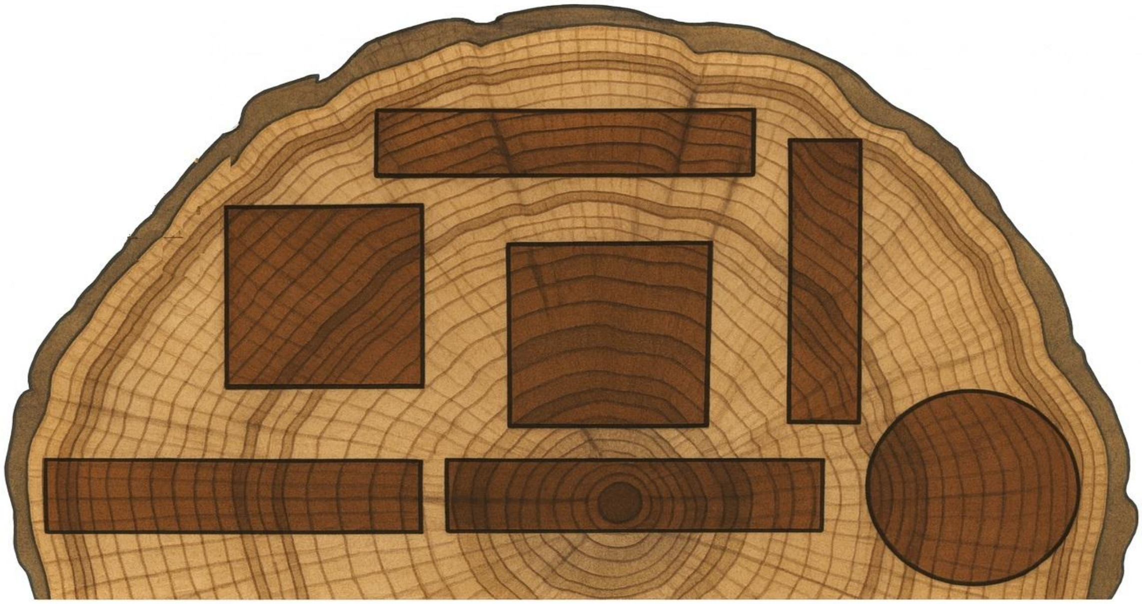
BUAT/EM/12/2026

E- Practical cum Teaching Manual of Wood Science and Technology



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Wood Science and Technology

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PREFACE AND ACKNOWLEDGEMENTS

Wood is technically a secondary xylem formed by the axial and radial tissues derived from the fusiform initials and ray initials, respectively. Being a complex tissue it is composed of vessel, tracheids, fiber and xylem parenchyma. In gymnosperms, the axial featureshave the abundance of tracheidsand small amount of fiber and parenchyma, however in angiosperm it has abundance of vessels followed by fiber, tracheids and parenchyma. These vessels and tracheids are responsible for conduction of water–minerals and provide mechanical support to leaving tree.

These features can be categorised into macro features like density, hardness, Bark, heartwood-sapwood, texture, color etc. and Micro features like size and arrangement of vessel, parenchyma, rayetc. These unique anatomical characteristics are important in determining many of the properties of the species, such as strength, dimensional stability, acoustical, conductivity, and ease of utilization for various applications. These unique anatomical characteristics/features, allow a trained eye to identify the species.Each species has unique cellular structure that creates differences in wood properties and ultimately determines the suitability for a particular use. Cellular characteristics provide a blueprint for accurate wood identification.

The manual is prepared with an aim to cover the practical part of wood anatomy subject of B.Sc. Forestry. It has covered all the major topics like Tissue, Tissue system, Monocot and dicot anatomy, secondary growth, wood formation, Macro and micro features of woods and wood identification. In developing the material for this manual authors have relied upon the literature from several sources which is highly acknowledged. Some of the help came from discussion, field visit and various other sources. The author extends his gratitude to Hon'ble Vice Chancellor Dr. (Prof.) S.V.S. Raju, Dr. **A.C.Mishra** Director of Research Banda University of Agriculture & Technology Banda. Dr. A.K Shrivastva Director PMEC, Dr. Sanjeev Kumar Dean CoF,and Dr.Yogesh Y.Sumthane Assistant Professor FPU for their encouragement to write this manual. The Author also would like to thank all those, who have helped in anyway in preparation of this manual.

