of forestry is called coppicing, which involves removing long, thin, low-growing branches from trees such as hazel and willow in a careful and respectful way that does no long-term damage.

3.17 Seasoning

A freshly cut tree is a bit like a sponge that comes presoaked in water, so it has to be completely dried out or seasoned before it can be used. Dry wood is less likely to rot and decay, it's easier to treat with preservatives and paint, and it's much lighter and easier to transport (typically, half a freshly felled tree's weight may come from water trapped inside). Dry wood is also much stronger and easier to build with (it won't shrink so much) and if a tree is destined for burning as firewood (or an energy crop), it will burn more easily and give out more heat if it's properly dried first. Typically wood is dried either in the open air (which takes anything from a few months to a year) or, if speed is important, in vast heated Oven called kilns (which cuts the drying time to days or weeks). Seasoned wood is still not completely dry: its moisture content varies from about 5–20 percent, depending on the drying method and time.

3.18 Preserving and other treatment

In theory, wood might last forever if it weren't attacked by bugs and bacteria; preservatives can greatly extend its life by preventing rot. Different preservatives work in different ways. Paint, for example, works like an outer skin that stops fungi and insects penetrating the wood and eating it away, but sunlight and rain make paint crack and flake away, leaving the wood open to attack underneath. Creosote (another popular wood preservative) is a strong- smelling, oily brown liquid usually made from coal-tar. Unlike paint, it is a fungicide, insecticide, miticide, and sporicide: in other words, it works by stopping fungi, insects, mites, and spores from eating or growing in the wood.

Different kinds of treatment help to protect and preserve wood in other ways. It's a great irony that wood can be used to build a fine home that will last many decades or burn to the ground in minutes. Wood is so plentiful and burns so well that it has long been one of the world's favorite fuels. That's why fire-protection treatment of wooden building products is so important. Typically, wood is treated with fire retardant chemicals that affect the way it burns if it catches fire, reducing the volatile gases that are given off so it burns more slowly and with greater difficulty.

3.19 Cutting

There's a big difference between a tree and the table it might become, even though both are made from exactly the same wood. That difference comes mainly from skillful cutting and woodworking. How much cutting a tree needs depends on the product that's being made?

Something like a utility pole or a fence post is not much more than a tree stripped of its branches and heavily treated with preservatives; that's an example of what' called roundwood. Trees need a bit more work in the sawmill to turn them into lumber, timber, or sawnwood (the three names are often used interchangeably, though they can be used with more specific meanings). Flat pieces of wood can be made from trees by cutting logs in two different directions. If you cut planks with the saw running in lines parallel to the length of the trunk, you get plainsawn (sometimes called flatsawn) wood (with ovals or curves on the biggest flat surface of the wood); if you fell a tree, cut the trunk into quarters, then slice each quarter into parallel planks, you get quartersawn wood (with the grain running along the biggest flat surface in broadly parallel stripes). See how attractive those patterns look? Not surprisingly, wood that's destined for furniture and other decorative uses has to be cut much more thoughtfully and carefully with regard to what's called its figure. This is the way a particular tree is cut to show off the growth patterns it contains in the most attractive way in the final piece of wood. The figure can also depend on which part of a tree is used. Wood cut from near the stump of a tree will sometimes produce a more attractive figure than wood cut from higher up.

3.20 Other wood products

Round wood and sawn wood are what you might call natural wood products, because they involve using cut pieces of tree more or less in raw form. There are many other ways of using trees that involve greater amounts of processing. Some woods are very rare and expensive, while others are cheap and plentiful, so a common technique is to apply an outer layer of expensive and attractive wood to a core of cheaper material. Veneer is a thin decorative layer applied to cheaper wood made by turning a log against a blade, much like peeling an apple.

Using veneer means you can get an attractive wooden finish at much lower cost than by using a solid piece of expensive wood. Plywood is made by taking layers of wood (or plies) and gluing them together with an outer coating of veneer. Typically each ply is placed at 90 degrees to the one underneath so the grains alternate. That means a piece of plywood is usually much stronger than a piece of the natural wood from which it's made. Laminated wood is a weaker kind of plywood in which the grain of each layer runs in the same direction. Particle board (often called chipboard) is made by taking the waste chips, flakes, and sawdust from a mill and forcing it under high pressure, with glue, in a mold so it sticks together to make planks and panels. Low-cost and self-assembly furniture is often made this way. Fiber-board is similar, but made with wood-pulp fibers instead of wood chips and sawdust. Hardboard is a thin sheet of wood made from wood fibers in much the same way. Not all wood products are immediately recognizable as such. A great deal of the paper and cardboard people use is made by turning cellulose from trees into a fibrous pulp, for example Lignin (the other main chemical inside wood) also has many uses, including making plastics (such as the celluloid used in old-fashioned photographic film), paints, turpentine, and yeast products.

Unit-4 Merits and Demerits of Wood

Unit Structure

4.0 Learning objectives

After studying this unit you will be able to understand about:

- Merits and Demerits of Wood
- Defects and abnormalities of wood
- Natural defects, method of evaluation and measurement
- Influence of defects on conversion and utilization
- Defects during processing, manufacturing, seasoning and wood destroying agents

4.1 Introduction

As you know, Timber is one of the important construction materials. Wood is used as structural elements in buildings, widely for doors, windows and partitions and fined large use through secondary wood products like plywood, particle boards and laminated boards, etc. Both hard and soft woods are in use. As such defects in the construction material for buildings will affect the structural safety, aesthetic aspects and even functional use including fire protection. No tree is perfect. It's subject to defects from the time it emerges as a seedling to the last stages of seasoning. A defect is simply an abnormality or irregularity found in wood. There are many different types of defects arising from many different causes. For instance, there are natural and acquired defects caused by a broken limb or other injury, insect and fungal attack, or rapid tree growth. There are innate defects caused by the natural characteristic of wood to shrink or expand in response to water vapor in the air. And, there are artificial and mechanical defects caused by incorrect sawing or machining (conversion), improper drying (seasoning), or improper handling and storage.

Defects may be responsible for reducing wood's economic value, lowering its strength, durability and usefulness, marring its appearance, and in some cases, causing its decay.

4.2 Natural Wood Defects

During its lifetime, a tree is subjected to many natural forces that cause defects in the wood. Woodworkers are quite familiar with these defects – knots, splits, ugly dark streaks or stains, worm holes, even decay. Some of the more common wood defects all woodworkers face include:

Fig.1 Wood Deflects

(i) **Bark pockets –** Formed when a small piece of the bark protrudes into the lumber. This area is generally considered unsound.

(ii) **Bird pecks –** Caused by birds, especially woodpeckers, which peck on trees mainly to cause panic to the insects living in or under the bark and in the wood of the tree. This causes the insects to come out enabling the birds to eat them. Bird pecking can cause small injuries to the tree, resulting in grain changes that later show up as various forms of figure in the wood (figure is the "look" or appearance of a piece of wood).

(iii) **Burls –** Burls are a deformed growth formed when a tree receives a shock or injury in its young age. Due to its injury, the tree's growth is completely upset and irregular projections appear on the body of the timber.

(iv) Continued tree growth follows the contour of the original burl deformity, producing all manner of twists, swirls and knots in the wood fiber. Usually, this results in spectacular patterns in the wood that can be used to great effect in woodworking. Burl wood is normally darker than the rest of the tree and, in some cases, may be a significantly different color altogether.

(v) **Coarse grain –** If the tree grows rapidly, the annual rings are widened. It is known as coarse grain timber and possesses less strength.

(vi) **Fungal damage –** Fungi generally damages timber or wood by discoloration and/or decay. The resulting wood is generally weaker or of a different color than is typical for that species. The more common effects of fungal damage include:

- **Blue stain –** Common in pine, maple, and many other woods, blue stain (also called "sapstain") is caused by a fungus that feeds on the sap. It does not live in live trees due to lack of oxygen. The bluish color (sometimes gray or dark gray) is the fungus itself, not the color of the sapwood. The color does not degrade the cellular structure and does not count against wood in the grading process.
- **Brown rot –** A form of wood decay found only in softwoods that destroys the wood's cellulose, eventually causing cracks across the grain. Advanced brown rot tends to leave the wood more brown than normal. It is a precursor to dry rot.
- **Dry rot –** After the wood infected with brown rot dries out, the cell walls of the remaining wood turns into dry powder when crushed. This is called dry rot.
- **Heart rot –** This is formed when a branch has come out of the tree. The heart wood is exposed to an attack of atmospheric agents. Ultimately, the tree becomes weak and it gives a hollow sound when struck with a hammer.
- **Wet rot –** Some kinds of fungi cause chemical decomposition of a wood's timber and in doing so converts timber into a grayish brown powder known as wet rot. Alternative wet and dry conditions favor the development of wet rot. If unseasoned or improperly seasoned timber is exposed to rain and wind, it easily becomes vulnerable to wet rot attack.
- **White rot –** This is just the opposite of brown rot. In this type of fungi attack, the wood's lignin and the wood itself assumes the appearance of a white mass consisting of cellulose compounds. Some of the white rots

during their early stages of development form what is commercially termed "spalted wood." This wood has a unique color and figure, and some woodworkers highly prize it.

(vii) **Insect defects –** There are a number of insects that eat wood. Many other insects use wood as a nesting place for their larvae which results in holes and tunnels in the wood. The damage they cause ranges from minor to catastrophic. Some of the more common insects include:

- **Wood boring beetles –** Wood boring beetles, such as buprestid, powder post, ambrosia, furniture, and longhorn, tunnel through wood to deposit their larvae. Some larvae eat the starchy part of the wood grain. Many species attack live but usually stressed trees, while others prefer recently dead hosts.
- **Pin-hole borers –** They damage fresh-cut logs and unseasoned lumber, but also attack weakened, stressed, dying trees, and healthy trees with bark injuries.
- **Termites –** Termites not only tunnel through wood in various directions, but eat away the wood from the cross-section core. They usually do not disturb the outer shell or cover. In fact, the timber piece attacked by termites may look sound until it completely fails.

(viii) **Knots –** A knot is the base of a branch or limb that was broken or cut off from the tree. The portion of the remaining branch receives nourishment from the stem for some time and it ultimately results in the formation of dark hard rings known as knots. As the continuity of wood fibers are broken by knots, they form a source of weakness. There are several types of knots:

- **Sound (or tight knots**) are solid and cannot be knocked loose because they are fixed by growth or position in the wood structure. They are partially or completely inter grown with the growth rings.
- **Unsound knots (or loose knots)** are knots which fall out of the lumber when pushed or have already fallen out. They are caused by a dead branch that was not fully integrated into the tree before it was cut down.
- **Encased knots** are those which are not intergrown with the surrounding wood.

- **Knothole** is a hole left where the knot has been knocked out.
- **Spike knots** are limbs which have been cut across or cut lengthwise, showing the endwise or lengthwise section of the limb or knot. These knots generally have splits and severe grain deviations near them.

(ix) **Raised grain –** Anything that gives the wood a corrugated feel. Typically, this is caused by the harder summerwood rising above the softer springwood in the growth ring. The growth rings do not separate.

(x) **Shake –** A lengthwise crack or separation of the wood between the growth rings, often extending along the board's face and sometimes below its surface. Shakes may either partly or completely separate the wood fibers. The separations make the wood undesirable when appearance is important. Although this is a naturally occurring defect possibly caused by frost or wind stress, shakes can also occur on impact at the time of felling and because of shrinkage in the log before conversion. There are two types of shakes:

- **Star Shake:** A group of splits radiating from the pith or center of the tree in the form of a star. It is wider on the outside ends and narrower on the inside ends. Star shakes are usually formed due to extreme heat or severe frost during the tree's growth. Also referred to as heart shake.
- **Ring Shake:** Also known as "cup shake" or "wind shake," this rupture runs parallel to the growth rings. A ring shake is not easily detected in green logs and lumber, but only becomes apparent after drying. It's caused by any one of numerous factors, including bacteria, tree wounds, tree age, and environmental conditions such as excessive frost action on the sap when the tree is young.

(xi) **Split –** A split is a rupture or separation in the wood grain which reduces a board's appearance, strength, or utility. One of the more typical ruptures of this type is called ring shake. In a ring shake (also known as cup shake or wind shake), the rupture runs parallel to the growth rings. It's not easily detected in green logs and lumber, but only becomes apparent after drying. It's caused by any one of numerous factors, including bacteria, tree wounds, tree age, and environmental conditions.

(xii) Stains – Stains are a discoloration that penetrate the wood fiber. They're caused by a variety of conditions and can be any color other than the natural color of the wood. A number of non-wood destroying fungi can cause stains or discoloration. Some stains may indicate decay or bacteria are present.

(xiii) Spalting – Any form of wood discoloration caused by fungi. It's typically found in dead trees, so if the wood isn't stabilized at the right time it will eventually become rotten wood. There are three types of spalting that are typically incorporated into woodworking as design elements: pigmentation ("sapstain"), white rot, and zone lines.

(xiv) Twisted fibers – These are known as wandering hearts and caused by twisting of young trees by fast blowing wind. The timbers with twisted fibers is unsuitable for sawing.

4.3 Wood defects due to conversion

Conversion is the process of converting raw timber to forms suitable for woodworking or construction projects. During this process, the following defects may occur:

(i) Chip mark – Shallow depressions or indentations in the surface of a board caused by shavings or chips getting imbedded in the surface during the process of dressing. They may be formed by a planer or jointer.

(ii) Diagonal grain – Wood in which the annual growth rings are at an angle with the axis of a piece as a result of sawing at an angle. In other words, rather than running parallel to the long edge of a board, for example, the grain runs at an angle to it. Such wood is not permitted for structural applications in the American Forestry Association guidelines because it lacks the same structural strength as an equal-sized piece that has the grain running parallel to the edge.

(iii) Torn grain – An irregularity in the surface of a board where wood fibers below the level of the dressed surface have been torn or broken out by a planer.

(iv) Wane – The presence of bark or the absence of wood on the corners or along the length of a piece of lumber. Wane, in the form of bark, is more commonly associated with rough milled lumber. In the case of construction lumber (e.g., 2x4s), it can be bark or missing wood.

(v) **Machine burn –** A darkening of the wood due to overheating by machine knives or rolls when pieces are stopped in the machine.

(vi) Machine bite – A depressed cut of the machine knives at the end of the piece.

(vii) **Machine gouge –** A groove cut by the machine below the desired line.

4.4 Wood defects due to seasoning

Seasoning is the process of drying lumber (either in a kiln or air drying) to an appropriate level of moisture for woodworking and other commercial uses. During this process, a board may become warped. The term "warped" is a nonspecific term that refers to a distorted or misshapen board. More specific terms for warping include cupping, twisting, bowing, crook, and spring. Common seasoning defects, including types of warping, include:

(i) **Bowing –** A curvature formed in the direction of the length of timber. A bowed board is flat, but bent, like a road going over a hill.

(ii) **Check –** A check is a crack which separates the fibers of wood. It does not extend from one end to the other. It occurs across the growth rings and is usually caused by poor or improper drying processes.

(iii) **Crook –** Where the board remains flat, but the ends move away from the center. Another type of warp.

(iv) **Twisting –** Where the board curves in length and width like a propeller.

(v) **Cupping –** Where the face of a board warps up across its width such that if one looks at the end of the board, it will look like a shallow letter "U." Is common with plain-sawn lumber.

(vi) **Spring –** Occurs when the board remains flat in width, but curves in length like a river going around a bend.

(vii) **Case hardening –** When lumber or timber is dried too quickly, wood shrinks much at the surface, compressing its damp interior. This results in unrelieved stress. Case-hardened wood may warp considerably and dangerously when the stress is released by sawing. Extreme cases of case hardening leads to honeycombing.

(viii) **Honeycombing –** During drying, internal stresses cause various radial and circular cracks to develop in the interior portion of the wood resembling a honeycomb texture. Honeycombing is among the worst of drying defects because it's irreversible and usually cannot be detected by looking at the face of the lumber.

4.5 Dealing with defects

Many woodworkers prefer to avoid wood with defects because they detract from the beauty or value of the finished product. For others, though, defects in their works are often highly prized.

Take, for example, wood microphone maker Greg Heumann of Geyersville, Calif., and tree sculptor Cecil Ross of Bainbridge Island, Wash. They often seek wood with certain defects because they believe they add character to the wood and ultimately their final product.

"Heumann says he love wood with color variations, knots, and insect holes because they make each microphone unique,". "As long as there is no threat to the mic's structural strength, he normally leave them in as is." Ross also seeks wood with blemishes, knots, and holes. "They form the basis or focal point of my sculpture's design," he notes. On the other hand, mandolin maker Austin Clark of Boise, Idaho purposely avoids all defects in the spruce and maple he uses to create his mandolins. "My mandolin customers are pretty traditional, so they want the wood in their instruments to be straightforward. Meaning they need to be free of any defects," he says.

Many woodworkers rely on suppliers to ship them the wood they want. Most suppliers are reputable and they are careful to send their customers wood that is generally free of deformed or irregular wood.

On the other hand, woodworkers who buy their wood from a lumberyard or big box store should carefully check the wood and select only those pieces that are usable. They may have to get permission to sort through the lumber and also promise to restack everything when done.

Not all woodworkers, however, want to sort through stacks of lumber. Instead, they may opt for the most expensive-grade available, whether it's needed or not. There are times when the best grade is the best choice, especially for premium furniture makers, but more often, woodworkers can save money and get good wood for their projects by using lower grades. Often, lower-grade boards display more beautiful figure and character than better boards. The catch to finding these pieces, though, is to know the basics about buying lumber.

Some woodworkers may even obtain wood from fence rows and fields, and perhaps old abandoned barns or other buildings. But they need to be wary of getting wood that might contain bullets, nails, or barbed wire which could damage a saw blade. For most woodworkers, the easiest way to deal with natural defects is to simply avoid using the wood. Another option, though, is to hide the defect. Furniture maker John Landis of Warminster, Pa., says, “At times he use a knot in a tabletop as long as can keep it underneath and it doesn’t pose a structural problem. he won’t sacrifice a beautiful side of a board and use for making a tabletop if the knot is underneath, not visible, and isn’t a structural problem.”

Defects can also play a supporting role – provided they enhance the beauty of a piece. For instance, when Landis comes across wood that has attractive burls, he rarely uses it as a slab in and of itself because the wood is usually unstable. Instead, he slices it into quarter-inch thick pieces and applies it to a stable backing inside door panels or uses it as a veneer on furniture. Wood sculptor Jose Rivera from San Antonio, Texas, works with various woods, especially mesquite. He often encounters mesquite with knots and longhorn beetle holes, but has learned to incorporate them into his finished pieces.

According to Rivera “knots are common in mesquite, they add to the beauty and characteristic of the wood.” “As for the insect holes, he prefers not having them. But they do appear in some of my pieces. Actually, the holes are acceptable to my clients because most of them know that’s how mesquite wood is.”

4.6 Moisture-related defects

Wood is a hygroscopic material. This means it naturally absorbs and releases water (moisture) to balance its internal moisture content with the surrounding environment. Because wood retains its hygroscopic nature after it is put into use, it is subjected to fluctuating humidity. Shrinkage and swelling may occur in wood when there are changes in humidity and temperature. This may eventually result in cracks, gaps, and weak joints.

One major problem that occurs when drying wood is the tendency of its outer layers to dry out more rapidly than the interior ones. If these layers are allowed to dry much below the fiber saturation point while the interior is still saturated, drying stresses are set up because the shrinkage of the outer layer is restricted by the wet interior. Rupture in the wood tissues occurs, and consequently splits and cracks occur if these stresses across the grain exceed the strength across the grain.