(Mohammed Nasir)

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Practical 1. Wood as a Material Advantage and Disadvantages

Objective-To study the advantages and disadvantages of wood as a structural and industrial raw material

Wood as a Raw Material: Advantages

Strength	As strong as iron in many applications. 5–6 times stronger than cement concrete on a weight-to-strength basis.
Physical properties	Excellent thermal insulation. Good sound absorption. High electrical resistance.
Marine structures	Resistant to corrosion by seawater. Suitable for docks, poles, underwater components.
Earthquake Uses	Light weight and good flexibility. Timber structures behave as composite units and withstand shocks better.
Renewable natural	Wood is renewable natural resource whereas steel/cement depend on non-renewable minerals.
Highly versatile	Used for beams, rafters, flooring, partitions, doors, windows, panels, roofing, etc. No complete substitute exists for its wide range of uses.
Reduced wastage	Waste wood converted into plywood, laminated board, blockboard, MDF, particleboard.
Raw Material	Major raw material for the pulp and paper industry.

Wood as a Raw Material: Demerits

Hygroscopic:	Absorbs and loses moisture → swelling and shrinkage.
Anisotropic:	Properties differ in longitudinal, radial and tangential directions; affects machining and design.
Biological degradation	Prone to biological degradation due to starch and carbohydrates:

	Fungi, termites, borers attack easily.
Limited availability:	Long rotation age; slow regeneration. Restrictions on green felling and forest harvesting limit supply.
Combustibility:	Catches fire faster than steel or concrete. Can be treated with fire retardants but not fully fireproof.
Seasoning requirement:	If not felled at the proper time or not seasoned correctly, wood develops defects like warping, cracking and checking.
Availability	High-quality species becoming costlier due to demand–supply gap.

Students Activity

1. Identification of Merits: Observe and list wood used in doors, windows, frames and furniture in the workshop/building.
2. Observation of Demerits: Examine seasoned vs. unseasoned wood samples and identify defects (cracks, warp, twist).
3. Waste Utilization Demonstration: Examine plywood, laminates, MDF, and particleboard samples.

Learning Outcomes

1. Ability to list major advantages and limitations of wood.
2. Understanding of wood's practical behaviour as a structural and industrial material.
3. Skill to recognize biological deterioration, seasoning defects and physical limitations.
4. Awareness of sustainable wood use and material substitution.

Practical 2. Equilibrium Moisture Content (EMC), Shrinkage & Swelling Behaviour of Wood

Objective- To study the relationship between equilibrium moisture content (EMC), fibre saturation point (FSP), and dimensional stability of wood.

Introduction

Wood is a hygroscopic material that continuously exchanges moisture with the environment. Once dried below its Fibre Saturation Point (FSP)—typically 20–30% moisture content—wood does not regain free water except through prolonged soaking. However, it continues to lose or absorb bound water until it reaches a moisture level that is in balance with its surrounding atmosphere. This stable moisture level is called the Equilibrium Moisture Content (EMC)**.**

1. Equilibrium Moisture Content (EMC): EMC is the moisture content at which wood is in equilibrium with the ambient temperature and relative humidity (RH). It is always below FSP, generally less than 30%. Factors Controlling EMC- are Relative Humidity (RH) and Temperature
2. Shrinkage and Swelling Behaviour : When moisture begins to leave wood below the FSP, the cell walls shrink. When moisture is absorbed, swelling occurs.
3. Repeated fluctuation in humidity causes cyclic dimensional changes leading to defects such as warping, splitting, cracking, and open joints.
4. Anisotropic Nature: Wood shrinks differently in different anatomical directions because its structure is non-uniform:

Direction	**Typical Shrinkage**
Longitudinal	0.1–0.3%
Radial	2.1–7.9%
Tangential	4.7–12.7%

Method of shrinkage calculation

$$\text{Shrinkage (\%)} = \frac{\text{Wet dimension - Dry dimension}}{\text{Wet dimension}} \times 100$$

$$\text{Swelling (\%)} = \frac{\text{Wet dimension - Dry dimension}}{\text{Dry dimension}} \times 100$$

Specific Gravity: Heavier wood with higher density shows greater shrinkage.