Since wood shrinks and changes shape as it dries, the bulk of that shrinkage and change of shape should occur before a woodworker starts working with it. The amount of shrinkage varies from species to species, but generally wood shrinks 8 to 10 percent tangentially, 4 to 5 percent radially, and close to zero percent lengthwise. In other words, the surface of the board where the grain intersects it perpendicularly, or close to perpendicularly, shrinks the most. This means woods of different shapes will shrink differently based on how they're cut from the tree.

Some kiln-dried wood can change 1/8" to ¼" in width for every foot. They may not seem like much, but when you add it up, a 4-foot wide table can vary in width by as much as an inch from dry season to wet season.

4.7 Moisture changes and wood defects

Moisture, therefore, is certainly the most important factor affecting the performance and service life of wood and wood products. Because moisture affects the dimensional movement of wood and wood products, under certain conditions moisture change can lead to major dimensional change. Once kiln-dried wood arrives, woodworkers should store the wood in a climate-controlled shed or shop in order to avoid wood movement. Seasonal changes in humidity can cause wood to shrink or swell.

Some woodworkers, however, prefer to buy green lumber and dry it themselves – either by air drying or using a solar kiln. This can help offset the high price of kiln-dried lumber. Depending on where wood is stored and under what conditions, wood can easily absorb or release moisture. For that reason, all wood should be monitored regularly and certainly before use in order to avoid moisture-related problems.

This is one of the reasons why more woodworkers today are using moisture meters to prevent problems such as warping, loose joints, or cracked tabletops.

Source:

https://www.wagnermeters.com/

Unit-5 Physical Properties of Wood: The physical features of wood

Unit Structure

5.0 Learning objectives.

After studying this unit you will be able to understand:

- Directional Properties of wood
- Moisture Content of wood
- Dimensional Stability of wood
- Thermal Expansion of wood
- Pyrolytic Properties of wood
- Density and Specific Gravity of wood
- Electrical Resistance of wood
- Decay Resistance of wood
- Chemical Resistance of wood

5.1 Introduction

5.1.1 Physical properties of wood

Physical properties are the quantitative characteristics of wood and its behavior to external influences other than applied forces. Included here are directional properties, moisture content, dimensional stability, thermal and pyrolytic (fire) properties, density, and electrical, chemical, and decay resistance. Familiarity with physical properties is important because they can significantly influence the performance and strength of wood used in structural applications.

The physical properties of wood most relevant to structural design and performance are discussed in this section. The effects that variations in these properties have on the strength of wood are more fully discussed in previous units.

5.2 Directional Properties

Wood is an orthotropic and anisotropic material. Be- cause of the orientation of the wood fibers and the manner in which a tree increases in diameter as it grows, properties vary along three mutually perpendicular axes: longitudinal, radial, and tangential (Fig. 3). The longitudinal axis is parallel to the fiber (grain) direction, the radial axis is perpendicular to the grain direction and normal to the growth rings, and the tangential axis is perpendicular to the grain direction and tangent to the growth rings. Although most wood properties differ in each of these three axis direc- tions, differences between the radial and tangential axes are relatively minor when compared to differ- ences between the radial or tangential axis and the longitudinal axis. Property values tabulated for struc- tural applications arc often given only for axis direc- tions parallel to groin (longitudinal) and perpendicular to grain (radial or tangential).

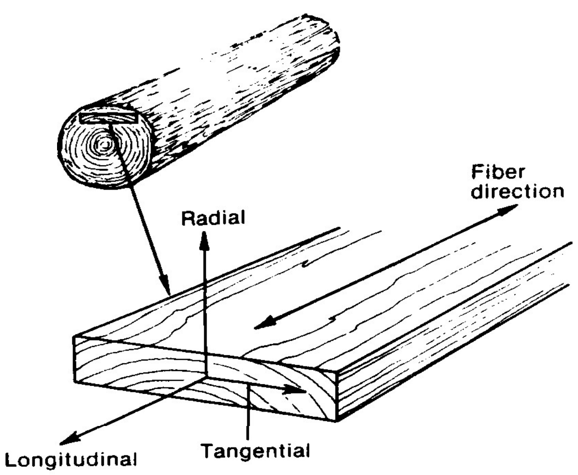


FIG. 3 Three principal axes of wood with respect to grain direction and growth rings

5.3 Moisture Content

The moisture content of wood is defined as the weight of water in wood given as a percentage of ovendry weight. In equation form, moisture content (MC) is expressed as follows:

$$MC = \frac{\text{Moist Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100\% . \qquad (1)$$

Water is required for the growth and development of living trees and constitutes a major portion of greenwood anatomy. In living trees, moisture content depends on the species and the type of-wood, and may range from approximately 25% to more than 250% (two and a half times the weight of the dry wood material). In most species, the moisture content of sapwood is higher than that of heartwood.

Water exists in wood either as bound water (in the cell wall) or free water (in the cell cavity). As bound water, it is bonded (via secondary or hydrogen bonds) within the wood cell walls. As free water, it is simply present in the cell cavities. When wood dries, most free water separates at a faster rate than bound water because of accessibility and the absence of secondary bonding. The moisture content at which the cell walls are still saturated but virtually no water exists in the cell cavities is called the fiber saturation point. The fiber saturation point usually varies between 21 and 28%.

Wood is a hydroscopic material that absorbs mois- ture in a humid environment and loses moisture in a dry environment. As a result, the moisture content of wood is a function of atmospheric conditions and depends on the relative humidity and temperature of the surrounding air. Under constant conditions of temperature and humidity, wood reaches an equilib- rium moisture content (EMC) at which it is neither gaining nor losing moisture. The EMC represents a balance point where the wood is in equilibrium with its environment.

In structural applications, the moisture content of wood is almost always undergoing some changes as temperature and humidity conditions vary. These changes are usually gradual and short-term fluctua- tions that influence only the surface of the wood. The time required for wood to reach the EMC depends on the size and permeability of the member, the tem- perature, and the difference between the moisture content of the member and the EMC potential of that environment. Changes in moisture content cannot be entirely stopped but can be retarded by coatings or treatments applied to the wood surface.

5.4 Dimensional Stability

Above the fiber saturation point, wood will not shrink or swell from changes in moisture content because free water is found only in the cell cavity and is not associated within the cell walls. However, wood changes in dimension as moisture content varies be- low the fiber saturation point. Wood shrinks as it loses moisture below the fiber saturation point and swells as it gains moisture up to the fiber saturation point. These dimensional changes may result in split- ting, checking, and warping. The phenomena of dimensional stability and EMC must be understood, recognized in good timber design.

Dimensional stability of wood is one of the few properties that significantly differ in each of the three axis directions. Dimensional changes in the longitudinal direction between the fiber saturation point and oven dry are between 0.1 and 0.2% and are of no practical significance; however, in reaction or juvenile wood, these percentages may be significantly higher. The combined effects of shrinkage in the tangential and radial axes can distort the shape of wood pieces because of the difference in shrinkage and the curvature of the annual rings (Fig. 4). Generally, tangential shrinkage (varying from 4.4 to 7.8% depending on species) is twice that of radial shrinkage (from 2.2 to 5.6%).

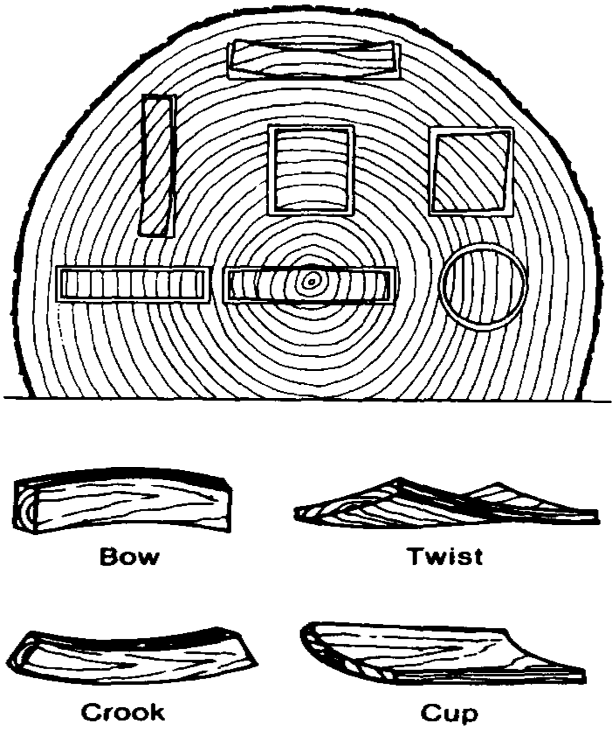


FIG. 4 Characteristic shrinkage and distortion of wood as affected by direction of growth rings. Such distortion can result in warp, generally classified as bow, twist, crook, and cup.

5.5 Thermal Expansion

Thermal expansion of dry wood is positive in all directions; wood expands when heated and contracts when cooled. Wood that contains moisture reacts to temperature changes differently than dry wood.

The linear expansion coefficients of dry wood par- allel to grain are generally independent of specific gravity and species and range from approximately 3 x 10^{-6} to 4.5 x 10^{-6} per °C. The linear expansion coefficients across the grain (tangential and radial) are in proportion to density and range from approxi- mately 5 to 10 times greater than parallel to grain coefficients.

When moist wood is heated, it tends to expand because of normal thermal expansion and shrink be- cause of moisture loss from increased temperature. Unless the initial moisture content of the wood is very low (3 to *4%),* the net dimensional change on heating is negative. Wood at intermediate moisture contents of approximately 8 to 20% will expand when first heated, then gradually shrink to a volume smaller than the initial volume as moisture is lost in the heated condition.

5.6 Pyrolytic Properties

Under appropriate conditions, wood will undergo thermal degradation or pyrolysis. The by-productsof pyrolysis may burn, and if enough heat is generated and retained by the wood, the wood can be set on fire. In the presence of a pilot flame (independent source of ignition), the minimum rate of heating necessary for ignition is of the order of 0.3 calorie per square centimeter. In the absence of a pilot flame, the minimum rate of heating necessary for ignition is of the order of 0.6 calorie per square centimeter, nearly double the rate of the pilot flame situation. Still, heavy timber construction deserves an extremely favorable fire-insurance rating because it will generally not produce sufficient heat energy to maintain combustion unless an external heat source is present. Timber will gradually produce a char layer from the residue of wood combustion. This char acts as a thermal insulator. On heavy timbers, this char layer will eventually inhibit combustion by establishing a thermal barrier between the uncharred wood (interior to char) and the heat of the fire (exterior to char). Heavy timber is virtually self-extinguishing, but steel, which has a thermal conductivity 100 times that of wood, will absorb heat until it reaches a temperature at which it yields under structural load without actually burning.

5.7 Density and Specific Gravity

The density of a material is the mass per unit volumeat some specified condition. For a hydroscopic material such as wood, density depends on two factors: the weight of the wood structure and moisture retained in the wood. Wood density at various moisture contents can vary significantly and must be given relative to a specific condition to have practical meaning.

Specific gravity provides a relative measure of the amount of wood substance contained in a sample of wood. It is a dimensionless ratio of the weight of an oven dry volume of wood to the weight of an identical volume of water. In research activities, specific gravity may be reported on the basis of both weight and volume oven dry. For many engineering applications, the basis for specific gravity is generally the oven dry weight and volume at a moisture content of 12%. For example, a volume of wood at some specified moisture content with a specific gravity of 0.50 would have a density of 500 kg/m^3.

5.8 Electrical Resistance

Wood is a good electrical insulator. However, significant variations in conductivity do exist. These variations in electrical resistance can be related to variations in grain orientation, temperature, and moisture content. The conductivity of wood in the longitudinal axis is approximately twice that in the radial or tangential axes. The electrical conductivity of wood generally doubles for each 10^{o}C increase in temperature. Generally, variations in conductivity related to wood density and species are considered minor.

The correlation between electrical resistivity and moisture content is the basis for electrical resistance- type moisture meters that estimate moisture content by measuring the resistance of the wood between two electrodes. Moisture content meters, as these instruments are commonly called, need to be calibrated for temperature and species and are effective only for moisture content ranges of 5 to *25%.* They are generally unreliable for high resistivity at moisture con- tents below 5 or 6%, for estimating the moisture content of green timber, or for estimating moisture content of treated timbers (most treatments alter conductivity).

5.9 Decay Resistance

Wood decay fungi and wood-destroying organisms require oxygen, appropriate temperature, moisture, and a food source. Wood will not decay if kept dry (moisture content less than 20%). On the other hand if continuously submerged in water at sufficient depths wood will usually not decay. Whenever wood is intermediary to either of these two extremes, problems with wood decay can result. To avoid problems with decay where moisture cannot be controlled, the engineer or designer can use either naturally durable species or treated timber. The natural durability of wood to the mechanisms and processes of deterioration is related to the anatomical characteristics and species of wood. In general, the outer zone or sapwood of all species has little resistance to deterioration and fails rapidly in adverse environments. For heartwood, natural durability depends on species. Heartwood forms as the living sap- wood cells gradually die. In some species, the sugars present in the cells are converted to highly toxic extractives that are deposited in the wood cell wall. Many species produce durable heartwood, including western red cedar, redwood, and black locust; how- ever, durability varies within a tree and between trees of a given species. To enhance durability, wood can be treated with an EPA-registered, toxic preservative chemical treatment.

5.10 Chemical Resistance

Wood is highly resistant to many chemicals, which gives it a significant advantage over many alternative building materials. Wood is often considered superior to alternative materials, such as concrete and steel, partly because of its resistance to mild acids (pH more than 2.0), acidic salt solutions, and corrosive agents. Generally, iron holds up better on exposure to alkaline solution than does wood, but wood can be treated with many of the common wood preservatives (e. g., creosote) to greatly enhance its performance in this respect. Heartwood is far more durable than sapwood to chemical attack because heartwood is more resistant to penetration by liquids. Many preservative treatments, such as creosote or pentachlorophenol in heavy oil, can also significantly increase the ability of wood to resist liquid or chemical penetration, or both. Chemical solutions may induce two general types of action: normal reversible swelling by a liquid and irreversible chemical degradation. With the former, removal of the liquid will return wood to its original condition. With the latter, permanent changes occur within the wood structure from hydrolysis, oxidation, or delignification.

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Unit-6 Mechanical properties of wood

Unit Structure

6.0 Learning objectives.

After studying this unit you will be able to understand about:

- The mechanical properties of wood
- Wood Elasticity
- Strength Properties of wood
- Energy Absorption Resistance of wood
- Factors Affecting Properties of Wood

6.1 Introduction

6.1.1 Mechanical properties

Mechanical properties are the characteristics of a material in response to externally applied forces. They include elastic properties, which characterize resistance to deformation and distortion, and strength properties, which characterize resistance to applied loads. Mechanical property values are given in terms of stress (force per unit area) and strain (deformation resulting from the applied stress). The mechanical property values of wood are obtained from laboratory tests of lumber of straight-grained clear wood samples (without natural defects that would reduce strength, such as knots, checks, splits, etc.).

6.2 Elastic Properties

Elastic properties relate the resistance of a material to deformation under an applied stress to the ability ofthe material to regain its original dimensions when the stress is removed. For a material with ideal elastic properties loaded below the proportional (elastic) limit, all deformation is recoverable and the body returns to its original shape when the stress is re- moved. Wood is not ideally elastic in that some deformation from loading is not immediately recovered when the load is removed; however, residual deformations are generally recoverable over a period of time. Although technically considered a visco-elastic material, wood is usually assumed to behave as an elastic material for most engineering applications.

For an isotropic material with equal property values in all directions, elastic properties are measured by three elastic constants: modulus of elasticity (E), modulus of rigidity (G) and poisons ratio (μ). The following equation shows the relationship:

$$\mu_{ij} = E_k/G_{ij}, \qquad (2)$$

where i, j, and k represent the three principal axes. Because wood is orthotropic, 12 constants are required to measure elastic behavior: three moduli of elasticity, three moduli of rigidity, and six Poisson's ratios.

6.2.1 Modulus of Elasticity: Modulus of elasticity relates the stress applied along one axis to the strain occurring on the same axis. The three moduli of elasticity for wood are denoted EL, ER, and ET to reflect the elastic module in the longitudinal, radial, and tangential directions, respectively. For example, EL relates the stress in the longitudinal direction to the strain in the longitudinal direction.

Elastic constants vary within and between species and with moisture content and specific gravity. The only constant that has been extensively derived from test data is EL. Other constants may be available from limited test data but are most frequently developed from material relationships or by regression equations that predict behavior as a function of density.

(i) Shear Modulus: Shear modulus relates shear stress to shear strain. The three shear module for wood are denoted GLR, GLT, and GRT for the longitudinal-radial, Longitudinal tangential and radial tangential planes respectively. For example, GLR is the modulus of rigidity based on the shear strain in the LR plane and the shear stress in the LT and RT planes.

(ii) Poisson's Ratio: Poisson's ratio relates the strain parallel to an applied stress to the accompanying strain occurring laterally. For wood, the six Poisson's ratios are denoted μ_{LR}, μ_{LT} μ_{RL}, μ_{RT}, μ_{TL} and μ_{TR}. The first subscript refers to the direction of applied stress; the second subscript refers to the direction of the accompanying lateral strain. For example, is the Poisson's ratio for stress along the longitudinal axis and strain along the radial axis.

6.3 Strength Properties

Strength properties me the ultimate resistance of a material to applied loads. With wood, strength varies significantly depending on species, loading condition, load duration, and a number of assorted material and environmental factors.

Because wood is anisotropic, mechanical properties also vary in the three principal axes. Property values in the longitudinal axis are generally significantly higher than those in the tangential or radial axes. Strength- related properties in the longitudinal axis are usually referred to as parallel-to-grain properties. For most engineering design purposes, simply differentiating between parallel- and perpendicular-to-grain proper- ties is sufficient because the relative tangential and radial directions are randomized by the primary sawing process (i. e., conversion from logs to boards).

6.3.1 Compression

When a compression load is applied parallel to grain, it produces stress that deforms (shortens) wood cells along their longitudinal axis. When wood is stressed in compression parallel to grain, failure initially begins as the micro fibrils begin to fold within the cell wall, thereby creating planes of weakness or instability within the cell wall. As stress in compression parallel to grain continues to increase, the wood- cells themselves fold into S shapes forming visible wrinkles on the surface. Large deformations occur from the internal crushing of the complex cellular structure. The average strength of green clear wood specimens of Douglas-fir and loblolly pine in compression parallel to grain is approximately 26.1 and 24.2 MPa, respectively.

When a compression load is applied perpendicular to grain, it produces stress that deforms the wood cells perpendicular to their length. Once the hollow cell cavities are collapsed, wood is quite strong because no void space exists. In practice, compressive strength of wood perpendicular to grain is usually assumed to be exceeded when deformation exceeds *4%.* of the proportional limit stress. Using this convention, the average strength of green clear wood specimens of Douglas-fir and loblolly pine in compression perpendicular to grain is approximately 4.8 and 4.6 MPa, respectively.

Compression applied at an angle to the grain produces stresses that act both parallel and perpendicular to grain. The strength at any intermediate angle is intermediate to values of compression parallel and perpendicular to grain and is determined using Han- Kinson's formula.

6.3.2 Tension

Parallel to its grain, wood is very strong in tension. Failure occurs by a complex combination of two modes: cell-to-cell slippage and cell wall failure. Slippage occurs where two adjacent cells slide past one another. Cell wail failure involves rupture within the cell wall with little or no visible deformation prior to complete failure. Tensile strength parallel to grain for clear wood has been historically difficult to obtain; it is often conservatively estimated from bending test values because clear wood normally exhibits initial failure on the face stressed in tension.