Wood with higher FSP shrinks more.

Uneven shrinkage causes internal stresses as different parts of a board dry at different rates. Poor seasoning or storage leads to defects affecting strength and service life.

Students' Activity

1. Determine EMC of sample wood pieces by placing them in controlled humidity chambers.
2. Measure dimensional changes to calculate shrinkage and swelling in all three anatomical directions.
3. Compare shrinkage values of low-density vs high-density woods.
4. Study moisture absorption behaviour above and below FSP.
5. Evaluate wood samples using selected suitability indices.
6. Prepare a report correlating EMC, shrinkage behaviour, and wood performance.

Learning Outcomes

1. Ability to measure and interpret EMC under different environmental conditions.
2. Understanding of dimensional stability and defect formation due to moisture changes.
3. Capacity to compare wood species based on shrinkage properties and suitability indices.
4. Improved skill in selecting appropriate wood for structural and commercial applications.

Practical 3. Sawn Timber, & Sawing Patterns

Objective: To study the sawing Patterns of logs.

Introduction

Sawn timber refers to wood cut from logs into specific shapes and sizes, most commonly rectangular sections such as beams, planks, and boards. Timber may also be wedge-shaped depending on the conversion method. Sawing patterns, log quality, and processing techniques significantly influence timber strength, stability, drying behaviour, and appearance.

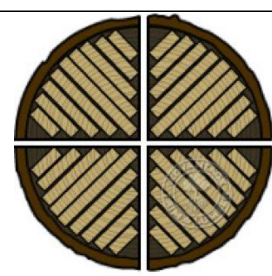
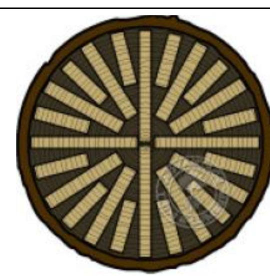
Log Preparation

• Logs are first debarked and cleaned; branches are removed using specialised machinery.
•Debarking exposes heartwood and most sapwood.
• Logs intended for poles or piles may require sapwood removal to produce a uniform round or faceted section.

Sawing Patterns

Advantages	Disadvantages
A. Quarter Sawn Timber: Growth rings perpendicular to board surface.	
• Attractive grain; radial face ideal for finishes • Excellent for flooring, furniture • Lower width shrinkage; reduced cupping and warping • Reconditionable after collapse	• Slower drying • Higher likelihood of face-splitting when nailed
B. Back Sawn (Flat Sawn / Tangential Cut) : Most common method; growth rings parallel	

to board width.	
• Faster seasoning • Good figure on face • Less risk of nail splitting • Wide boards obtainable • Few edge knots	• Higher shrinkage across width • Higher risk of warp and cup • Collapse more difficult to recondition
C. Radial Sawn Timber: Boards cut like wedges from the centre outward.	
• Excellent dimensional stability • Minimal warping and cupping • Lowest wastage in milling	Wedge-shaped cross section • Difficult to stack; less common

Plain Sawn	Quarter Sawn	Rift sawn
		

➢ Faster to produce ➢ More affordable and stable ➢ Displays varied grain patterns & the unique "cathedral" appearance ➢ Readily available	➢ More stable than plain sawn lumber ➢ Increased moisture resistance ➢ Less likely to cup, twist & warp ➢ Beautiful ribbon aka "fleck" patterns are prevalent in species like White Oak & Red Oak ➢ Less expensive than rift sawn lumber	➢ Ideal for custom furniture makers to use for table, chair and other straight pieces ➢ The most dimensionally stable cut of lumber available ➢ Unique, linear appearance on both sides of the lumber planks

Students' Activity

1. Measure log defects and classify logs as per quality standards.
2. Observe debarking and initial processing at a sawmill.
3. Compare timber surfaces from split, cant, and green sawn boards.
4. Identify quarter sawn, back sawn, and radial sawn boards based on grain pattern.
5. Evaluate shrinkage and stability differences among sawing patterns.
6. Prepare a short report on the suitability of each sawing method for structural vs appearance-grade applications.