In contrast to tension parallel to grain, wood is relatively weak when loaded in tension perpendicular to grain. Stresses in this direction act perpendicular to the cell lengths and produce splitting or cleavage along the grain, which can have a significant effect on structural integrity. Deformations are usually low prior to failure because of the geometry and structure of the cell wall cross-section. Strength in tension perpendicular to grain for clear green samples of Douglas-fir and loblolly pine average 2.1 and 1.8 MPa, respectively. However, because of the excessive variability associated with ultimate stress in tension perpendicular to grain design situations that induce this stress should be avoided.

6.3.3 Bending

Flexural (bending) properties are critical. Bending stresses are induced when a material is used as a beam, such as in a floor or rafter system. The bending strength of clear Dougias-fir and loblolly pine aver- ages 52.6 and 50.3 MPa, respectively, while the modulus of elasticity averages 10.7 and 9.7 GPa, respectively. Because tensile and compressive strengths parallel to grain are different from each other, the strength in bending is less than in tension but more than in compression.

6.3.4 Shear

When used as a beam, wood is exposed to compression stress on one surface of the beam and tensile stress on the other. This opposition of stress results in a shearing action through the section of the beam. This parallel-to-grain shearing action is termed horizontal shear. The horizontal shear strength of clear Douglas-fir and loblolly pine averages 6.2 and 5.9 MPa respectively. Conversely, when stress is applied perpendicular to the cell length in a plane parallel to grain, this action is termed rolling shear. Rolling shear stresses produce a tendency for the wood cells to roll over one another. In general, rolling shear strength values for clear specimens average 18to 28% of the parallel-to-grain shear values.

6.4 Energy Absorption Resistance

Energy absorption or shock resistance is a function of the ability of a material to quickly absorb and then dissipate energy via deformation. Wood is remark- ably resilient in this respect and is often a preferred material for shock loading. Several parameters are used to describe energy absorption depending on the eventual criteria of failure considered. Work to proportional limit, work to maximum load, and work to total failure (i. e., toughness) describe the energy absorption of wood materials at progressively moresevere failure criteria.

6.5 Fatigue

The fatigue resistance of wood is sometimes an important consideration. Wood, like many fibrous materials, is quite resistant to fatigue (i. e., the effectsof repeated loading). In many crystalline metals, repeated loadings of 1 to 10 million cycles at stress levels of 10 to 15%. of ultimate can induce fatigue- type failures. At comparable stress levels, the fatiguestrength of wood is often several times that of most metals.

6.6 Hardness

Hardness represents the resistance of wood to indentation and marring. Hardness is comparatively measured by force required to embed a 11.3-mm ball one-half its diameter into the wood.

6.7 Factors Affecting Properties of Wood

To this point, our discussions of wood properties have mostly been based on tests of straight-grained specimens of clear wood. Clear wood properties are important, but by no means do they totally represent the engineering performance of solid-sawn lumber, timber or glulam (glued-laminated timber) containing knots, slope of grain, and other strength- reducing characteristics. To understand the properties of these end-use products, the user must appreciate the impacts of several anatomical and processing- related factors. The user must also appreciate the interactive nature of environmental factors. This section will attempt to briefly relate the importance of many of these factors independently and in aggregate.

6.7.1 Anatomical Factors

The mechanical properties of wood vary between species; they are often compared via species averages. However, because mechanical properties vary within a species, it is incorrect to think that all material of Species A is stronger than material of Species B if, for example, average values are 10 to 15% different.

(i) **Specific Gravity and Density**: The property values of wood increase with increasing specific gravity (SG). While density is a measure of weight per unit volume often reported with kilograms per cubic meter, SG is a dimensionless ratio of the density of wood at specified moisture content to the density of water. Because changes in moisture contents result in dimensional changes, SG and density should be compared at the same moisture content. Specific gravity is an index of mechanical property values of wood free from defects; the higher the SG, the higher the appropriate property value. However, SG and density values for lumber are also affected by the presence of gums, resins, and extractives, which contribute little to mechanical properties.

(ii) **Knots**: A knot is that portion of a branch that has become incorporated in the bole of the tree. The influence of a knot on mechanical properties of a wood member is due to the interruption of continuity and change in direction of wood fibers associated with a knot. The influence of a knot depends on its size, its location, its shape, its soundness, and the type of stress measured. Most mechanical property values are lower at sections containing knots. Knots generally have a greater effect on tensile strength than on compressive strength. For this reason, knots have their greatest influence in the tension zone when exposed to bending stress. The effects of knot size, type, and location are specifically addressed by the grading rules that specify limits for each commercially marketed species-size–grade combination.

(iii) Slope of Grain: The mechanical properties of wood are quite sensitive to fiber and ring orientation. For example, parallel-to-grain tensile or compressive strength property values are generally 10 to 20 times greater than those perpendiculars to grain. Deviations from straight grain in a typical board are termed slope of grain or cross-grain. The terms relate the fiber direction to the edges of the piece. Any form of cross- grain can have detrimental effects on mechanical properties.

(iv) Juvenile Wood: During the first 5 to 20 years of growth, the immature cambial tissue produces wood cells with distinct variations in micro-fibril orientation throughout the important S_2 layer of the cell wall. This wood is referred to as juvenile wood. Juvenile wood exhibits excessive warp age because of anatomical differences within this S_2 layer of the cell wall. It also exhibits lower strength properties and becomes a problem within the wood industry because of the trend toward processing younger, smaller diameter trees as the larger diameter, old-growth stock becomes more difficult to obtain.

(v) Creep: Wood is a visco-elastic material. Initially, it will act elastically, experiencing nearly full recovery of load- induced deformation upon stress removal. However, wood will experience non-recoverable deformation upon extended loading. This deformation is known as creep. For example, the magnitude of additional creep-related deformation after a 10-year loading will roughly equal the initial deformation caused by that load. The rate of creep increases with increasing temperature and moisture content.

6.7.2 Environmental

Moisture Content: Mechanical property values of wood increase as wood dries from the fiber saturation point to 10 to 15% moisture content. For clear wood, mechanical property values continue to increase as wood dries below 10 to 15% moisture content. For lumber, studies have shown that mechanical property values reach a maximum at about 10 to 15% moisture content then begin to decrease with decreasing moisture con- tent below 10 to 15%. For either product, the effects of moisture content are considered to be reversible in the absence of decay.

Temperature: Strength and stiffness decrease when wood is heated and increase when cooled. The temperature effect is immediate and, for the most part, reversible for short heating durations. However, if wood is exposed to elevated temperatures for an extended time, strength is permanently reduced because of wood substance degradation and a corresponding loss in weight. The magnitude of these permanent effects depends on moisture content, heating medium, temperature, exposure period, and to a lesser extent, species and specimen size. As a general rule, wood should not be exposed to temperatures above 65°C. The immediate effect of temperature interacts with the effect of moisture content so that neither effect can be completely understood without consideration of the other.

Decay and Insect Damage: Wood is conducive to decay and insect damage in moist, warm conditions. Decay within a structure cannot be tolerated because strength is rapidly reduced in even the early stages of decay. It has been estimated that a *5%* weight loss from decay can result in strength losses as high as 50%. If the warm, moist conditions required for decay cannot be controlled, then the uses of naturally decay resistant wood species or chemical treatments are required to impede decay. Insects, such as termites and certain types of beetles, can be just as damaging to mechanical performance. Insect infestation can be controlled via mechanical barriers, naturally durable species, or chemical treatments.

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Unit-7 Seasoning of woods

Unit Structure

7.0 Learning objectives.

After studying this unit you will be able to understand:

- What is wood seasoning
- Principles and methods of wood seasoning
- Kinds of seasoning air, solar and klin seasoning
- Seasoning defects and their control

7.1 Introduction

Wood Seasoning is gradual removal of moisture from timber without degrading health of timber. Seasoning of timber is essentially a drying process of timber wherein undesired water present in freshly cut timber is gradually removed in controlled manner so that timber becomes fit for making any product. Freshly cut wood may contain as much water as up to two-third of its un- dried volume in form of moisture. Before making a product out of wood, it passes through series of processing steps like sawing in required sizes in a saw mill, seasoning of wood in a kiln, product manufacturing (cutting, thickness , sanding, boring, mortising etc.) finishing. After sawing of timber, it is sent to kilns for seasoning process wherein undesired water present in wood is removed to certain level to make the timber suitable for making a product. If product it made without seasoning the timber, the product fails due to its poor strength properties and other physical qualities. For example, if a cricket bat is made out of unseasoned *Salix alba* wood, its impact strength will be poor and the bat will not give the desired stroke for hitting a ball out of boundary.

Freshly felled timber contains large quantity of moisture, in many cases moisture content inwood is more than 100% based on the oven-dried weight of the timber. For the satisfactory performance of the timber, it is essential to remove this excess water from the timber before making any product out of it. Seasoning improves overall quality of timber and makes it fit for making a good quality product. It is like 'older is the rice better is its quality' in terms of tasteand texture after cooking. The older rice gradually gets seasoned with time in go downs that's why it is costlier than the fresh rice. It is appropriate to say that wood seasoning is an art highly blended with science. It requires lot of practice to become an efficient wood seasoning kiln operator. The scientific input to an experienced kiln operator saves lot of wood from wastage.

7.1.1 Difference between Drying and Seasoning

Both the processes are essentially same but seasoning is little more than drying. Let us understand this by one practical example of our day-to-day life. After taking shower bath in the morning, we generally hang our towel under the Sun for drying so that it can be reused next time.In case of a dark colored shirt, we dry it under shade after washing it because we are concerned about its color and it should not fade. In drying we are not bothered about the health of wood whereas in case of seasoning we take lot of care of health of wood so that it should not develop defects like warping, end splitting etc. Thus in drying, water is removed from wood in uncontrolled manner often resulting drying degrades in wood where as in seasoning water is removed from wood gradually in controlled manner so that drying degrades are under control.

7.1.2 Benefits of Seasoning

Freshly felled timber contains large quantity of moisture, in many cases it is more than 100% based on the oven-dried weight of the timber. For satisfactory performance of timber it is essential to remove this excess water from timber when in the green condition. During the removal of this moisture, wood shrinks and if the process of drying is not properly carried out in a specific controlled manner, this shrinkage results in several defects and degrades in the timber. Wood seasoning is one of the most important processing steps wherein wood is dried to specific moisture content depending on the surrounding atmospheric conditions in a controlled way. The primary objective of wood seasoning is to enhance the wood properties, minimizing any quality losses and thereby make timber more valuable. Some of the major advantages of wood seasoning are as follows:

- Timber with less than 20% maximum content (MC) has no risk of developing stain, decay or mould as a result of fungal activity.
- Seasoned timber is typically more than twice as strong as wet timber.
- Seasoning improves nail and screw holding properties of wood.
- Seasoned timber is lighter and hence transportation and handling cost are reduced.
- Wood seasoning results in dimensional stability in timber while in service. Products made from wet wood often shrink substantially as the wood dries.
- Gluing, machining and finishing are much easier to accomplish with seasoned wood.
- Timbers which are to be chemically treated with wood preservatives have to be properly dried to allow for quick penetration of the treating chemicals.
- Seasoned timber exhibits better electrical and thermal insulation properties.

7.1.3 Factors Affecting Drying Rate of Timber

In case of commercial production of wooden articles, seasoning of timber plays an important role in value addition to wooden articles. In business, time is an important factor. Seasoning of timber generally takes many days and is more time consuming and energy intensive process as compared to other processes of product manufacturing. Hence, it becomes essential to understand the factors affecting drying rate of timber. Drying rate of timber is volume of moisture removed from timber per unit time. Normally it is represented by moisture content percentage removed per day (MC %/Day). The three essential things required for seasoning of timber are: heat, air flow, humidity. Heat works as a force to bring out moisture from core of wood to its surfaces. Air flow helps in transferring the heat evenly through wood stack in kilns, and humidity maintainsthe health of timber by avoiding over-drying of timber and release of tension from timber insidea kiln.

The rate of drying of wood is governed by an interaction of the external drying conditions, viz., temperature, relative humidity, rate of air circulation, and the rate of moisture diffusion withinthe wood, as detailed below-

- **(i) Temperature:** If relative humidity is kept constant, the higher is temperature the higher is dryingrate. Temperature influences the drying rate by increasing the moisture-holding capacity of air, as well as by accelerating the rate of diffusion of moisture through the wood.
- **(ii) Relative Humidity:** If temperature is kept constant, lower relative humidity results in higher drying rates. This is affected by increased moisture gradient in wood, resulting from the reduction of moisture content of surface layers when the relative humidity of air is reduced.
- **(iii) Air circulation:** With constant temperature and relative humidity, the higher possible drying rateis obtained by rapid circulation of air across the surface of the wood. This is brought about by therapid removal of moisture evaporating from the wood, so that the relative humidity of air in contact with wood is not allowed to rise beyond the relative humidity being maintained in the body of the drying air.
- **(iv) Species:** Some species dry much faster than others. This is mainly related to the resistance whichwood offers to moisture diffusion, which is governed by the dimensions, alignment and structure of capillary system of wood, and the nature and extent of plugging of this structure by gums, extractives, organic growth like tyloses, pit aspiration, etc.
- **(v) Initial moisture content:** The amount of moisture contained in wood affects the time required tobring it to given moisture content. As a general rule, wood dries at a faster rate when green. The rate decreases with decrease of moisture content under constant drying conditions. This isbecause initially the

evaporation from green wood is confined to the surface layers, which can dry by direct evaporation of the moisture into the surrounding air. Afterwards, the rate of outward diffusion of moisture within the wood becomes controlling factor, as moisture has to be brought out from the interior to the surface for further evaporation.

(vi) **Grain direction:** Wood dries much more rapidly in the longitudinal direction than in transverse direction. The rate of drying from end-grain is 10 to 15 times faster than from the radial or tangential surfaces. In practice, however, timber is mostly sawn with its length conforming to the general direction of grain and with the width and thickness transverse to the grain. Because of the large difference between longitudinal and transverse dimensions, drying of timber in common commercial size timber occurs mostly from its lateral faces by transverse movement rather than from the end-grain faces by longitudinal movement of moisture

(vii) **Thickness:** Thicker timber requires more time to reach given moisture content than the thinner timber.

7.1.4 Classification of wood species based on their refractoriness to seasoning

For the purpose of seasoning, timbers are classified into three classes depending upon their behaviour with respect to cracking and splitting, and drying rate while seasoning (IS 1141:1993):

(i) **Class A (Highly refractory woods):** These are slow drying timbers and difficult to season free from cracking and splitting. Examples are heavy structural timbers, such as Sal (*Shorea robusta*) and Laurel (*Terminalia alata*). Their permeability (ease of movement of water inside wood) is very poor. They are kiln dried using Schedule no 5, 6, 7 as given in IS:1141. They take lot of time (28-35 days) to season in the range of 12-8 % moisture content.

(ii) **Class B (Moderately refractory woods):** These timbers may be seasoned free from surface and end cracking within reasonable short time periods, given a little protection against rapid drying conditions. Examples are moderately heavy furniture class of timbers, such as Shisham (*Dalbergia sissoo*) and Teak

(*Tectona grandis*). They are kiln dried using schedule no. 3 and 4. They take 18 -25 days to season in the range of 12-8 % moisture content.

(iii) Class C (Non-refractory woods): These timbers may be rapidly seasoned free from surface and end cracking even in open air and sun. If not rapidly dried, they develop blue stain and mould on the surface. Examples are light broad leaved (hardwood) species for packing cases, such as Semul (*Bombax spp.*) and Salai (*Bosewellia serrata*), and almost all coniferous species. They are kiln dried using schedule no. 1 and 2 and take 5-8 days to season in the range of 12-8 % moisturecontent.

7.2 Methods of Determination of Moisture Content in Wood and Bamboo

Before seasoning of timber and bamboo, one needs to know the moisture content present in the wood and bamboo. There are many devices present in the market for the purpose, like pin type moisture meters and sensor based moisture meters. These moisture meters have their own working limitations also. The methodof oven drying the timber for moisture determination, as recommended in IS: 11215, 1991 is more reliable as it is based on average weight loss of timber during oven drying. In this method, 12 to 20 mm long moisture strip is cut from middle portion of a timber length andweighed in a digital balance with least count of 1 mg. The strip is then kept inside a laboratory oven for drying in a temperature 103±2 ^{0}C. After 24 hours of oven drying, the strip is taken out and weighed again. Then again it is kept inside the oven in same temperature and weighed in every two hours till its weight becomes stable (does not decrease further). The stable weight indicates that all the moisture present in wooden strip has been removed and its moisture content at this stage is practically zero. This final weight is called its oven-dried weight.

The formula explained in Bureau of Indian Standards (IS: 11215, 1991) is used for calculation of moisture content (MC) in wood samples.

$$MC\,(\%) = \frac{(Initial\ Weight - Ovendry\ Weight)}{Ovendry\ Weight} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where initial weight refers to weight of sample before any particular drying treatment is initiated and oven-dry weight refers to the constant weight achieved by the sample after drying it in an oven at 103±2 ^{0}C temperature.

7.3 Types of Water in Wood

In freshly cut wood, water is present in two forms. The water which is present inside cell cavities (lumens) and is free to move easily is called free water. The water present inside the cell wall andis chemically bonded with wood material is called bound water. When wood is seasoned, free water starts coming out first followed by bound water. During kiln drying process, it is costlier toremove bound water from wood compared to free water as removal of bound water requires moretime and energy and at the same time health of timber is to be maintained during removal of bound water.

7.3.1 Equilibrium Moisture Content:

When wood is exposed to air at a constant temperature and relative humidity (RH), the wood will lose (or gain) moisture until it reaches moisture equilibrium with the surrounding air. AT equilibrium moisture content (EMC), the moisture in wood is in equilibrium with the Relative Humidity (RH) of the surrounding air. There is no transaction of moisture between wood and surrounding atmosphere at EMC of wood. A slight change in RH and/or temperature of surrounding air disturbs this equilibrium and the process of transaction of moisture again starts between wood and surrounding air.

7.3.2 Fiber Saturation Point:

The moisture content of wood at the point at which all the free water has been removed from the fiber cavities and, cell walls are fully saturated with bound water is known as the 'Fiber Saturation Point (FSP) of the wood and is different for different wood species. It is highly criticalpoint in the drying of wood as wood begins to shrink from this point onwards as the swollen fibers start releasing moisture. During commercial drying of timber, more attention is required below its FSP. Fiber saturation point varies with wood species. It has been also found to vary within the same species of wood obtained from the different regions.

7.4 Wood seasoning methods

As a thumb rule, a wood is supposed to be seasoned when its moisture content is in the range of 8% – 12% with respect to its oven dry weight and is fit for making any indoor used product. The maximum permissible moisture content allowed in any product is given in IS: 287 and is a reference guide for how much seasoning is to be done on a timber meant for an end product.