Learning Outcomes

1. Understanding of log selection criteria and conversion methods.
2. Ability to identify sawing patterns and relate them to timber stability.
3. Knowledge of processing stages from log to finished timber.
4. Skill in comparing dimensional behaviour and end-use suitability of different sawn timber products.

Practical 4. Juvenile Wood – Formation, Characteristics and Utilization

Objective: To study the formation, anatomical and physical characteristics of juvenile wood, observe its differences from mature wood, and understand its impact on processing and utilization.

Introduction

Wood produced during the early developmental stages of a tree differs significantly from mature wood. This early wood, known as juvenile wood, forms near the pith and is influenced by apical meristem activity. Juvenile wood is also present in leaning stems, branches and roots, and together with reaction wood forms a major part of the variability in wood quality within trees. Understanding juvenile wood is essential, especially today, as industries increasingly utilize entire trees—including branches and small-diameter logs—for pulp, panels, and engineered wood products.

Formation of Juvenile Wood

In the first year of a tree's life, the stem center consists of pith, surrounded by primary xylem. Subsequent growth from the vascular cambium forms secondary xylem, which becomes the bulk of usable wood. However, the earliest secondary xylem laid down by the cambium retains the influence of the apical meristem and is therefore considered juvenile wood.

Juvenile wood extends from the pith outward for several years (species-dependent). As the cambium enlarges the stem, each new layer becomes physically farther from apical influence, gradually transitioning into mature wood. This results in a gradual, not abrupt, change in properties from juvenile to mature zones.

Branches, leaning stems, and roots frequently contain juvenile and reaction wood. Such wood forms rapidly as the tree adapts to external stresses such as gravity or suppression by neighbouring trees.

Characteristics of Juvenile Wood

Juvenile wood generally has lower quality compared to mature wood. The key characteristics include:

1. Juvenile wood cells are significantly shorter.
2. In softwoods, mature tracheids may be 3–4 times longer than juvenile ones.
3. In hardwoods, fibre length near the pith may be only half that of mature wood.

Density and Strength

1. Juvenile zones contain more earlywood and fewer latewood cells, resulting in thin cell walls. Consequently, wood density near the pith may be 10–15% lower in typical conifer species. Strength properties may be 15–30% lower, and in extreme cases (e.g., plantation-grown Caribbean pine), stiffness may fall to as low as 26% of normal mature values.
2. The S2 layer of the cell wall in juvenile wood has a much larger MFA. Large MFA contributes to: Higher longitudinal shrinkage, Lower tensile strength, Reduced stiffness. Whereas, the large MFA is also common in reaction wood, which often occurs in juvenile regions.
3. Juvenile wood tends to exhibit spiral grain, further reducing mechanical performance and contributing to warping during drying.
4. High longitudinal shrinkage in juvenile wood leads to greater instability, warping, and distortion when used in solid-wood applications.

Utilization and Implications

Juvenile wood is generally considered undesirable for solid wood products, especially those requiring stability, strength, or stiffness, such as beams, flooring, and furniture components. However, understanding its properties enables better industrial use.

1. Pulp and paper: Short fibres remain usable, though pulp strength is lower.
2. Composite boards: Density deficits can be compensated with adhesives.
3. Engineered wood: Products like oriented strand board (OSB) and MDF often use small-diameter juvenile-rich logs.
4. As industries focus on plantation forestry and shorter rotations, juvenile wood content in harvested logs increases, making knowledge of its behaviour essential for processing strategies.

Students' Activity

1. Examine cross-sections of young and mature wood samples; identify pith, juvenile zone, and mature wood.
2. Measure differences in cell length using slides or micrographs.
3. Compare density of juvenile and mature wood segments using water displacement or oven-dry method.
4. Conduct shrinkage tests along longitudinal and transverse directions.
5. Observe spiral grain and reaction wood in branches or leaning stem samples.
6. Prepare a comparative table summarizing properties of juvenile vs mature wood.

Learning Outcomes

1. Identify juvenile wood in cross-sections and distinguish it from mature wood.
2. Explain how apical meristem influence results in juvenile wood formation.
3. Describe the anatomical and physical differences—cell length, density, microfibril angle, shrinkage—between juvenile and mature wood.
4. Understand limitations of juvenile wood in solid-wood applications and its appropriate industrial uses.
5. Recognize how juvenile wood contributes to variation within trees and affects timber quality and grading.