To avoid manufacturing problems with the finished products, especially warping, splitting and checking, timber must be dried to a final moisture content that is close to the middle of the range of moisture content values. A finished product should not have moisture content more than the recommended value. India has been divided into four climatic zones based on annual average relative humidity from the point of view of the optimum moisture content for seasoned wood.The zones are:

- Zone I: Places in India where average annual RH is less than 40%
- Zone II: Places in India where average annual RH is between 40 to 50%
- Zone III: Places in India where average annual RH is between 50 to 67%
- Zone IV: Places in India where average annual RH is above 67%

Table1. Recommended maximum permissible moisture content in wood products

Use	**Moisture Content (%)**			
	Zone I	**Zone II**	**Zone III**	**Zone IV**
Aircraft	12	12	14	15
Agricultural implements	12	14	16	16
Artificial limbs	8	10	12	12
Automobile bodies				
50 mm and above thickness	10	12	14	14
Thinner than 50mm	8	10	12	12
Doors and windows				
More than 50mm thickness	10	12	14	16
Less than 50mm thickness	8	10	12	14
Furniture and cabinet making	10	12	14	15
Shuttles and bobbins	8	10	12	12
Sports goods	10	12	14	16
Ship and boat building	12	14	16	18
Handles	12	12	14	15
Toys, carved items, pencils	8	10	12	12

(Source-IS: 287)

The moisture content may be higher for special user other than furniture, cabinet, and millwork such as timber used for bending or destined to be exported. Typical desired final moisture content values for these kinds of products are listed in Table below. Once timber is properly dried, it must be stored, manufactured and warehoused at humidity conditions that are at or slightly below the expected in use humidity conditions. Failure to adhere to these maximum permissible moisture content values will result in serious economic losses for the manufacturing firm due to defects in products. This table was formulated long ago when a typical wood product was not travelling far offplaces. Now, a product can travel any part of the Globe within a month through ships. Hence, column of Zone 1 is more relevant for commercial timber dryers. They must follow moisture content recommended in this column for different products while kiln seasoning their timber.

7.4.1 Seasoning Process

The seasoning of timber is a two-stage process involving-

- The movement of moisture from the interior to the surface of the planks.
- The evaporation of the moisture from the surfaces to the moving air stream.

When wood dries, surface zones dry in advance of the interior because of direct evaporation of moisture at the surfaces. As a result, a moisture gradient is set up which causes the moisture to move from the interior to the surface, these processes take place concurrently, but it is essential that the rate of evaporation be controlled and in balance with the rate at which moisture moves to the surface. If evaporation is too rapid, excessively steep moisture gradients will result and this will be accompanied by drying stresses, which may exceed the tensile strength of wood causing checking and related damage to the timber. At any time, drying may be due to one or more of these possible processes: Evaporation, Mass flow or Diffusion.

In drying process above FSP, free water may move through the cell cavities via the intercommunicating pit openings under capillary pressure gradient in a mass flow. Below the FSP, water can move as vapour through cell cavities, and as bound water diffusion through the finer capillaries of the cell walls.

The relative importance of diffusion and mass flow within the wood depends on the permeability (ease of movement of water inside the timber being seasoned) of the timber. With highly permeable timbers the mass flow component within the wood is of great significance inthe early period of drying.

$$\text{Rate of drying} \propto 1/\text{density} \propto 1/\text{thickness}$$

(Since, more cell material is traversed per unit distance and this offers resistance to diffusion).

The quantity of water to be removed is proportional to the density of the timber and the thickness of the timber. Even with a permeable timber, diffusion assumes increasing importance as the average moisture content approaches FSP while drying. Indeed, in those parts of timber where the moisture content approaches FSP the drying is diffusion controlled.

Permeable and impermeable timbers of similar densities should dry from FSP at about same rate. In practice, drying is rarely controlled by a single process. A convenient empirical approach is to assume that the time to dry is proportional to (density) ^{n} and (thickness) ^{n}. The value of power coefficient is generally about 1.5.

7.4.2 Stacking of Timber

Stacking technique is most important single factor in satisfactory air seasoning of timber. Proper stacking of timber ensures uniform drying and reduces seasoning degrades considerably, particularly warping and biological deterioration through mould and stain. The rate of drying can be controlled to a certain extent by regulation of the rate of air circulation through the stack by adjusting the height of the foundation, width and height of stack, thickness of spacers and spacing between the adjoining planks in a layer to suit individual cases. In most of the cases of timber (planks, poles, sleepers etc) horizontal stacking is in practice.

The stacking should be done on level foundation over skids (longitudinally placed scantlings) having cross-section of about 10 cm x 10 cm. Spacers (also known as crossers) should be of seasoned and reasonably strong timber, of uniform thickness of cross section, say 2.5 cm x 2.5 cm, for stacking planks up to 5 cm thickness. The distance between the successive crossers in a layer should be about 60 cm for 2.5 cm thick planks. For thicker planks the spacing may be increased to 75 cm. Planks thinner than 2.5 cm should be stacked with crossers spaced less than 60 cm apart to prevent or minimize warping and sagging of planks.

7.4.2.1 Stacking of timber using spacers

The crossers should be in vertical alignment in a stack. As far as possible, the stack should be constructed so that the ends and sides of stack are “boxed”, with the ends of timber nearly sandwiched between the lines of spacers. This is termed as box piling. In case of mixed lengths, longest planks should be at bottom and the shortest at the top. In order to cope with the heavy inflow of timber, and also where the stacking operations cannot be stopped for particular lengths of planks, the stacks may be made separately for long, medium and short lengths timbers. The same holds good for mixed thickness also. Heavy beams should be placed in well distributed form at the top of the stack to prevent top layers from warping. The stack should be raised to convenient heights. The width of individual stack should not ordinarily exceed 1.5 m, but if it does, an open space, about 25 cm wide, should be left in the middle of the stack from top to bottom to permit good air circulation in centre of the stack.

7.4.3 Air Seasoning

The technique of air seasoning consists mainly in making a good stack of sawn timber with the help of spacers on raised foundations, in a clean and dry place, under shade (like a verandah). Asatmospheric air is the drying agent, the rate and quality of drying largely depend on the climatic conditions. Even so, losses of timber through cracking, splitting, warping, decay through fungal and insect attack can be considerably minimized by proper attention to the method of stacking, protection of stacks against the sun and hot and dry winds, and sanitary conditions in the yard. In case of forced-air drying, pedestal fans are used to speed up the drying of timber stack. It is always advisable to apply two coats of bitumen paint on both the cross sections of each logbefore the onset of cracks at the ends. This saves wood from wastage. In absence of professional kiln dryers, a common man can plan ahead before the construction of house and furniture, and air-season his wood by stacking it in above manner neither in a place where stack is neither exposed to direct sun light nor to rain. Depending on climate of the place, wood stack takes about 10 to 24 months to naturally season and becomes fit for making household furniture, door and window shutters etc.

7.4.4 Kiln Seasoning

Commercial drying of timber is done on big capacity kilns. Capacity of kiln is volume of timber which can be seasoned at a time in a kiln. For example, a 2000 cft capacity kiln can season 2000 cft of timber at a time.

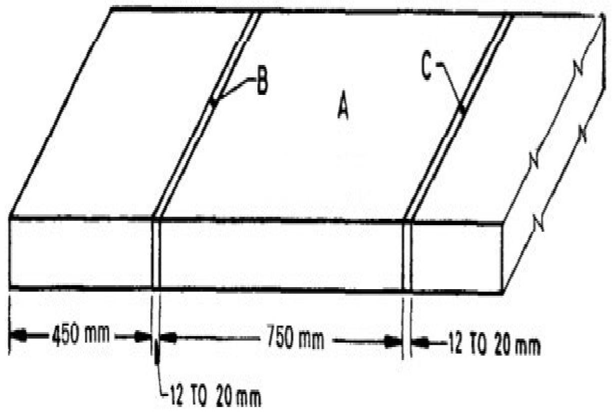
In kiln seasoning, drying of timber is done by using heat generated from source like steam, electricity, solar energy etc. The timber is stacked in chambers, called seasoning kilns fitted with equipment for manipulation and control of temperature and relative humidity of the drying air, its circulation through the timber stack, and partial venting. Kiln seasoning provides a means of overcoming the limitations imposed by vagaries of the weather in open air seasoning. In kiln seasoning, the drying of timber is practically at a faster rate than in air seasoning without increased degrade. This is obtained by the accelerated rate of diffusion of moisture from the interior to the surface as a result of increased temperature of the timber. There is flexibility of control over relative humidity conditions, and also a well distributed uniform air circulation through the stack. This allows the surface moisture content to be controlled despite the higher temperatures and the faster drying, during those stages in drying which are critical for the development of cracking degrade. The advantages of kiln seasoning are rapidity, adaptability andprecision. The temperatures employed inhibit and often kill insects and fungi, so that sterilization (at least partial) is achieved simultaneously with seasoning. Kiln seasoning enables wood to be dried to any desired moisture content regardless of weather conditions.

7.4.5 Types of Kilns

As per the heating source, the name of a kiln is given. Solar kiln, Steam-heated kiln, Dehumidifier kiln, electrically heated kiln, vacuum kiln are different types of seasoning kilns being used by wood industry all over the world. Depending on the requirement of seasoned timber per month, the type of kiln is preferred. Solar kiln is the cheapest kiln available for wood seasoning compared to any other commercial kiln. This is suitable for small scale rural saw millers and handicraft industry. Timber seasoning cost in a solar kiln works out to be one third ofthe cost which comes in a steam-heated kiln. Solar kiln takes more time in terms of days to season a timber to desired moisture content compared to steam-heated kiln. Also a solar kiln works for only nine clear months in North India and has to be closed during rainy season. Dehumidifier kiln is run by electricity but it is energy saving kiln. Due to incorporation of heat- pump in it, heat is not lost during typical venting operation in a dehumidifier kiln which is not possible in steam-heated kilns and solar kilns normally. Vacuum kilns are fastest among all typesof commercial kilns being used in wood industry. High vacuum helps in speeding up drying process by sucking loosely bound water molecules from wood surface. Also, the emissions from vacuum kiln are nil just as in case of Solar kiln. High capacity vacuum kilns require huge drying vessel and high horse power vacuum pumps hence are costlier affair above 150 cft capacity kiln.

7.4.5.1 Preparation of Kiln Sample

Kiln sample works as a probe for measurement of daily moisture content of timber being dried inside a kiln. It is prepared as per the specifications given in IS: 1141 of 1993.



Method of cutting kiln sample and moisture strips. (A) Represents the kiln sample, (B&C) represents the moisture strips

As per IS: 1141, the wettest and the heaviest sound planks are selected to make kiln samples. 75 cm long sample is cut from a distance of at least 45 cm from one end of each plank from its centre as illustrated in figure below. At the same time as this sample is cross cut from plank, a full cross-section (called moisture strip) measuring 12 to 20 mm along the length of plank is cross cut from near both ends of the kiln sample. The kiln sample and the two moisture strips so obtained are marked accordingly using marker pen for ease of identification.

The number of kiln samples needed for any kiln charge depends upon the condition and drying characteristics of the timber, the performance of the dry kiln, and the final use of the timber.

Practically 6 kiln samples should be prepared for 500 cft of wood stack in a kiln. This gives accurate average of moisture content of planks being kiln seasoned.

Samples are selected from the thickest, wettest and slowest drying stock in the kiln charge. In general heart wood samples with slowest rate of drying are preferred to sapwood. Samples selected should be free from knots and other natural defects

The number and the placement of kiln samples inside stack in a kiln is very important aspect. Ina 500 cft capacity kiln at least 6 kiln samples must be used and this number should be repeated for every additional 500 cft of timber to be dried in a kiln. The samples must be placed in stackso that they are well distributed along the height and breadth of kiln stack so that while averaging the daily moisture content of these samples, one must get true idea of average moisture content ofall the timber planks of a stack inside a kiln.

After kiln samples are cut, end coated and weighed they are placed in sample pockets. Sample pockets are usually placed at several locations along the length of the kiln on both sides of the stack. Since the kiln samples are intended to be representative of timber being dried, they should at all times be exposed to the same drying conditions as the rest of the timber in the kiln.

A check test should be made towards the end of drying for average MC, moisture distribution in the section and casehardening on all the kiln samples. Three complete test cross sections. 12-20 mm long in the direction of grain are cross cut from a point at least 16 cm one end of each kiln sample. One of the three test sections is weighed immediately after cutting and then oven dried to determine the average MC in the whole section. The second test section is subdivided into shell and core zone (if thickness is 40 mm or less) or shell, intermediate and core zone (if thickness is > 40 mm). The two outside portions of the shell are weighed together and their OD weight is calculated. Similar calculation is also made for intermediate zones. But core is weighed as single piece for its oven dry weight calculation. The third section is marked and sawn so as to produce 3 prongs of equal thickness is 40 mm or less, and six prongs if thickness is > 40mm. Themiddle prong in the former case and second and fifth prongs in the latter are broken out. The shape of prong sections is traced in a paper and then prongs are allow to dry for 24 hours in room temperature and after that their shape is again traced adjacent to their original shape for comparison. Based on comparison in shape, the change is noticed and degree of casehardening is arrived at. Following is the key for determining the probable condition of developed stress from prongs:-

- **When the prongs turn out on sawing:** The surface is in tension (attempting to shrink),and the center is in compression (opposing surface shrinkage).

(i) If the prongs turn in after room drying: Indication of unequal moisture distribution, with the surface drier than the center.

Occurrence: In the early stages of drying.

Remarks: The timber does not need steaming at this time. If a tendency to surfacecheck is noticed, use a higher humidity to retard surface drying.

(ii) If the prongs do not change after room drying: Indication of practically equal moisture distribution, with the surface in tension andthe center in compression.

Occurrence: After over steaming at a low moisture content.

Remarks: The timber should have received less severe steaming treatment.

- **When the prongs turn in on sawing:** The center is in tension (attempting to shrink) andthe surface is in compression (opposing center shrinkage).

(i) If the prongs pinch tighter after room drying: Indication of unequal moisture distribution, with the surface drier than the center.

Remarks: An advantageous point to relieve stresses by steaming.

(ii) If the prongs become straight or turn out after room drying: Indication of unequal moisture distribution, with the center drier than the surface.

Occurrence: After steaming and before re-drying.

Remarks: After re-drying the prongs should remain practically straight.

- **When the prongs remain straight on sawing:** The timber is free from stresses.

(i) If prongs remain straight after room drying: Indication of freedom from stresses, with equal moisture distribution.

(ii) If the prongs turn in after room drying: Indication of unequal moisture distribution, with the surface drier than the center.

Remarks: A short steaming treatment to balance the moisture content should relieveall stresses.

(iii) If the prongs turn out after room drying: Indication of unequal moisture distribution, with the center drier than the surface.

Occurrence: During some period of re-drying after steaming.

(Source: Anonymous, 1929)

7.4.5.2 Kiln Records

Good record keeping of kiln run details can be useful to the kiln operator in several ways, such as for modifying drying schedules on subsequent charges to obtain faster drying without sacrificing quality and for checking kiln performance for causes of non uniform drying or drying defects. During the drying time of each kiln charge records of the following items should be kept.

(a) Dry bulb temperature and Wet bulb temperature of entering air

(b) Stoppage of working parts in the kiln

(c) Weight and calculations made in the preparation of kiln sample

(d) Periodic weighing and moisture content data of kiln samples

(e) Results of check test

7.4.5.3 Kiln Seasoning Schedules for Indian Timbers

As discussed the wood species have been broadly divided in three categories based on their refractoriness to seasoning. This classification helped in understanding the drying nature of species. However, during commercial seasoning of timber in kilns, we come across many drying defects if seasoning is not done cautiously. For Indian timbers seven seasoning schedules have been developed for their kiln seasoning. A seasoning schedule is a guide chart for kiln operator to operate his kiln so that drying defects are under permissible limits in kiln seasoned timber. These recommended seasoning schedules have been given in BIS standard IS:1141 of 1993. Schedule I is fastest and recommended for timber species having very good permeability (ease of movement of water inside wood) and are very easy to dry defect-free. Schedule VII is slowest and recommended for timber species having very poor permeability and very difficult to dry defect-free.

The kiln-drying schedule is a guide chart with respect to the temperature and humidity conditions to be maintained in a steam-heated kiln when the moisture content of the wettest samples of wood on the entering airside in the kiln has reached the stage specified in theschedule. It may be noted that the kiln schedule is only rough guide for running a seasoning kiln while drying a certain species of timber at particular moisture content. The schedule is to be regulated in the light of the progress of drying, formation of moisture pockets, quality of timber, purposefor which timber is required, type of kiln, and several other factors like the permissible seasoningdegrade and the speed of air circulation employed in the kiln. For this reason the operation of a seasoning kiln should be entrusted to a trained operator. The seven seasoning schedules are given as below (Source: IS 1141 of 1993):

(i) Schedule I: These timbers will take 4 to 5 days to season. Initial steaming of kiln charge for 2 hours at 55^0C and 100 % RH should be carried out to kill mould growth and equalization of surface Moisture content (MC) of all the planks.

(ii) Schedule II: These timbers will take 5 to 7 days to season. Initial steaming of kiln charge for 2 hours at 55^0C and 100 % RH should be carried out to kill mould growth and equalization of surface MC of all the planks.

(iii) Schedule III: These timbers will take 8 to 10 days to season. In addition to initial steaming, one intermediate steaming and one final steaming towards the end of kiln charge for 2 to 3 hours at 55^0C and 100 % RH should be carried out.

(iv) Schedule IV: These timbers will take 12 to 15 days to season. In addition to initial steaming, one intermediate steaming and one final steaming towards the end of kiln charge for 2 to 4 hours at 55^0C and 100 % RH should be carried out.

(v) Schedule V: These timbers will take 13 to 16 days to season. In addition to initial steaming, two intermediate steaming and one final steaming towards the end of kiln charge for 2 to 4 hours at 55^0C and 100 % RH should be carried out.

(vi) Schedule VI: These timbers will take 16 to 20 days to season. In addition to initial steaming, two intermediate steaming and one final steaming towards the end of kiln charge for 2 to 4 hours at 55^0C and 100 % RH should be carried out.

(vii) Schedule VII: These timbers will take 24 to 30 days to season. In addition to initial steaming, at least tree intermediate steaming and one final steaming towards the end of kiln charge for 2 to 4 hours at 55^0C and 100 % RH should be carried out.

All the above schedules are for 2.54 cm (1 inch) thick planks. For thicker planks, schedules are fined tuned as per IS:1141.

- Schedule I is for species used for packing case manufacture.
- Schedule II is for species used for light planking or moderately heavy type of packing cases.
- Schedule III is for species used for most light furniture.
- Schedule IV is for species used for common furniture.
- Schedule V is for species used for furniture, constructional work, bobbins and other turneryarticles.
- Schedule VI is for species used for structural purposes and heavy planking. Schedule VII is for several heavy and highly refractory timbers.

Table 2. Details of kiln drying schedules recommended for few species

Kiln Drying Schedule No.	Species recommended for kiln drying
I	Fir, Ailanthus spp., Alnus spp.,Semul and didu, paper mulberry, white dhup,Spruce, lambapatti, amra, gutel.
II	Kadam, salai, rudrak, bakota, ficus spp., mango, chir, kail, poplar, vellapine.
III	Mundane, chalpash, kathal, deodar, cypress, gamari, silver oak, kanju, jhingan, machilus spp., raini, willow, hillock, hemlock.
IV	Kokko, kala siris, safed siris, amari, aini, poon, chestnut, khadig, satin wood, chickrassy, rosewood, shisham, white cedar, eucalyptus hybrid, benteak, morus spp., padauk, chilauni, bahera, white chuglum, dudhi.
V	Maple, haldu, lakooch, birch, boxwood, cinnamom, gurjan, hollong, rubberwood, walnut, kaim, teak, toon.
VI	Babul, horse chestnut, kumbi, ebony, marblewood, dhaman, jarul, bijasal,Indian oak, mahogany, arjun, laurel, ber.
VII	Acacia tortilis, axel wood, amaltas, sundry, hopea, sal, rohini, jamun.

7.5 Wood Seasoning Defects: Causes, Prevention and Remedies

The greatest challenge in kiln drying of timber is to dry the timber defect free. This requires a lot of experience and blending of wood science.