Practical 5. Reaction Wood-Tension and Compression wood

Objective: to Study Reaction Wood: Compression Wood and Tension Wood – Formation, Properties, Identification and Utilization

Introduction

Trees frequently encounter mechanical stresses such as wind, slope, uneven crown development, or external forces that cause deviation from vertical growth. In response, they develop a specialized adaptive tissue known as reaction wood, which helps the tree restore its original orientation. In softwoods, this reaction tissue forms on the lower side and is called Compression Wood (CW), whereas in hardwoods, it forms on the upper side and is called Tension Wood (TW). Although compression and tension wood occur in different plant groups and exhibit different anatomical features, the basic function of both is the same: to produce internal mechanical stress and reposition the leaning stem or branch.

Characteristic	**Compression Wood (Softwoods)**	**Tension Wood**
Formation	Forms on lower side of leaning stems. Pushes stem upward. Characterized by: thick-walled tracheids, high lignin, high microfibril angle.	Forms on upper side of leaning stems. Pulls stem upward. Characterized by: gelatinous (G) layer, high cellulose, fewer vessels.
Properties	Tracheids ~30% shorter. Higher lignin and hemicellulose content. Extremely high longitudinal shrinkage (1–7%). Dense, darker, brittle. Hard to pulp (especially sulfite process).	High cellulose; low lignin. Contains gelatinous G-layer. Moderate longitudinal shrinkage (<1%). Prone to collapse when drying. Fuzzy surface when machined.
Identification	Dark reddish colour.	Hard to detect visually.

	Eccentric growth rings. Thick-walled rounded tracheids. Intercellular spaces common.	Elliptical cross-section. Fuzzy tearing during sawing. Microscopic confirmation required (G-layer presence).
Utilization Issues	Poor stability in solid wood. Difficulties in pulping and paper strength. Acceptable only for non-precision products.	Good for dissolving pulp (rayon, cellophane). Suitable for mechanical pulp. Poor performance in solid wood uses.

Compression Wood vs. Tension Wood (Comparison)

Characteristic	**Compression Wood**	**Tension Wood**
Occurs in	Softwoods	Hardwoods
Position	Lower side	Upper side
Key Feature	High lignin, high MFA	G-layer, high cellulose
Shrinkage	Very high	Moderate
Solid Wood Use	Poor	Poor
Pulping	Difficult	Favorable

Student Activity

1. Visit the college campus or a nearby forest area.
2. Identify natural examples of leaning trees and note possible presence of reaction wood.
3. Record ring eccentricity and branch angle adjustments.
4. Prepare a short note on problems caused by reaction wood in:hard wood and soft wood

Learning Outcomes

1. Differentiate between compression wood and tension wood based on formation, position, structure, and chemical composition.
2. Identify reaction wood microscopically, including recognizing the G-layer and thick-walled tracheids.
3. Understand the impact of reaction wood on industrial processing, including pulping behavior and solid wood defects.
4. Predict defects such as warp, twist, collapse, and fuzzy surfaces based on the presence of reaction wood.
5. Interpret field observations like eccentric growth rings and leaning stems.
6. Apply anatomical knowledge to real-world wood quality problems in timber industries.

Practical 6. Study of Branch Wood and Root Wood – Properties and Utilization

Objective-To study the anatomical, physical, and chemical characteristics of branch wood and root wood, and to understand their suitability, limitations, and utilization potential in wood-based industries.

Introduction

Increasing demand for wood has led to the total-tree utilization concept, which emerged in the 1960s. Unlike traditional harvesting—which removes only the main stem—total-tree harvesting includes branches, twigs, tops, foliage, and even roots. Though this method significantly increases yield, it introduces variability in raw material quality, particularly due to differences in branch wood and root wood compared to stem wood.