Table 3. The main defects which a kiln operator comes across during commercial drying of timber

Drying Defects	Causes	Prevention	Possible Remedies
Case-hardening: The conditionexisting in wood inwhich the outer layers have undergone rapid drying and become set without Corresponding shrinkage, causing stress between the inner and outer layers. It causes warping of the wood when further converted.	Too rapid surface drying owing to use of too low humidity in early stages and/or too high temperature in laterstages.	Use higher humidity in early stages and limit temperature in final stages.	At the end of the kiln run long conditioning period or a relief treatment viz., raise temperature and humidity for 2 to 6 hours according to severity of stresses.

Surface Checking: A separation of the fibers along the grain forming a crack or fissure in the wood not extendingthrough the piecefrom one surface toanother. It occurs across the rings of annual growth.	Too rapid drying of surface in relation to the core.	Use higher humidity in early stages.	No cure obviously. Checks will tend to close when wood is fully dried touniform moisturecontent.
End Splitting: A separation of fiber along the grain forming a crack or fissure that extends through the piece from one surface to another. A split at the end of a piece of wood is called end a split.	Ends drying more rapidly than the rest Overhanging ends. Too much circulation of air over ends and too little through stack.	Paint ends with bituminous paint. Stack properly with spacers at or very near to ends of rows. Baffle off ends and make all air go through stack.	None
Honey Combing: Separation of fibers (checks) in the interior of the wood induced by drying stresses when the outer layers have become case-hardened.	Severe case hardening in early stages followed by internal checking from excessive stress in centre. Too high temperature in final stages.	Use higher humidity in early stages. Periodic steaming and limit final temperature.	None
Cupping: A curvature occurring in the cross section of a piece of wood.	Differential shrinkage across grain in tangential and radial directions.	Cannot be prevented but all forms of distortion can be minimized by the following: Stack very carefully, place spacers at frequent intervals and perfect vertical alignment, place spacers at ends of all planks. Place heavy weights on the top of the stacks.	Apply conditioning treatment and if stacking is not proper dismantle it and restack properly before steaming.

Spring: A curvature of a piece in the plane of its edge. **Bow:** A curvature of a piece of wood in the direction of its length.	Differential shrinkage along thegrain owing toirregular or curved grain or reaction wood.	-	-
Twist: Spiral distortionalong the grain of a piece of wood.	Spiral grain or inter locked or irregular grain.	Use lower temperature schedule. Place heavy weights on the top of the stacks.	Condition to the correct moisture content.
Mould Growth	Poor circulation of air, very slow drying at moderate temperatures.	Speed up circulation. Use higher temperature if spices are not liable to warp or collapse badly.	-

(Source: Gnanaharan *et. al,* 2002)

7.6 Seasoning of Bamboo

Green bamboo may contain 50-150 % of moisture. As in the case of wood, seasoning of bamboo is necessary before its efficient utilization.

Round bamboo is often baked over open fire, after applying linseed oil, for primary protection against fungal decay and insect attack during short-term storage. Apart from rapid drying of the outer portions, the slight charring caused is believed to provide some protection against bio-degradation. It is, however, neither a universal technique applicable to all bamboo species without degrade nor is it a method for complete seasoning. Baking should be carried out only over a gentle fire, otherwise severe collapse occur irrespective of the species or the maturity of culms.

7.6.1 Air Seasoning of Split and Round Bamboo

Air seasoning of split or half round bamboo does not pose much problem but care has to be taken to prevent fungal and insect attack during seasoning. Fungal and insect attack can be controlled by rapid drying in open sun as usually adopted for several handicraft items like baskets, mats, chicks, etc. Seasoning of round bamboo presents considerable problem. A study on seasoning behaviour of *Dendrocalamus strictus, D. hamiltonii, D. membranaceus, D. calostachyus, D. longispathus, Bambusa nutans, B.*

tulda, B arundinacea and *B. polymorpha* indicated that immature bamboo gets invariably deformed in cross section and thick walled immature bamboo generally collapses. Thick mature bamboo tends to crack on surface with the crack originating at the nodes and at decayed points. Moderately thick immature and thin and moderately mature bamboo season with much less degrade. Bamboo with poor initial condition on account of decay, borer hole, etc. generally suffer more drying degrades. Round bamboo should be kept in vertically standing position for air-drying.

7.6.2 Chemical Seasoning of Round Bamboo for its Value Addition

Seasoning of round bamboo poses considerable problem in several species of bamboo. Many species of bamboo are more or less liable to surface cracking during drying. Some species like *Bambusa nutans, Bambusa tulda* and *Dendrocalamus giganteus* crack more than the others. Unlike timbers, drying under mild conditions cannot always prevent cracking in round bamboo. End splitting, surface cracks and cracking at the nodes are common problems faced during air- drying even at slow rate of air seasoning and mild weather. Due to these problems, artisans are not able to use these species of bamboo for novelty items like flower vase, table-lamp stands etc. Chemical seasoning of bamboo properly solves the problem of surface cracks and wrinkles in bamboo.

The process of air or kiln seasoning the wood after treatment with anti-shrink chemicals, chiefly with the object of minimizing seasoning degrades is known as "Chemical Seasoning". Chemical seasoning of round *Bambusa tulda* in green condition to avoid surface cracks, splitting and fungal discoloration has been tried. A solution made by dissolving 40 % urea and 2 % of boric acid (W/V) in water was used as anti-shrink and anti-borer treatment. This treatmentenables forced-air-drying (using electric fans for 7-8 days) of the bamboo with negligible drying degrades whereas the untreated bamboo shows drying degrades unacceptable to be used in round from for novelty items like flower vases.

In this method freshly felled green mature culms of bamboo (*Bambusa tulda*, *Dendrocalamus giganteus*) are converted into small pieces of length 40-50 cm with one endopen and another end with a node (example of flower vase). The nodal partition was kept intact. These pieces are dipped for 72 hours in a mixed solution of urea (40% w/v) and boric acid (2% w/v) in water maintained at 45^{0}C initially for 8 hours. Temperature is used for creating a partial vacuum inside the bamboo so that absorption of chemicals would be increased. Boric acid treatment prevents borer attack in subsequent use of the bamboo. After treatment the treated pieces are wrapped in polyethylene sheets and kept indoor for better diffusion of chemicals. After a week these pieces are forced air dried using electric fans. After drying the product is coated with polyurethane coating in order to avoid problem of sweating during rainy season.

Chemical seasoning method is very useful in avoiding cracks during drying of round bamboo. However, it is suggested that anyone planning to use the treatment commercially should make a series of tests on the species size and shape of specimens to be used, varying the chemical concentration and the treatment time in order to attain an optimum bulking concentration of the chemical.

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Unit-8 Preservation of Wood

Unit Structure

8.0 Learning objectives

After studying this unit you will be able to understand about:

- Principles, processes, need, types of wood preservatives
- Development of Wood Preservatives
- Carrier Liquids or Solvents
- Major Chemical Preservatives
- Preservative Treating Processes
- Methods of Applying Preservatives

8.1 Introduction

The science of wood preservation could be defined as the process of adding adequate quantities and concentrations of toxic or repellent substances to a given wood product to upgrade its resistance to biological attack and make it highly durable. All wood preservatives recommended for ground contact use are capable of protecting against wood-destroying organisms, providing the wood cell structure will allow sufficiently deep and uniform penetration into the wood.

Wood preservation involves the pressure or thermal impregnation of chemicals into wood. The process results in long-term resistance to attack by fungi, bacteria, insects, and marine borers. This has the economic advantage of reducing maintenance costs for industry sectors such as the railroad industry, which faces significant costs for replacement of ties. On average, approximately 3000 railroad ties are needed for every mile of track that is installed. Hence the longer ties remain in service, the lower the maintenance costs for supporting rail operations.

This unit provides a description of the technologies and equipment used. There are two general classes of wood preservatives: oils, such as creosote and petroleum solutions of pentachlorophenol; and water-borne salts that are applied as aqueous solutions. The effectiveness of the preservative varies and can depend not only upon its composition, but also upon the quantity injected into the wood, the depth of penetration, and the conditions to which the treated material is exposed in service, and the species of wood treated. There is considerable art in the preservation of wood, for which other authoritative references may be consulted.

Some species of wood have natural durability, or resistance to decay and insect damage, which is due to the presence of substances called extractives in the heartwood. Extractives are chemicals that form when the tree is growing, which are harmful to the sensitive cambium. To protect this growth zone, the harmful substances are passed (like transporting liquid toxic waste through pipes) along the rays and deposited in the dead cells of the heartwood. Not surprisingly, extractives are often toxic to insects and fungi as well as to the cambium, so they act like preservatives.

The type and quantity of extractives are characteristic of each wood species, giving it a greater or lesser degree of natural durability, and sometimes a distinctive color and odor of its own.

The heartwood is the only part of some wood species that exhibits high natural decay resistance (see Table 1). The sapwood of all known tree species is very susceptible to decay, regardless of any natural resistance of the heartwood. Unless sapwood is entirely removed or impregnated with preservatives, decay is likely to occur even in durable species. Also, some of these very durable species are becoming scarce and costly, as has happened with mahogany and teak. The high cost of these species practically rules out their use solely for high decay hazard situations. Scarcity limits the use of many such species to veneers and small parts so that the wood of each tree will provide optimum raw material utilization and profitability.

There are several reasons why durable species have become scarce.

- Some species, once abundant have been decimated by the introduction of foreign diseases or insects.
- After harvesting, virgin forestland that once grew durable species has been converted to farmland or replaced with non-durable tree species.
- Naturally durable trees are typically older trees, but the young, fast growing trees that replace the old trees have higher proportions of sapwood-which has no natural durability.
- The world’s human population has doubled in just the last 40 years, creating tremendous demands on our forest resources.
- The use of naturally durable wood has declined and will continue to diminish. Our future need for durable wood products will be provided by forests replanted with fast-growing trees of low natural durability, but the wood from these trees will be treated with preservative chemicals for use under high-risk decay situations.

8.2 Development of Wood Preservatives

Wood decay has plagued humans since they began building with wood thousands of years ago. When trees with natural durability were available, they were commonly used. But the scarcity of durable timbers in some areas of the world, coupled with a need to make our wood products and structures last longer, led us to develop techniques to preserve wood.

Charring is perhaps the oldest wood preserving technique, first done over 4,000 years ago by plunging round stakes in fire. The Temple of Diana at Ephesus in ancient Greece was built on charred wooden piles. Throughout the centuries, just about every new chemical discovered has been tried as a wood preservative. The Greeks poured oil into bored holes to preserve the pillars supporting buildings. Vegetable and mineral oils were used to preserve wood by several early peoples, including Romans, Chinese, Burmese, Greeks and Egyptians. Impregnating wood with chemicals using vacuum and pressure processes started in 1831 with a French invention, making it possible to test thousands of chemicals as preservatives. The testing of new chemical formulations is a never- ending process. Despite this effort, very few new chemicals are suitable for today's wood preserving needs.

Table 1. Heartwood decay of domestic woods.

Resistant or Very Resistant	Moderately Resistant	Slightly or Nonresistant
Bald cypress (old growth)[1]	Bald cypress (young growth)[1]	Alder
Catalpa	Douglas fir	Ashes
Cedars	Honeylocust[3]	Aspens
Cherry, black	Larch, western	Basswood
Chestnut	Oak, swamp chestnut	Beech
Cypress, Arizona	Pine, eastern white[1]	Birches
Junipers	Pine, longleaf[1]	Buckeye[3]
Locust, black[2]	Pine, slash[1]	Butternut
Mesquite	Tamarack	Cottonwood
Mulberry, red[2]		Elms
Oak, bur		Hackberry
Oak, chestnut		Hemlock
Oak, gambel		Hickories
Oak, Oregon white		Magnolia
Oak, post		Maples
Oak, white		Oak (red and black) species[3]
Osage orange[2]		Pines (most other species)[3]
Redwood		Poplar
Sassafras		Spruces
Walnut, black		Sweetgum[3]
Yew, Pacific[2]		Sycamore
		Willows
		Yellow poplar

[1] Southern and eastern pines and bald cypress are now largely second growth with a large proportion of sapwood. Consequently, it is no longer possible to obtain substantial quantities of heartwood lumber in these species for general building purposes.
[2] Exceptionally high decay resistance.
[3] These species or certain species within the groups have higher decay resistance than most woods in this grouping.

Source: Nicholas, Darrel D., 1973. Wood Deterioration and Its Prevention by Preservative Treatments. Vol. 1 Degradation and Protection of Wood. Syracuse University Press, Syracuse N.Y.

8.3 Carrier Liquids or Solvents

Preservatives are used in liquid form. They rely on solvents to carry the toxic chemicals into the wood during impregnation. Each wood preserving chemical has its own unique proper- ties, like solubility and boiling range. In practice, therefore, each is commercially linked to one or more particular solvents that suit the physical properties of the preservative chemical.

Table 2 shows how carrier liquids (or solvents) are classified, and which major wood preservative chemicals are used commercially with each carrier.

As the table shows, creosote is unique in acting as both preservative and carrier. This is because creosote is a very complex liquid mixture of chemicals recovered from the heating of coal or wood in the absence of air; only a few of these chemicals are good wood protectors, the others act as carriers or filers.

Table 2. Main solvents used with preservatives in North America

Preservative Chemical	Main Liquid Carriers or Solvent				
	Creosote	Heavy Petroleum Oil	Light Petroleum Solvent	Water	Ammonia and Water
Creosotes	**X**	**X**			
Pentachlorophenol(PCP)	**O**	**X**	**X**	**O***	**O**
Chromated Copper Arsenate (CCA)				**X**	
Ammoniacal Copper Arsenate (ACA)					**X**
Copper Naphthenate		**O**	**O**	**O***	
Zinc Naphthenate		**O**	**O**	**O***	
Copper-8 Quinolinolate				**O***	
Bis-(Tri-N-Butyltin) Oxide (TBTO)			**O**		
Behavior of CarrierAfter Treatment	Little evaporation; most remainsin wood permanently	Little evaporation; most remainsin wood permanently	Most evaporates from wood	Water evaporates to Equilibrium Moisture Content (EMC)	Water and ammonia evaporates to EMC
Key to table: X = Major use	O = Some use	* = In dispersed or emulsified form			

8.4 Major Chemical Preservatives

The basic properties and uses of the major wood preservatives are discussed in this section and summarized in Table 3. Detailed descriptions of their chemical and physical properties are published annually in the American Wood Preservers Association (AWPA) Standards.

8.4.1 Creosotes

Creosotes are brownish-black, oily liquids, with a heavy "smoky" smell. Creosotes and other tar oils are produced when a naturally occurring carbon-rich substance (such as coal, lignite or wood) is heated without air. The tars and creosotes vaporize from the hot mass and are recovered by condensation.

Creosotes are probably the oldest commercial wood preservatives. Creosotes are viscous (thick) liquids. At ordinary temperatures, they do not soak into wood enough to preserve it effectively. That disadvantage was rectified in 1838 when John Bethell introduced the Bethell or full cell process, which uses pressure to force hot creosote into the wood cells.

The main form of creosote used in North America is coal tar creosote, a by-product of the production of coke. Coke is produced from coal and is used in steel manufacturing. Coal tar creosote is always heated before being pressurized into wood. Sometimes it is mixed with other coal distillation by-products such as tar oils or heavy petroleum oils. AWPA standards list the allowed combinations of ingredients.

The success of coal tar creosote since the Bethell process was invented has been phenomenal. All kinds of uses for wood were made possible; even wood species that had little natural durability could be used. Without creosote, it is hard to imagine how North American railroads could have been built. Creosoted crossties, mainly of Douglas fir, southern yellow pine and oak have stabilized tracks for 30 to 50

years. Think, too, of the success of electrification of rural areas and telephone networks, all using creosoted poles; trestle bridges for the nation’s road and rail crossings; and fencing to contain cattle and other livestock. These developments, extending over half a century, depended on the wood-preserving qualities of coal tar creosote. Sixteen percent of the treated wood products in the U.S. were preserved with creosote in 1990.

Products treated with creosote:

Railroad crossties	100%
* Switch and bridge ties	100%
Piling	35%
Poles	18%
Posts	14%

** % of each product’s volume treated with creosote compared to the total volume of this product treated.*

Creosote is unsuitable for:

- Use inside some buildings where people live or work.
- Most situations where there is contact with people or animals.
- Wood products in contact with or near food. Wood surfaces requiring paint.

Permanent weight gain from creosote treatments can be significant. Retentions vary from 5 to 25 pounds per cubic foot (pcf) of wood.

8.4.2 Pentachlorophenol (PCP or penta)

Pentachlorophenol is a crystalline white solid made in a controlled chemical process. The preservative ability of PCP was discovered around 1935, and was developed into a very successful wood preservative.

Pentachlorophenol is usually dissolved in either light or heavy petroleum oil to produce wood-preserving liquids. It can also be dissolved in water (as ammonium pentachlorophenate) and can be dispersed or emulsified using water as its carrier. Penta can also be added to creosote and petroleum oil mixtures to boost performance.

Penta treating solutions impregnated into wood have a tendency to evaporate, causing blooming (Table 3). Blooming is the formation of crystals on the surfaces of treated wood as a result of exudation and evaporation of the solvent. This evaporation is minimized by the inclusion of a nonvolatile liquid in those preservative solutions using an evaporating carrier or solvent. Protection from contact with penta crystals can be accomplished by sealing the dried, treated surfaces with a coating of urethane, shellac, varnish or latex epoxy enamel.

Note: Sodium pentachlorophenate, the water-soluble form of pentachlorophenol, and the closely-related tetrachlorophenol, were once widely used in anti-sapstain dips for treating lumber in sawmills. This treatment and other anti-sapstain chemicals are not covered in this program. Eight percent of the treated wood products in the U.S. were preserved with penta in 1990.

Table 3. Summary of advantages, disadvantages and properties of the restricted-use pesticides creosote, pentachlorophenol and inorganic arsenicals.

Pesticide	Advantages	Disadvantages
Creosote	1. Excellent protection against fungi, insects and most marine borers. 2. Insoluble in water. 3. Excellent stability, suitable for thermal and Boultonizing processes. 4. Provides excellent water repellency and mechanical stability.	1. Poor protection against certain marine borers. 2. Leaves dark, oily, unpaintable surface. 3. Tendency to bleed or exude from wood surface. 4. Strong odor–cannot be used in homes or other living areas because of toxic fumes. Harmful to plants. 5. Contact with treated wood may cause skin irritation or burns.

		6. Heating is required to reduce viscosity. 7. Can ignite, so it must be heated cautiously. 8. Treated wood remains considerably heavier: 25-50% weight increases are common.
Pentachlorophenol	1. Excellent protection against fungi and insects. 2. Can be dissolved in oils having a wide range of viscosity, vapor pressure and color. 3. Can be glued or painted depending on carrier. 4. Water repellents can be added to improve weatherability. 5. Good heat stability-buhteating Penta is not common. 6. Low weight increase (1-2%) if an evaporating carrier is used.	1. Poor protection from marine borers. 2. Can leave oily, unpaintable surface, depending on carrier used. 3. Irritating smell, toxic to plants, animals and people. 4. Not suitable for use in homes or other living areas. 5. Contact with treated wood may cause skin burns or irritation. 6. All oil carriers are flammable. 7. Permanent weight increases of 20- 50% if heavy oils are used. 8. Tendency to “bloom” (p. 34)
Inorganic arsenicals	1. Excellent protection against fungi insects and most marine borers. 2. Produces no smell or vapors. 3. Suitable for use indoors. 4. Non-toxic to nearby growing plants. 5. Treated surfaces can be painted. 6. Permanent weight increases of only 1-2% after wood has reseasoned.	1. Only moderate protection from pholad marine borers. Will not prevent mildew. 2. Does not protect wood from excessive weathering. 3. Not heat stable above 140° F; therefore cannot be used in thermal or Boultonizing process. 4. Temporary weight increases of 20- 90% immediately after treatment. Swells wood when treated, so some seasoning defects may occur when redried.