	Branch Wood	**Root Wood**
Characteristics	High proportion of bark, especially in material < 1 inch diameter. Branch wood often contains more vessels and rays in hardwoods and more resin canals and ray volume in softwoods. Narrow growth rings and shorter fibers (25–35% shorter than stem wood). Specific gravity is variable: Softwood branches: generally 5–20% lower than stem wood. Hardwood branches: species-dependent, sometimes higher.	Contains 20–25% additional fiber volume of the main stem (as per Koch). Roots are difficult to clean; dirt causes excessive wear to pulp mill machinery. High bark proportion in small roots.
Processing and	High bark content results in dirt	**Softwood**

Product Properties	contamination, affecting pulping and particleboard quality. Particleboard from branch wood shows: Lower stiffness and bending strength 30–65% lower mechanical properties than stem wood boards Kraft pulp from branch wood has: Lower tear, burst, and tensile strength Requires less beating time High reject percentage due to non-uniform chip size (over 50% rejects vs. 22% for bole chips). Suitable for hardboard manufacture, where branch material performs satisfactorily.	Few resin canals; lower ray volume Exceptionally large-diameter cells Cell length variable (reports show both longer and shorter than stem) Frequent compression wood, spiral grain, high microfibril angles Thin-walled tracheids in many species **Hardwoods:** Higher vessel and parenchyma content Lower fiber volume Cells show abnormal size variation Tyloses and ring-porosity often absent
Utilization Potential	Mixture with traditional pulpwood Fuelwood and energy generation Chemical extraction Potential use as small-, medium-, and large-size classified raw material according to Keays (1971)	Fiber recovery for pulping (with limitations) Wood energy and fuel Limited suitability for high-grade wood products due to compression wood and spiral grain

Students Activity

1. Prepare stained microscopic slides of branch wood, root wood, and stem wood.

2. Create a comparison of anatomical and physical properties of Branch wood, Root wood and Stem wood
3. Write a short note (1 page) on the industrial challenges of using branch and root wood in Pulping, Particleboard and Fuel and energy applications
4. Collect small samples from campus trees

Learning Outcomes

1. Differentiate branch wood, root wood, and stem wood based on anatomical, physical, and chemical characteristics.
2. Understand the impact of raw material variability on product quality (pulp, particleboard, hardboard).
3. Evaluate suitability of branch and root wood for various industrial applications.
4. Develop skills in microscopic analysis, comparison, and technical report preparation.

Practical 7. Tree Bark

Objective To study Bark Structure, Chemical Composition and Function

Introduction

Bark is an important component of the tree and a significant by-product of the wood industry. Globally, hundreds of millions of cubic meters of bark are generated annually during timber processing. Although once regarded as a waste material, bark is now recognized for its diverse applications including industrial fuel, soil amendment, ground cover, and potential chemical feedstock. Understanding bark structure, formation, and composition is essential for wood science students, as it influences both tree physiology and industrial utilization.

1. Structure of Bark

Bark consists of two major regions: inner bark (phloem) and outer bark (rhytidome). These layers arise from different meristems and differ significantly in structure and function.

Inner Bark (Secondary Phloem)

Secondary phloem is produced by the vascular cambium, the same tissue that forms secondary xylem (wood). Because of this common origin, several bark cells resemble wood cells, but the phloem also contains unique elements.

Major cell types include:

Sieve Cells

These are the main conductive elements of the phloem. They are similar in form to xylem tracheids but lack secondary wall layers and lignification. They contain living protoplasm and conduct food materials through pores in sieve areas.

Phloem Fibers

Long, strong, thick-walled cells that contribute mechanical strength to bark. They are particularly significant in hardwoods but generally absent in softwoods such as pines.

Phloem Parenchyma

Thin-walled living cells involved in storage and metabolic activity. Anatomically, the inner bark is more complex than wood due to the diversity of cell types and their functional roles.

Outer Bark (Periderm and Rhytidome)

As stems increase in girth, the original epidermis cannot expand and is shed. A new protective tissue called the **periderm** develops beneath it.

Periderm Components

The periderm is produced by the **phellogen (cork cambium)**, a secondary meristem originating from cortical or epidermal parenchyma. It consists of:

Phellem (Cork)

Outermost cells, generally suberized or lignified. These cells act as a moisture barrier and provide mechanical protection.

Phellogen (Cork Cambium)

A thin meristematic layer producing cork outward and phelloderm inward.

Phelloderm

Living parenchyma cells that offer additional protection and sometimes thermal insulation.