8.5 Preservative Treating Processes

8.5.1 Flow of Liquids in to Wood

There are great differences in permeability to preservatives among individual species of softwoods and hardwoods. Some cells allow liquids to pass through them easily and into other cells and some do not. Several factors determine how permeable a particular piece of wood is:

Types of cells amount of ray, cells types, size and number of pits presence of extractives

Two other factors affecting a wood's permeability must also be understood:

1. 1 Whatever the shape or size of wood to be treated, preservatives can only get in from the outside. So the permeability of the outer cells is critical if they refuse to accept preservative, none can possibly penetrate to cells inside the wood.
2. In wood that is green (high moisture content) nearly all the cells are fully or partially full of free water and the cell walls will also be saturated with bound water. Preservatives cannot be forced into such wood, so penetration and absorption will be negligible.

Softwoods: Look at the softwood cube illustrated in Fig 1a. This is a greatly enlarged model of a tiny piece of dry softwood. What would happen if a real wood cube was dipped in a light petroleum oil carrier? As Fig 1a shows, the liquid would mainly enter four of the six faces of the cube, that is, the two cross-sectional or transverse faces and the two tangential faces. The two radial faces, which have no exposed open ends of cells, will be relatively unimportant in absorbing liquids.

The cross-sectional faces expose end-grain or open tracheid cells to the oil. These tracheids, acting as hollow tubes, will accept liquid easily. Their small diameter actually encourages "sucking-in" of the liquid by capillary action, like blotting paper or a sponge. Oil will pass through the pits in the cell walls into adjoining tracheids.

The two tangential faces expose open ends of ray tracheid cells to the oil. The rays are also capable of capillary absorption of liquids, so they accept and transport the oil in a radial direction.

Within seconds of immersion in oil, the tiny softwood block will have absorbed perhaps enough oil to fill three-fourths of its cell cavities. How can this happen? What happened to the air that was in the block?

First, the capillary force is so strong it causes the air to squeeze up, or compress, in the cells. This allows space for the liquid oil. Second, some compressed air will escape through wider cells having less capillary pressure and will bubble out of the wood surfaces to make room for more liquid. Thus, the tiny softwood block will absorb a good proportion of its void volume in seconds, and most of the cells will receive some oil.

If preservation of this small cube of wood had been our objective and if the oil had contained a good wood preservative chemical, we could confidently say that the softwood cube had been well-preserved.

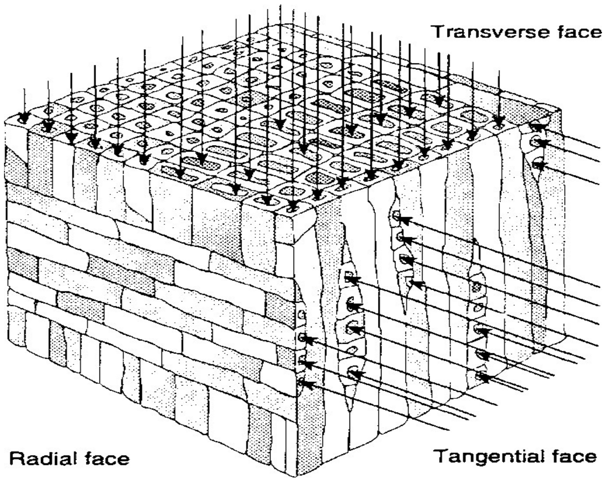


Fig 1a. In softwoods most preservative flow occurs by means of the vertical fiber tracheids and the horizontal ray tracheids. As these make up virtually all the wood volume, it is possible to fully saturate some softwoods with preservative.

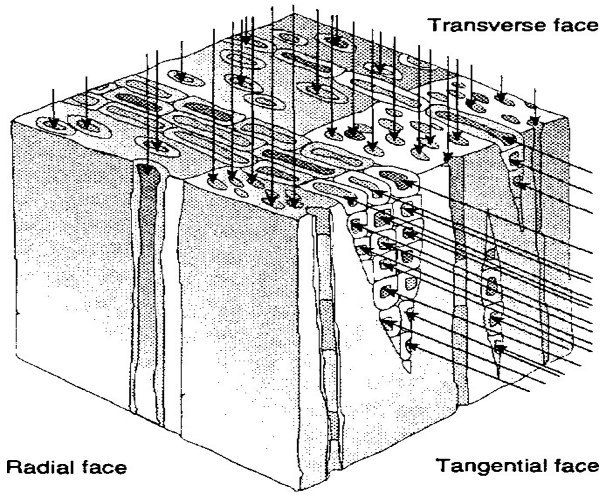


Fig 1b. In hardwoods only the vessels and the ray tracheids can conduct preservatives. This often leaves extensive regions of fibers unprotected. As these give hardwoods much of their strength, this can be a very serious situation.

Hardwoods: Now let's see what happens when we repeat the same experiment with a hardwood cube (See Fig 1b). First, note the similarities between hardwoods and softwoods. Capillary action will suck oil into the open- ended cells of the two cross-sectional faces and the ray cells of the two tangential faces. Again, little oil will enter the radial faces.

Now note the differences from the soft- wood experiment. The cell ends of hard-woods, exposed by cutting the transverse faces, are of two types: vessels and fibers. Vessel segments, with large diameter cavities are joined end-to-end with other vessel segments to form long tubes (the vessels). In most hardwoods, oil will easily enter these vessels, and trapped air can bubble out from the wide cavities, allowing the vessels to fill with oil.

Fibers respond differently, however. If you recall, they are narrow sealed cells that play no part in sap movement in the living tree.

The fibers, exposed by the transverse sections, can readily accept oil by capillary suction, but they cannot easily pass it on to the other fibers. Consequently these fibers will not normally receive oil from the trans- verse sections.

As with softwoods, the hardwood ray cells are like open networks of tubing, able to absorb oil easily. The rays in most hardwoods are wider than those in softwoods, so a greater uptake of oil may occur in the rays. Also, the rays can pass some oil to adjoining fibers, although the majority of fibers could remain dry.

Although quite a lot of oil may have been absorbed by the hardwood cubes, mainly in the vessels and ray cells, significant internal areas of the block (fiber areas) may have little or no oil. From a preservation standpoint, there is a lot of unprotected cellulose and lignin in these fibers that is liable to decay. What is worse the principal strength of hardwoods comes from these unprotected fibers.

- The explanations of how liquid oil is taken up by these small softwood and hardwood cubes are also applicable to treating full-sized wood products. For example:
- Even if pressure is not used in a wood-preserving process, capillary suction creates a negative pressure or partial vacuum because of the narrow diameter of wood cell cavities, so some liquid chemicals will be absorbed.

- Air in wood cells can be compressed easily.
- Air (compressed or not) is an obstacle to full impregnation of wood with liquids.
- Rays and vessels in hardwoods and the fiber tracheids and rays in softwoods are the main routes for liquid flow into wood.
- Fibers in hardwoods can act as a tight, impenetrable mass, which is difficult or impossible to treat with a preservative, depending on the species of wood.

8.6 Methods of Applying Preservatives

Let's discuss treating methods using a round fencepost of an easily-penetrated softwood species as an example of a wood product being treated with a selected preservative.

8.6.1 Brush-on and spraying

The simplest treating methods do not involve expensive equipment. We could brush or spray a post on all surfaces, expecting capillary action to give the preservative penetration into the wood. After several good brush coats, or sprayings and some obvious sucking-in of preservative, we would probably find that further absorption was negligible.

Additional applications would result in wet wood surfaces and there would be consider- able run-off. If we sliced the post end-to-end, penetration by the preservative might resemble something like **Fig 2a.** The deepest penetration is at the ends (trans- verse or cross-sections, where tracheid ends were exposed to the preservative liquid). Radial penetration into the post surfaces is shallow; the rays are largely responsible for the absorption seen in this direction. Note that all of the heartwood and much of the sapwood is left unpreserved by the brushing or spraying method. When the post is part of a fence, the ground line is where the combination of air, moisture, wood and fungal source meet, and it is in this area that the risk of decay is greatest (see Lesson 3). Even a shallow split in the post will expose untreated sapwood, and allow decay to start.

Brushing and spraying are not good treat- ing methods for preserving wood exposed to high risk of decay, such as for ground contact uses.

8.6.2 Cold soaking or steeping

The term *cold soaking* is used when an unheated oil solution of preservative, such as penta or copper naphthenate, is used. The term *steeping* is used for treatments of wood by preservatives in a water solution. The process consists of partially filling an open tank with preservative and immersing a dry, round fencepost in the tank. The post floats, so it must be weighted down to keep it sub- merged. The post is soaked for 24 or more hours, then removed. If we cut it lengthwise as before, the pattern of penetration using this treating method may look like **Fig 2b.** Note that both end-grain penetration and radial penetration are better than that obtained by brushing. Cold soaking or steeping has three advantages over brushing or spraying:

(i) It allows a longer time for absorption to occur.

(ii) By holding the post below the surface of the preservative, a slight pressure is created which helps to force the preservative into the wood cells, thereby enhancing ordinary capillary action.

(iii) It is easier than having to rebrush or respray the post with more preservative at various intervals during the 24-hour treating period.

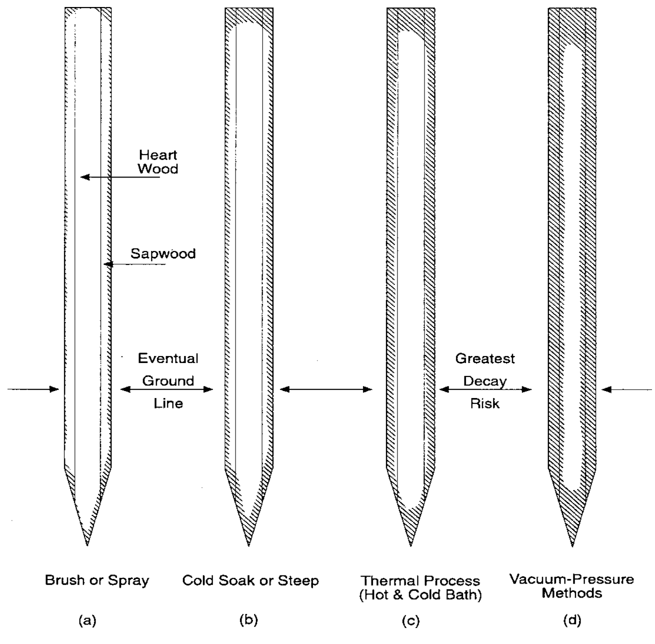


Fig. 2 a, b, c, d Effect of treatment on penetration

Diagram of round pine fence posts rip-sawn after treatment by four methods using the same preservative and showingthe penetration pattern for each method.

Note that methods (a) and (b) leave untreated sapwood which could easily be exposed to decay through checks orsplits that develop in the post as it dries out.

Unfortunately, although the penetration of preservative by soaking is better than by brushing, the ground-line area is still insufficiently-treated to provide long-term protection. Soaking was previously used commercially for treating fence posts and rails, but pressure treatment has replaced it. Today, there are two principal uses for this treating method:

(i) For exterior millwork such as window frame components. These parts get enough end-grain penetration to protect the very susceptible joints of the completed frame from decay in service.

(ii) For thin wood materials like trellis slats or lath panels for fencing. Modem pressure treatment, however, will give even better protection.

8.6.3 Thermal process or hot-and-cold bath

When using the cold soaking or steeping method, a dry fence post was submerged for 24 hours in a tank of preservative at ambient (existing) temperature. With the thermal process or hot-and-cold bath, the same equipment is used, but the preservative is heated with the post in the tank (taking precautions against fire if it is oil-based). As the fencepost heats up, air in the wood expands and bubbles out, escaping through the preservative liquid into the atmosphere. The preservative is heated until no more air escapes from the post, and then the whole tank and submerged post is allowed to cool down. This process can also be completed in 24 hours. Fig 2c, shows the effect of this treatment on preservative penetration.

There are several ways to use the thermal process. It is not necessary to use just one tank in which to heat and cool the preservative for each batch of poles or posts treated. Two storage tanks and a separate treating tank can be used. One storage tank is insulated for the *hot preservative* and an uninsulated tank is used for the *cold solution.* Posts or other wood products are placed in the treating tank and soaked in the hot preservative solution for about 6 hours. Then the hot liquid is pumped back into the insulated tank and the cold preservative from the other storage tank is flooded around the wood products still in the treating tank. This system requires more equipment than cold soaking, but saves time and energy, lowers labor costs and provides better treatment.

The thermal process produces much better penetration than treating by the brushing, spraying or cold soaking methods. There are several reasons for this improvement.

Much of the air in the cell cavities is forced to expand and escape from the outer post areas. When the preservative is allowed to cool, air remaining in the cells shrinks. So a partial vacuum is created in the cells and atmospheric pressure pushing on the treating liquid helps force more preservative into the post. For this reason, the thermal process might also be considered a non-equipment-induced vacuum-pressure method. Also by using heat, viscosity of the preservative solution (especially those thick with carriers) is reduced and it therefore penetrates the wood more readily. To enhance penetration, incising or puncturing the lower part of poles with slots or small holes is a necessary preparation required by AWPA standards for the thermal process.

The thermal process is used mainly for treating poles with creosote mixtures. The species preferred for this process are those which combine narrow sapwood bands with naturally durable heartwood. AWPA standards allow use of the thermal process for *full-length treatment* of western red cedar, Alaska yellow cedar and lodge pole pine poles and for *butt- only treatment* of western red, Alaska and northern white cedar poles. In butt-only treatments, the poles stand with the butt ends immersed in the preservative to a depth one foot greater than the eventual ground line.

8.6.4 Vacuum Pressure Methods

Conventional vacuum-pressure methods use *pumps* to create vacuum and pressure, thereby producing high pressure gradients and operator control over the process. By contrast the thermal process is limited to atmospheric pressure alone. However, by means of pumps, 10-12 atmospheres of pressure can easily and safely be produced. This is equivalent to about 140 to 175 pounds per square inch (psi) in a treating retort or cylinder. **Fig 2d** indicates the penetration of preservative that might result from vacuum-pressure treat- ments. Although there are various vacuum- pressure methods available such as the Double Vacuum Process and the Mississippi State University Process, the principal methods used by the U.S. pressure-treating industry are:

8.6.5 Full cell process (Bethell process) Empty cell processes (Lowry and Rueping) Modified full cell process

(i) Full cellprocess: This is the simplest and most common of the vacuum-pressure processes. It was developed by John Bethell in 1838. The full cell (or Bethell) process is used for most of the pres- sure treatments using chromated copper arsenate (CCA) and pentachlorophenol-based (PCP) preservatives, and a good proportion of the treatments with creosotes.

Features of the full cell process include:

- It gives the deepest possible penetration and the highest loadings (retentions) of preservative with easily-treated species. Virtually all of the air in the wood cells can be replaced with preservative.
- Sometimes this may produce a higher loading than necessary.
- The degree to which penetration and retention of preservative occurs depends on the permeability of the wood. For effective treatment, some species may need special preparation such as incising, steaming, or Boultonizing, which are described in a later section of this lesson.
- No vacuum-pressure process is more effective than the full cell in maximizing the uptake or penetration of preservative. The sequence of procedures used in the full cell process is shown in Fig 3, and is summarized below:
  - (A) Enclose dried wood (timbers, lumber, poles, etc.) in a pressurable cylinder or retort.
  - (B) Use a vacuum pump to remove most of the air from the cylinder. Hold a partial vacuum to allow air to be removed from the wood cells.
  - (C) Without releasing the vacuum, allow the cylinder to fill with liquid preservative.
  - (D) Apply pressure to the preservative to force it into the wood cell spaces previously occupied by air, now occupied by a partial vacuum.
  - (E) When the desired and measured amount of liquid preservative has been absorbed, release the applied pressure and drain the cylinder (initial drain).
  - (F) Apply a "final" vacuum to expand the air remaining in the wood. This forces excess liquid to exude from the surfaces and run off.
  - (G) Release final vacuum. As the remaining air in the cells contracts, much of the surface wetness will be reabsorbed into the wood (this reduces dripping later).
  - (H) Remove the treated wood products from the cylinder.

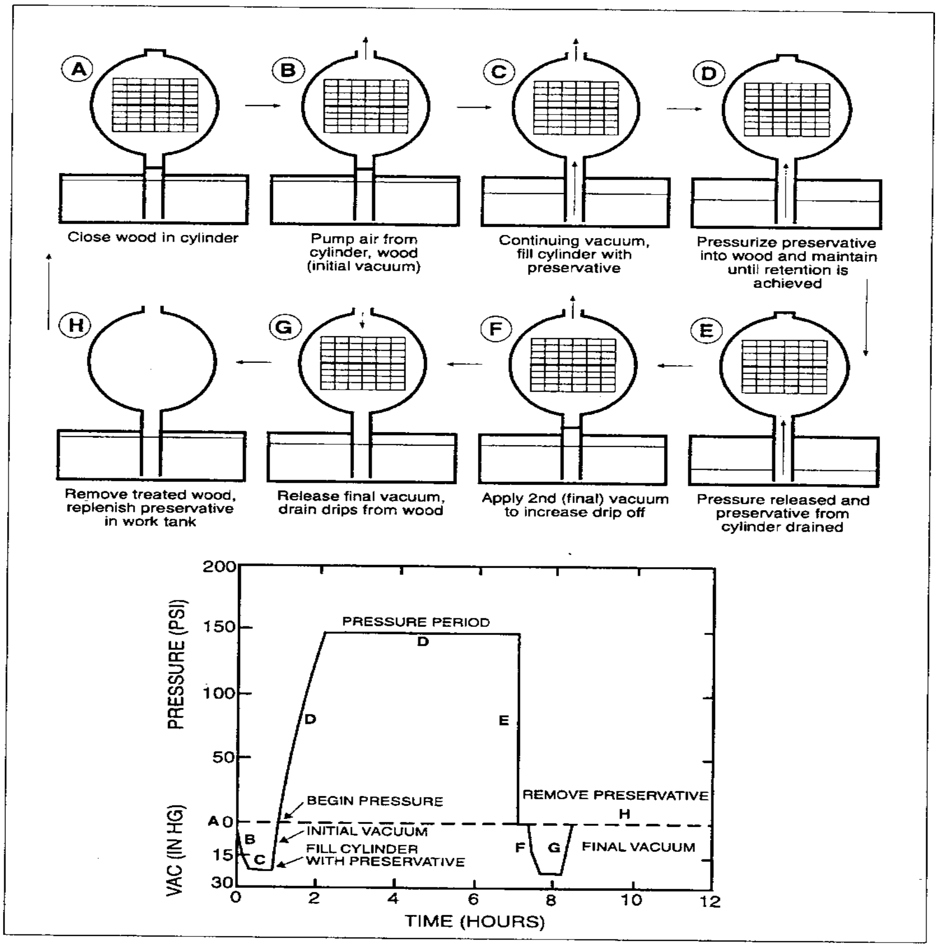
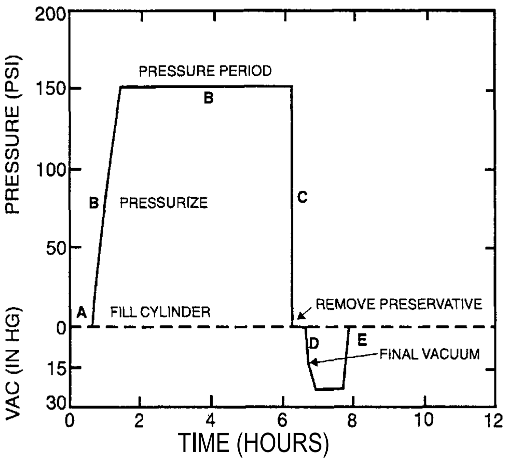


Fig 3. Treating schedule for the full cell (Bethell) process

Adapted from Nicholas, Darrel D. 1973. Wood Deterioration and Its Prevention by Preservative Treatments. Vol. 2. Syracuse University Press, Syracuse, NY.

(ii) Empty cell processes (Lowry and Rueping): For some purposes, it is necessary to ensure deep penetration of preservative without leaving all the cells full of preservative. An example would be coal tar creosote treatment for an above-ground use, such as fence rails, which require a retention of 8 pounds per cubic foot (pcf) in accordance with AWPA Standard C2. A full cell process, giving full-depth penetration of sapwood, would likely produce a retention of 12 pcf (4 pounds more than required). To ensure good depth of penetration, the empty cell process forces more creosote into wood than is needed, but then removes the excess to leave the average retention desired. Look at Fig 4 and 5, for the sequences followed during treatments with the Lowry and the Rueping empty cell processes. Both treating methods are similar to the full cell (Bethell) process except they omit the initial vacuum stage.

The Lowry Process is named for Cuthbert Lowry (1906, U.S.A.) In this process, after the wood has been closed in the cylinder, preser- vative is pumped in, and no air is allowed to escape. As the cylinder fills with liquid and pressure is applied, the air in the cylinder and in the wood cells is compressed into a smaller and smaller space. When the desired pressure is attained, air in the cells will occupy about one-tenth of the cell voids, and preservative can gradually fill up the other nine-tenths. The process then continues exactly as the full cell process, but the air compressed inside the wood expands when the pressure is released, thereby forcing some preservative out of the cells and eliminating overloading. The end result is that many cells are "lined" with preservative rather than "filled."



Lowry (Empty Cell) Process

A - Fill cylinder with preservative at atmospheric pressure

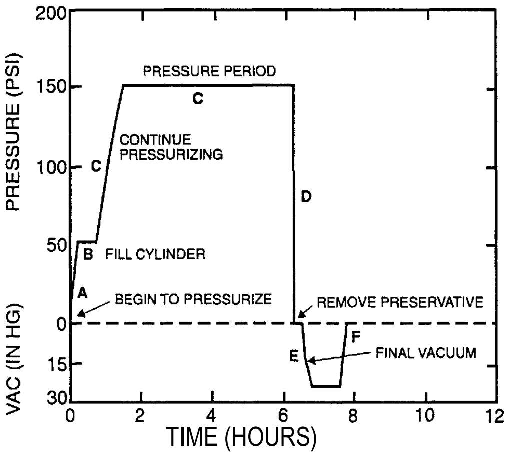
B - Pressurize cylinder to maximum and maintain until retention is reached

C - Release pressure and withdraw preservative

D - Apply final vacuum

E - Release final vacuum

Fig 4. Treating schedule of the Lowry (empty cell) process.



Rueping (Empty Cell) Process

A - Partially pressurize cylinder

B - Fill cylinder with preservative

C - Continue pressurizing to maximum and hold until retention is reached

D - Release pressure and withdraw preservative

E - Apply final vacuum

F - Release final vacuum

Fig 5. Treating schedule of the Rueping (empty cell) process

Fig. 4 and 5 adapted from Nicholas, Darrel D. 1973. Wood Deterioration and Its Prevention by Preservative Treatments. Vol. 2. Syracuse Universrty Press, Syracuse, NY.

The final vacuum period can be used to extract more or less preservative as needed, so it acts as a retention control stage. The word “empty” in the term empty cell process is a poor description because cells are partly filled with preservative, in contrast with the word “full” which appropriately describes the full cell process. The Lowry process is mainly used for treating wood with creosote, creosote/PCP mixtures and PCP preservatives.

The Rueping process is named for Max Rueping, (1902, Germany). This process is similar to the Lowry process. Here an air pressure higher than atmospheric is first applied to the closed cylinder and its charge of wood. The air pressure is generated by a compressor. A typical pressure used is four to five times atmospheric (about 60 psi). Treatment then continues as with the Lowry or full cell processes, but the amount of preservative removed (as the air compressed in the cells expands) is greater than in the Lowry process. This provides the necessary degree of penetration with even less final retention of preservative. The Rueping process also is mainly used with creosote, creosote/PCP mixtures and PCP preservatives. Other benefits of empty cell processes are:

- The final weight of treated wood is reduced compared to full cell treatment.
- A cost saving is realized from the use of less preservative chemical and carrier liquid.

(iii) Modified full cell process: This process is an adaptation of the Bethel1 process for use with waterborne preservatives like CCA. It, too, achieves full sapwood penetration with a reduction in the weight of water left in the wood. This is important if the wood is to be shipped after treatment, without thorough air-drying or kiln-drying. The lower weight of the treated wood is reflected in lower shipping costs.

The modified full cell process calls for a lower degree or period of initial vacuum than the full cell. By leaving more air in the cells, a greater amount of absorbed preservative is rejected when the pressure period is over. The concentration of CCA solutions can easily be changed, either by adding more CCA concentrate or more water. Usually higher concentrations of CCA are used with the modified full cell than with the full cell process, and essentially the same weight of CCA chemical is left in the wood, but less water. A 20%

reduction in overall weight of wood products treated in this way will give similar percentage savings in the cost of shipping undried products.

Technical Note: Before shipping, it is essential that treated wood has stopped drip- ping. A properly drained and covered drip-pad is used for this purpose. In the case of CCA preservatives, at least 24 hours should be allowed for chemical fixation to take place. Fixation time is appreciably longer in cold weather.

8.6.6 Vacuum-Pressure Treating Plant Equipment

Equipment used to apply preservatives under pressure is not standard in design, but most systems are capable of wood treatment by the full cell, Lowry or modified full cell processes. The compressed air required for the, Rueping process is not always available, but this process is not widely used. The major item of a pressure-treating plant is the treating cylinder or retort, which can vary in size but is commonly 4 to 8 feet in diameter and 30 to 150 feet long. Auxiliary equipment usually includes a boiler, dry kiln, pumps, tanks, gauges, thermometers, controllers and valves (Fig 6).

Specialized accessories such as incisors, steam generators, trams, hoists, lift trucks, debarkers, shavers, machinery for adzing and boring, condensers and water purification equipment are often needed. These are not usually directly connected with the pressure process, but rather with preparation of the wood items for treatment, or for pollution prevention.

Preparation or Pretreatment of Wood for Vacuum-Pressure Application: Before wood cells can accept sufficient preservative liquid to satisfy preservation standards, the product to be treated must meet the following conditions:

- **(i)** There should be no bark or inner bark, paint, varnish or other impediments to surface penetration of preservative.
- **(ii)** The wood product should be air-dried or kiln-dried to an average moisture content of 25% or less, unless pressure treatment is preceded by steam conditioning (drying green wood in the cylinder by steaming) or Boultonizing, described in the next section.
- **(iii)** Incising should be carried out whenever the treating standard calls for it. AWPA standards require incising of many "details).difficult to treat" species to increase surface penetration and retentions.

8.6.6.1 Boultonizing

This conditioning or drying method is used with creosote preservative. It is an alternative to conventional wood seasoning, an essential step for good penetration. It is accomplished by enclosing green wood products (poles, crossties, timbers, etc.) in the treating cylinder and introducing creosote at 210° F to 220° F while applying a vacuum. Water, removed from the wood by evaporation, is then condensed in special equipment outside the cylinder. Since the boiling point of water (in the wood) is lower under a partial vacuum than at atmospheric pressure, drying can occur rapidly at temperatures below 212" F (depending on the proportion of sapwood to heartwood). Although Boultonizing does not thoroughly dry wood, it improves the ability of many wood species to accept preservative by the conventional full cell process which follows Boultonizing. (See AWPA standards for commodities and species allowed for Boultonizing .

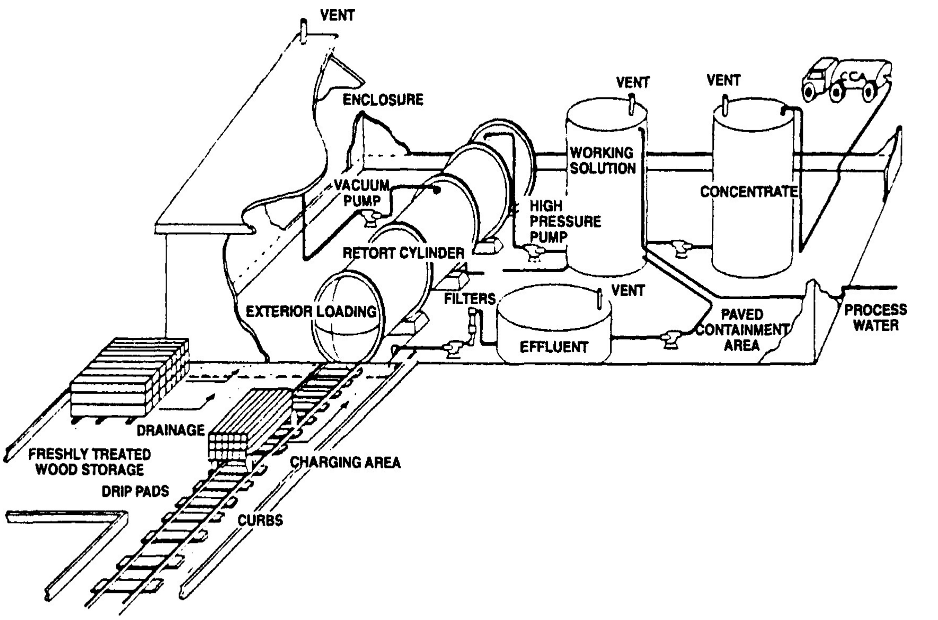


Fig 6. Conceptual diagram of CCA pressure-treating facility.

Source: Konasewich, D.E. and Henning, F.A. 1988. Chromated Copper Arsenate Wood Preservation Facilities. Environment Canada. Report No. EPS .VWP/3.

8.6.6.2 Steaming

In this preconditioning process, green or partially seasoned wood items are first subjected to pressurized steam at about 240" F for a limited time. The AWPA standards define the species, temperature and time allowed. Over-steaming reduces the strength of wood, often seriously, but a controlled steaming process, like Boultonizing, can reduce the moisture content of green wood products to a condition acceptable for treatment. Steaming is not used as extensively as it once was, and is mostly practiced today with west coast softwood species.

8.6.6.3 Incising

This is a process of mechanically puncturing the outer surfaces of wood products, usually poles, crossties, timbers and some- times lumber. Slots or holes of a controlled depth and spacing are made. This improves the uptake of preservative in "difficult to treat" species, and helps provide a treated zone around the outside of the wood item.

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Unit-9 Wood Instruments and Wood Working

Unit Structure

9.0 Learning objectives

After studying this unit you will be able to understand:

- Wood working and its procedure
- Wood working tools
- Handling of wood working tools

9.1 Introduction

Wood was one of the first materials used by early humans for tools and utensils, and use of the materials is closely tied to the development of aspects of modern human life.

Early civilization is known to have used wood to build hunting tools, vessels, coffins, chairs, idols, and more.

As civilization has advanced, so has woodworking as a craft. While the fundamentals remain largely unchanged, woodworkers are using modern technology to build new equipment and tools and create more advanced projects.

Woodworking is the process of making decorative and useful objects from wood, like cabinets, fine tables, instruments, bowls, and more. It encompasses techniques like wood carving, joinery, and woodturning. It is relatively simple to learn basic woodworking skills, to gain new expertise.

9.2 Wood Working Procedure -

9.2.1 Selection and Laying Out

First of all, the ends must be observed while selecting the stock, and if it contains small splits or defects, they must be trimmed. While laying out, 1 to 2 mm must be allowed in thickness, about 5 mm for each width and about 20 mm on length for planning and/or cutting. It must also be ensured that the grains are in the right direction.

9.2.2 Marking

(a) Accurate measuring and marking are treated as top priority for successful and beautiful wood working. In most of the cases, marking desired dimension is done by placing a square or rule and then making a fine narrow line, close to the edge of the square or rule.

(b) A soft pencil, that can make a line easily visible, serves the purpose for Carpentry However, for accurate marking it is advisable to use a blade.

(c) For marking with the help of marking gauge, it must be firmly held with fingers around the head and with the thumb behind the marking point and the gauge must be pushed forward against the surface. While pushing, the gauge should be kept slightly forward so that, the point gets dragged at the slight angle.

(d) If the job requires plane finish, an allowance must be provided for this, while marking.

(e) However, it must be kept in mind that removing excess material by a plane is a tedious and difficult job and hence should be kept as minimum as possible.

9.2.3 Laying-out an Angle

The following are the steps involved in laying out an angle on a wooden surface:

(a) Set the bevel to the required angle.

(b) Hold the handle against the face or edge of the board.

(c) Mark along the edge of the blade with a pencil or knife.

9.2.4 Planing

A plane cannot produce a proper work surface if the blade is not sharp (blunt) and not adjusted properly. There are two adjustments in built in the design of the plane. First one is to regulate the depth of cut and the other is to straighten the blade so that, it produces a flat surface. The first adjustment of the plane, i.e. depth of cut may be checked by feeling the edges of the blade with the first two fingers. And the second adjustment is checked by trying to move slide the blade holding at its comers and tightening the screw till it does not move i.e. firmly held.

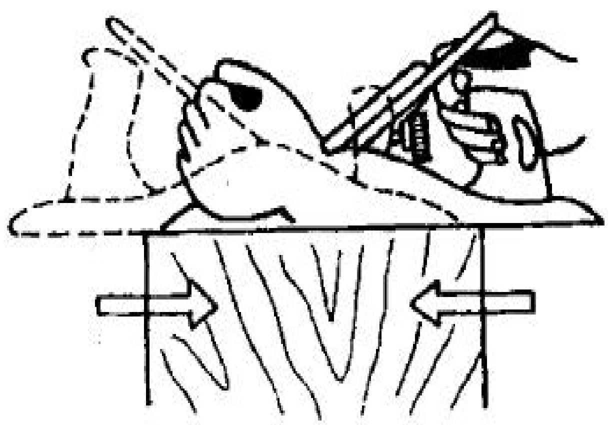

Fig 1. Plane Adjustment

9.2.4.1 Method of Using the Plane

The following may be noted while using the plane:

(a) Hold the handle of the plane with the right hand and the knob with the left hand.

(b) Stand to the left side of the job foot apart and with the left foot slightly ahead.

(c) While pushing the plane, gradually shifting weight to the left foot.

(d) While planning, keep the fore-arm straight in-line behind the plane.

(e) Always plane along the grains. Planning against the grains will result in rough work.

(f) When not in use, keep the plane on its side. This prevents the cutting edge becoming dull by contact with the bench top.

9.2.4.2 Planing a Surface

Planing is the first and foremost operation to be performed on any carpentry job.

The following are the steps involved in planning a surface:

(a) Start at one edge of the stock, plane with full length strokes to the other edge.

(b) Use the edge of the steel rule or try-square to test the surface placing the edge in various positions on the surface and see the underneath gaps to locate high and low places. For this, the order of the checking is as follows :

  (i) Place the straight edge cross-wise on the stock and move it slowly form one end to the other.

  (ii) Then place the edge lengthwise and move it slowly form one edge to the other.

  (iii) Finally place the straight edge on the one diagonal and then on the other.

(c) While planing, if it appears to be cutting at some spot and not in another, it indicates high spots in the surface. So continue to plane these high spots until they disappear and plane takes a shaving across the entire length.

(d) Select the best surface or edge as reference, since defects on the other surface or edge may be removed when the stock is reduced to the required thickness.

9.2.4.3 Planing End Grain

End grain is hard to plane. So, Jack plane is generally used for this. In this plane, the blade is set at low angle with the bevel side turned up, to make a shearing type of cut. The plane is to be held in one hand leaving the other hand free to hold or support the work. The planing should be carried out from both the edge as shown in above Fig 1.

9.2.4.4 Squaring Up a stock'

It is necessary in wood work, to plane all the sides and ends, at right angle to adjoining surfaces. **A** board or stock is considered to be squared. So that, all the surfaces/edges/ends are at 90^{o} to each other. This may be achieved in the following order:

(a) Plane any one surface smooth and true: This surface may then be treated as working surface. Mark it with one short line, near the edge to be selected next.

(b) Select that edge and plane it straight and square with the working surface. This edge is then called the working edge. Use straight edge for testing straightness and squareness. Mark two short lines, extending to the working surface.

(c) Plane the second edge, parallel to the above working edge. For this, mark to the desired width on both the surfaces and then plane to the marked lines.

(d) Mark one end with the square, cut it and make it straight and square with the working surface and the working edges.

9.2.5 Chiseling

The following are the noteworthy points to be observed while chiseling :

(a) Fix the work piece in a vice. Now both hands will become free to use on the chisel.

(b) Push the chisel away from the body and keep both the hand behind the cutting edge (Fig 2).

(c) Use the left-hand to guide the chisel, while the right-hand to push it forward.

(d) Use the chisel with the bevel down for roughing cuts and with the bevel up for finishing cuts.

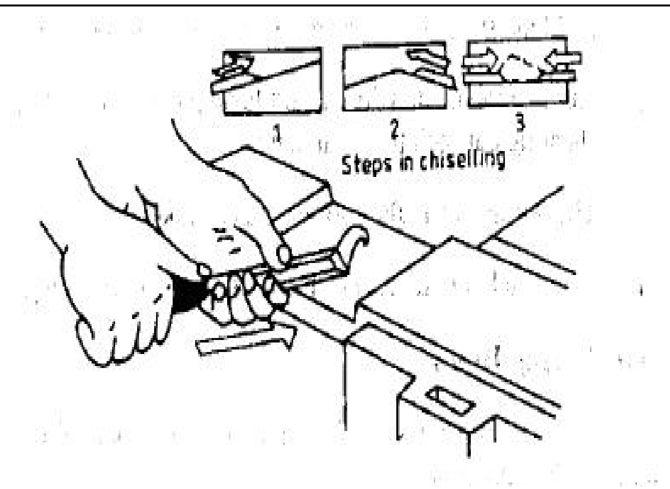

Fig 2. Chiseling

9.2.5.1 Chiseling Along the Grains

To reduce either the width or thickness of the stock chiseling is made along the

(i) Chiseling Across the Grain

The chiseling is done across the grains in making notches. The following points must be observed during the work:

(a) Hold the blade of the chisel between the thumb and first two fingers of the left hand and guide it while pushing with the right hand.

(b) Instead of cutting across the entire width, cut the mid way from one edge and then from the other to avoid 3plitting.

(c) Cut with the bevel side up, raising the handle just enough to make the chisel cut.

(ii) Chiseling Across end Grains

As far as possible, the chiseling work across the end grains may be avoided by careful marking and sawing leaving about 1mm or so (to be removed by chiseling). For this:

(a) Begin on the front edge and push forward at an angle.

(b) Straighten the handle to vertical, towards the end of the stroke.

(c) Guide the chisel with the left hand, while applying force with the right.

(d) It is better to use only about half the width of the chisel for cutting on each stroke, while keeping the remaining half, flat against the surface obtained by the previous cut.

(e) For through cutting, it is advisable to keep a piece of scrap lumber under the stock, to keep the chisel away from cutting into the bench.

(iii) Horizontal Chiseling

The following is the procedure for horizontal chiseling:

(a) Fasten the work in a vice or on a bench. ,

(b) Guiding the blade with the thumb and four fingers of the left hand push the chisel with the right hand.

(c) Make sure that the level of the chisel is turned-up during the work.