Rhytidome (Outer Bark)

Repeated formation of new periderm layers leads to the death of older outer tissues. The accumulated dead periderms and crushed phloem constitute the **rhytidome**. Its thickness varies widely—from a few millimetres in aspen to more than 30 cm in redwood or Douglas-fir.

2. Chemical Composition of Bark

Bark chemistry differs significantly from that of wood:

- **Lignin**: Higher in bark than in wood.
- **Cellulose**: Lower (20–35% in bark vs. 40–45% in wood).
- **Ash Content**: Much higher in bark due to mineral accumulation and entrapped soil particles (2–5%, sometimes up to 20%).
- **Extractives**: High extractive content (15–26%), including tannins, phenolics, waxes, and resins.

- Tannins are especially abundant and are used in leather tanning, drilling muds, inks, and dyes.

The pH of bark extractives tends to be acidic (3.5–6). This acidity may require modification in processing steps, such as adjusting resin formulations for particleboard containing bark.

Student **Activity**

1. Examine prepared slides or hand specimens of bark to identify sieve cells, phloem fibers, phellem, and phelloderm.
2. Using bark calipers, measure inner and outer bark thickness in different tree species and compare variations.
3. Perform a simple ferric chloride test on bark extract to detect the presence of tannins.
4. Determine moisture content of bark samples using oven-drying method and interpret results.
5. Prepare a short report on current industrial applications of bark and evaluate its potential as a biomass fuel.

Learning Outcomes

1. Distinguish inner bark and outer bark based on origin, anatomy, and function.
2. Describe periderm formation and the development of rhytidome.
3. Explain the major chemical constituents of bark and their industrial significance.
4. Evaluate the importance of bark moisture content, volume, and strength in wood utilization.
5. Recognize the potential uses and limitations of bark in forest product industries.

Practical 8. Wood and Water – Location, Nature, and Effects of Moisture in Wood

1. Introduction

Water is a natural and essential component of all living tree tissues. In the xylem, water typically constitutes more than half the total weight of green wood, meaning the mass of water is often equal to or greater than that of the dry wood substance. Once the tree is cut or processed into lumber, veneer, chips, or other products, wood begins to release moisture to the surrounding atmosphere. This drying process triggers important changes in the physical, mechanical, and biological properties of wood.

In manufactured wood products, some moisture remains stored within the cell wall structure even after visible liquid water has evaporated. The amount and behavior of this residual water influence strength, dimensional stability, durability, and susceptibility to decay. Since almost all wood properties are moisture-dependent, it is essential to understand where water is stored in wood, how it behaves, and how it affects performance.

Free Water

The lumen contains liquid water and dissolved organic materials such as sugars and minerals produced through photosynthesis. This fluid is commonly known as *sap*. The amount of water in the lumen varies with season and environmental conditions. During drying, free water is the first to be removed.

Bound Water

The water within the cell wall is held more firmly and does not flow like ordinary liquid water. Even after drying during manufacturing, wood retains some bound water depending on the target moisture content and the service environment. The cell wall moisture level determines key properties of wood products used in construction, furniture, paper, panels, and engineered materials.

Once wood has been dried, water re-enters the lumen only if the product is exposed to direct liquid water—such as rainfall, wet soil, or immersion. In normal indoor or protected outdoor conditions, the lumen remains free of liquid water and contains only water vapor.

3. Fiber Saturation Point (FSP)

A critical moisture level in wood science is the fiber saturation point (FSP). This point represents the condition at which:

- All free water has been removed from the lumen
- Cell walls remain fully saturated with bound water

Below FSP, moisture loss directly affects wood properties. Above FSP, changes in moisture content do not significantly alter strength, shrinkage, or stiffness, though weight does change.

Importance of FSP:

- Dimensional changes (shrinkage and swelling) occur only below FSP.
- Mechanical properties such as strength, hardness, and stiffness improve as wood dries below FSP.
- Susceptibility to fungi decreases when moisture content stays below 20%, which is close to the FSP range (typically 25–30%).

Most wood used in buildings and interiors is dried to a stable moisture content well below FSP, ensuring dimensional stability and structural reliability.