(iv) Vertical Chiseling

The following is the procedure for vertical chiseling:

(a) Fasten the work in a vice or a bench.

(b) Hold the flat side of the chisel against the wood in a vertical position.

(c) Guiding the blade with the left hand push the chisel, making a shearing cut with the right hand.

(d) The left hand should also serve as a brake.

(e) Use a mallet to drive the chisel, only when necessary.

9.2.6 Drilling or Boring Holes

To fit screws, bolts, dowels, etc. holes are drilled or bored in wood. The following steps involved are in the drilling process:

(a) Measure and layout the position of the hole by two cross lines on the best face of the stock.
(b) Punch a small hole with a bradawl at the intersecting point of the lines.
(c) Fasten the stock (work) in a vice firmly.
(d) Keep a piece of waste stock that will support the wood, when the bit cuts through.
(e) Select the correct, size bit and insert into the chuck of the brace.
(f) Set the bit on the spot marked for the centre of the hole.
(g) Guide it with the left hand and make few turns in a clockwise direction, with the brace to start the hole.
(h) Check the angle of boring by testing with a try-square against the bit.
(i) Check if the bit and work that should make a right angle.
(j) After boring, remove the bit from the hole, by turning the brace in counter-clockwise direction.
(k) While boring a large hole in a small piece of wood, it is better to apply pressure to the sides of the screw apart of the auger bit to prevent splitting.

9.2.6.1 Drilling with a Hand Drill

Follow the point given below while using of a hand drill:

(a) Hold the head of the hand drill with left hand guide the drill to the marking and then turn the crank steadily with the hand.
(b) Apply uniform and moderate pressure while drilling.
(c) Too slow or too high a speed or heavy pressure may break small drill bits.

9.2.7 Gluing

Gluing wood joins two or more pieces of wood together to create a larger piece. When you glue two pieces of wood together properly, the glued joint is stronger than the wood itself.

9.2.8 Sanding

Sanding is a finishing technique that smooth's the surface of the wood using sandpaper. Woodworkers often start sanding with a medium grit, and work their way to a finer grit to finish.

9.2.9 Finishing

Finishing is the process of refining or protecting a wooden surface by applying a penetrating finish or a surface finish.

9.3 Woodworking tools

Woodworking tools are used to cut, shape, join, and finish projects. Generally, there are many different types of each tool. The following are the tools used in wood working operations:

9.3.1 Marking and Measuring Tools

To produce parts to exact size we need to do marking first. To transfer dimensions onto work; the following are the marking and measuring tools that are generally used in carpentry.

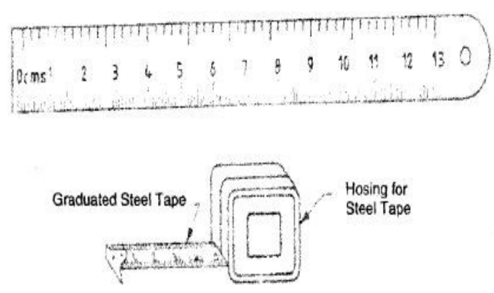

Fig 3. Steel Rule

(i) **Steel Rule:** It is an important tool for linear measurement and can also be used as a marking tool.

(ii) **Steel Tape:** It is used for large measurements, such as marlung on boards and checking the overall dimensional of the work.

(iii) **Marking Gauge**: Marking gauge is a tool used to mark lines parallel to the edge of a wooden piece. It consists of a square wooden stem with a sliding wooden stem with a sliding wooden stock (head) on it. On the stem is fitted with a marking pin, made of steel. The stock is set at desired distance from the marking point and fixed in position by a screw. It must be ensured that marking pin projects through the stem 3mm and the end is sharp enough to make a very fine line.

(iv) **Mortise Gauge**: A mortise gauge consists of two pins. In this, it is possible to adjust the distance between the pins, to draw two parallel lines on the stock.

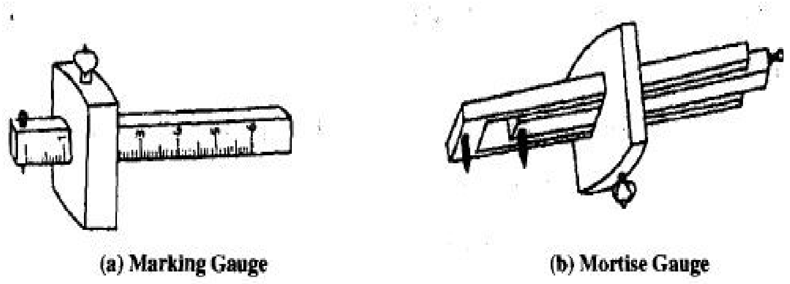

Fig. 4 Mortise Gauge

(v) Try-Square: It is used for making and testing the straightness and squareness (perpendicularity) of planed surfaces. It consists of a steel blade, fitted in a cast iron stock. It is also used for checking the planed surfaces for flatness. Its size varies from 150 to 300 mm, according to the length of the blade.

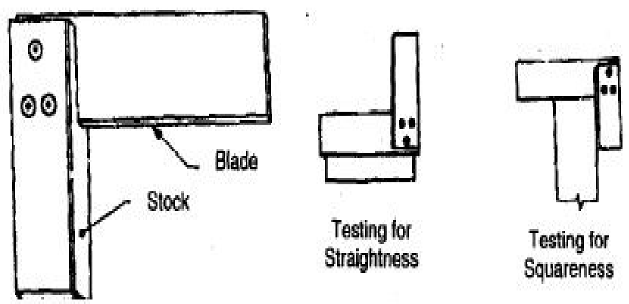

Fig 5. Try-Square

(vi) Compass and Divider: These are used for marking arcs and circles on the planed surfaces of the wood.

(vii) Scriber or Marking Knife: It is used for marking on timber. It is made of steel, having one end pointed and the other end formed into a sharp cutting edge.

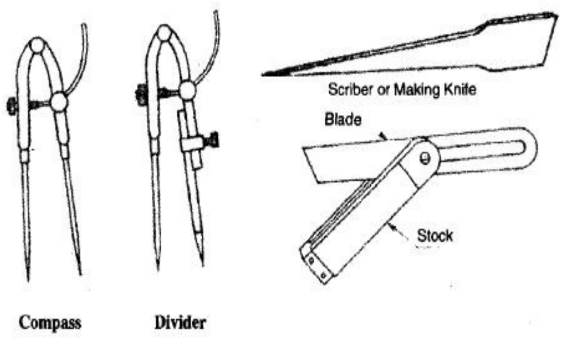

Fig 6. Scriber or Marking Knife

(viii) Bevel/Blade: It is used for laying-out and checking angles. The blade of the bevel is adjustable and may be held in place by a thumb screw. After it is set to the desired angle, it can be used in same way as a try-square. The extra advantage of this over try square is that it can be adjusted at any angle while try square can check only perpendicularity only. A good way to set it to the required angle is to mark the angle on a surface and then adjust the blade to fit the angle.

9.3.2 Holding Tools

(i) Woodworking Vice: The carpenter's bench vice, used as a work holding device in a carpenter shop. Its one jaw is fixed the side of the table while the other is movable by means of the screw and a handle. The jaws are lined with hard wooden faces.

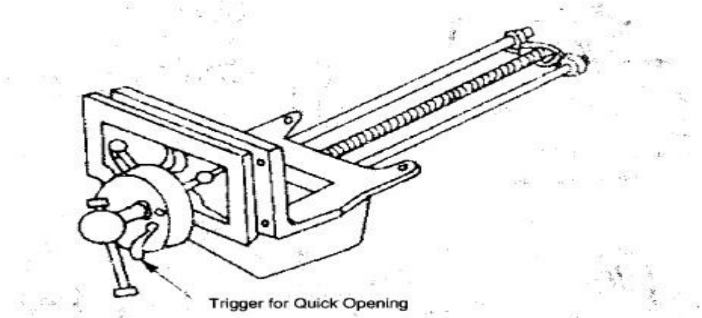

Fig 7. Woodworking Vice

(ii) Clamp: Clamps are necessary tools for joinery and an essential tool in the woodshop. They work great as vises, or as an extra set of hands to hold wood in place. The type of clamp you use will depend on the size and scale of the job at hand.

(iii) Bar Clamp: A bar clamp as shown in the following figure (Fig 8) is made of steel bar of T-section, with malleable iron fitting and a steel screw. It is used for holding wide works such as frames or tops.

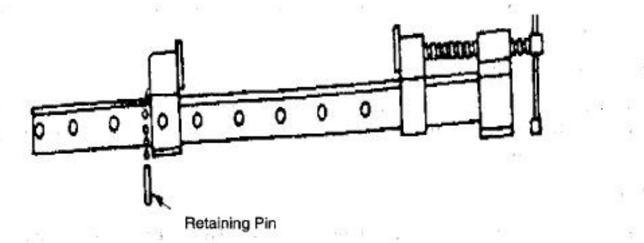

Fig. 8 Bar Clamp

9.3.3 Planning Tools

Planning is the operation carried out on wood to produce flat surfaces. A plane is a hand tool used for this purpose. The cutting blade of a plane is fitted in a wooden or metallic block, at an angle. This cutting blade used in a plane is similar to a chisel. Different types of planes used for different purposes are shown here below.

(i) Jack Plane: It is the most commonly used general purpose plane. It is about 30-40 cm long. The cutting blade has a cutting edge of slight curvature for quick removal of material on rough work and is also used in oblique planning.

(ii) Rebate Plane: It is used for making a rebate. A rebate is a recess along the edge of a piece of wood, which is generally used for positioning glass in frames and doors.

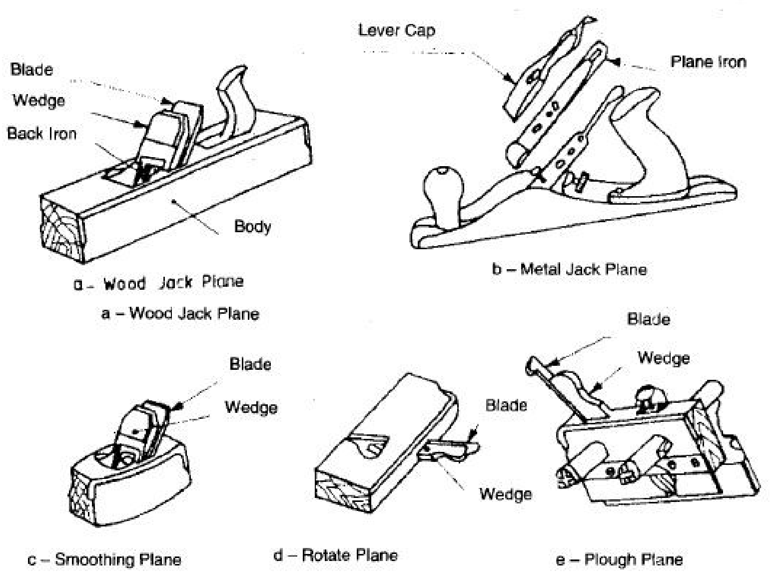

Fig 9. Planning Tools

9.3.4 Cutting Tools

(i) Saws: A saw is used to cut wood into pieces. A saw is specified by length of its toothed edge. There are many different types that are meant for different materials, jobs, and more. A handsaw does not require any power and is very portable. The different types of saws, designed to suit different purposes are shown below.

(a) Cross-cut or Hand Saw: It is used to cut across the grains of the stock. The teeth are so set that the saw kerfs will be wider than the blade thickness for moving free11 during the cut, without sticking.

(b) Rip Saw: It is used for cutting the stock along the grains. The cutting edge of this saw makes a steeper angle, i.c. about 60" (see Fig 10c), where as that of cross cut saw makes anangle of 45" with the surface of the stock.

(c) Tenon Saw: It is used to cut the stock either along or cross the grains. It is used for cutting tenons and in fine work. However, it is used for small and thin cuts. The blade of this saw is very thin and hence it is stiffened with a thick back steel strip. Hence, this is sometimes called back-saw also. (In fact in back saw, the teeth are shaped like those of cross-cut saw).

(d) Compass Saw: It has a narrow, longer and btronger tapering blade, which is used for heavy works. It is mostly used for radius cutting. The blade of this saw is fitted with an open type wooden handle.

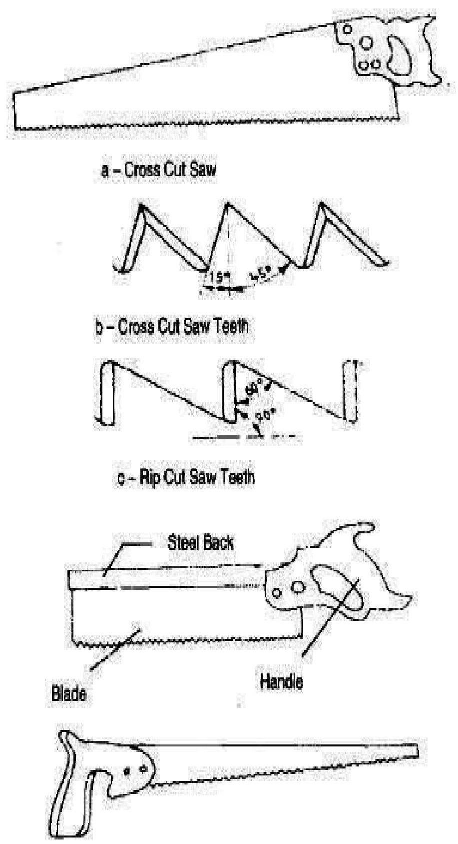

Fig 10. Saws

(ii) Chisels: Chisels are used for cutting and shaping the wood. Chisels used for wood working are made in various blade widths, ranging from 3 to 50 mm. They are also made in different blade lengths. Most of the chisels used for wood working are made into tang type, having a steel shank

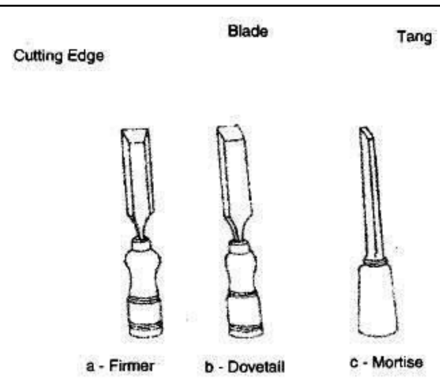

Fig 11. Chisels

which fits inside the handle as shown in the Fig 11. These are made of forged steel or tool steel blades.

(a) Firmer Chisel: The word 'firmer' means 'stronger' and hence firmer chisel is stronger than other chisels. It is a general purpose chisel and is used either by hand pressure or by a mallet. The blade of a firmer chisel is flat, as shown in Fig 11a.

(b) Dovetail Chisel: It has a blade with a beveled back, as shown in Fig 11b, due to which it can enter sharp comers for finishing, as in dovetail joints.

(c) Mortise Chisel: This is used for cutting mortises and chipping inside holes. The cross-section of the mortise chisel is so proportioned as to withstand heavy blows during mortising (Fig 11c). Further, the cross-section is made stronger near the shank.

9.3.5 Drilling and Boring Tools

(i) Brace: This is used for rotating auger bits, twist drills, etc., to produce holes in wood as shown in the Fig 12. Some braces have ratchet device. With this, holes may be made in a comer where complete revolution of the handle cannot be made. The size of a brace is determined by its sweep.

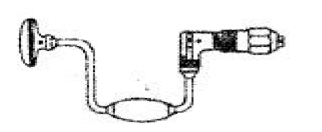

Fig 12. Brace

(ii) Auger Bit: It is similar to drill bit and is the common tool used for making holes in wood. During drilling, the lead screw of the bit guides into the wood, necessitating only moderate pressure on the braces. The helical flutes on the surface cany the chips to the outer surface (Fig 13).

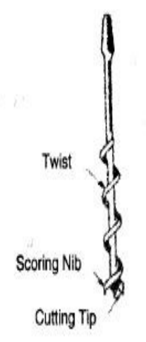

Fig 13. Auger Bit

(iii) Hand Drill: Drills can be hand-cranked or motorized, depending on the scale of your job. If you are working on a smaller project without access to power, you may opt to use a battery-powered drill. If your job requires more force and deeper holes to be drilled, you can invest in a drill press. This is used to make relatively large size holes; while hand drill is used for drilling small holes. A straight shank drill is used with this tool. It is small, light in weight and may be conveniently used than the brace.

The drill bit is clamped in the chuck at its end and is rotated by a handle associated with gear and pinion mechanism.

(iv) Gimlet: It has cutting edges like a twist drill as shown in the Fig 14. It is used to drill holes of large diameter with the hand pressure.

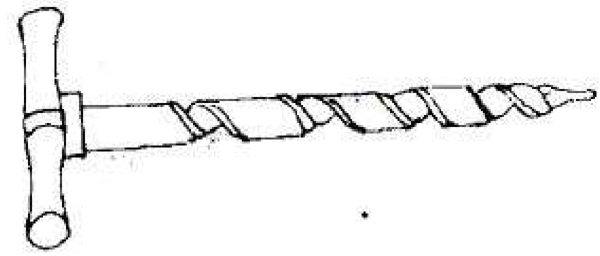

Fig 14 Gimlet

9.3.6 Miscellaneous Tools

(i) Mallet: A mallet made up of wood or rubber is like a hammer used to drive the chisel with considerable force to be applied, which may be the case in making deep rough cuts (Fig 15). Steel Iron hammer should not be used for the purpose, as it may damage the chisel handle. Further, it is advisable to apply a series of light taps with the mallet rather than a heavy single blow.

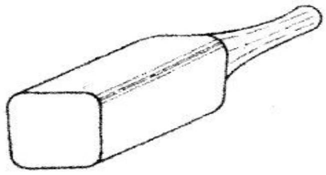

Fig 15. Mallet

(ii) Pincer: It is usually made up of two forged steel arms hinged and is used to pull-out small nails from wood. The inner faces of the pincer jaws are beveled and the other faces are plain. The end of one arm has a ball and the other has a claw. The beveled jaws and the claw are used for pulling out small nails, pins and screws from the wood.

Fig 16. Pincer

(iii) Claw Hammer: It has a striking flat face at one end and the claw at the other, as shown in the Fig 17. The face is used to drive nails into

Fig 17. Claw Hammer

wood and for other striking purposes and the claw extracting relatively large nails out of the wood. It is usually made up of cast iron.

(iv) Screw Driver: This is used for driving a screw (unscrew) into (from) the wood. In fact the screw driver of a carpenter is different from the other common types, as given in the Fig 18.

Fig 18. Screw Driver

The length of the screw driver is determined by the length of blade as the length of the blade increase, the width and thickness of the tip also increases. The following are some tips for using a carpenter's screw driver:

(a) Drill all the required holes first.

(b) If the work piece is a hard wood, apply soap or oil to the threaded section of the screw.

(c) Place the screw in the hole and place an appropriate screw driver tip into the slot of the screw.

(d) Steady the screw and screw driver tip with one hand while push and apply pressure on the handle with the other hand.

(e) Slowly rotate the screw driver.

(f) Keep the both hands on the screw driver once the screw driver starts going into the work.

(v) Wood Rasp File: It is a finishing tool used to make the wood surface smooth and/or remove sharp edges, finish fillets and interior surface as shown in the Fig 19. Sharp cutting teeth are provided on its surface for the purpose. This file is exclusively used in wood work.

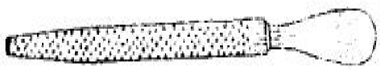

Fig 19. Wood Rasp File

(vi) Bradawl: It is hand operated tool used to bore small holes for starting a screw are large nail as shown in the Fig 20.

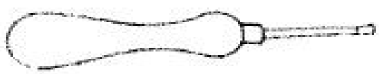

Fig 20. Bradawl

Sources:

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