4. Nature of Water in Wood

The behavior of water in wood is influenced by the microstructure of the cell wall. Water occurs in two forms:

1. Free Water

- Found in the lumen
- Easy to remove during drying
- Does not significantly influence physical properties except weight

2. Bound Water

- Held within the cell wall by adsorption forces
- Difficult to remove
- Strongly controls shrinkage, swelling, and mechanical behavior

Adsorption vs. Absorption

Adsorption is the process by which water molecules attach to the chemical components of the cell wall—cellulose, hemicellulose, and lignin—mainly through hydrogen bonding**.**

- Adsorption occurs on *sorption sites* (OH groups).
- Water molecules may form a monomolecular or multilayered film around cellulose chains.

Absorption, in contrast, occurs due to surface tension forces (as in sponges) and is not the same mechanism that retains water in the cell wall.

Wood Cell Wall Structure and Water

The cell wall contains crystalline and amorphous regions. Crystalline areas are tightly bonded and provide no sites for water retention. In contrast, amorphous regions contain accessible hydroxyl groups (–OH), which attract and hold water molecules.

In fully saturated cell walls, 5–6 water molecules may bond to a single sorption site. As the moisture content drops below FSP, remaining bound water becomes progressively more tightly held, influencing:

- Density
- Strength
- Dimensional stability
- Thermal conductivity

6. Student Activity

- Examine green wood and dry wood samples.
- Determine the initial mass of a wood sample (green weight).
- Oven-dry the sample at 103 ± 2°C.
- Record the oven-dry mass and calculate moisture content.
- Measure dimensions (length, width, thickness) of samples before and after drying to observe shrinkage.

7. Learning Outcomes

- Explain water distribution in wood and differentiate between free and bound water.
- Describe the importance of the fiber saturation point and its influence on wood properties.
- Measure and calculate wood moisture content accurately.
- Relate changes in moisture content to dimensional and mechanical changes.
- Demonstrate understanding of moisture's role in wood durability, stability, and performance in various environments.

Practical 9. Moisture Content, Environmental Influence, Shrinkage and Swelling of Wood

1. Introduction

Wood is a hygroscopic material that absorbs and releases moisture depending on the surrounding environment. Its moisture content (MC) significantly affects weight, dimensional stability, and physical and mechanical properties. Understanding how to measure moisture content, how wood interacts with atmospheric humidity, and how shrinkage and swelling occur is essential for wood processing, utilization, and quality control. This practical focuses on moisture measurement methods, moisture–environment relationships, and dimensional changes due to shrinking and swelling.

2. Calculating Moisture Content (MC)

Moisture content is defined as the amount of water in a wood sample expressed as a percentage of its oven-dry weight.

2.1 Moisture Content Formula

% MC=Weight of Water OD Weight×100\%MC = \frac{\text{Weight of Water}}{\text{OD Weight}} \times 100%MC=OD WeightWeight of Water×100

Because the denominator is oven-dry (OD) weight, green wood can have MC values greater than 100%.

2.2 Oven-Dry Method Formula

In practice, moisture content is calculated using:

$$\% \textbf{ Moisture Content} = \frac{(\textbf{Wet Weight} - \textbf{Oven Dry Weight})}{\textbf{Oven Dry Weight}} \textbf{X100}$$

This method requires drying the sample at 103 ± 2°C until all moisture is removed, as specified by ASTM Standard D2016. This is the most accurate method and is used for calibration of all other moisture measurement techniques.

3. Measuring Moisture Content

Moisture content is measured to ensure proper drying, maintain product quality, meet commercial standards, and predict performance in use.

3.1 Oven-Dry Method

- Most accurate
- Widely used in laboratory and standard testing
- Destructive method (sample must be cut)

3.2 Electrical Moisture Meters

Electrical meters are commonly used in industrial applications because they are:

- Quick
- Non-destructive
- Easy to operate

Types of Meters

1. **Resistance Moisture Meter**
    - Works by measuring electrical resistance between two pins driven into wood
    - Reliable for 6–30% MC range
    - Requires corrections for:
        - Temperature
        - Species (extractives influence resistance)

2. **Meters for Chips and Particles**
    - Used in composite board plants
    - Less precise but useful for rapid assessment

Above the fiber saturation point (FSP), electrical resistance meters are reliable only for qualitative measurement because resistance changes very little.

4. Moisture Content and the Environment

Wood is hygroscopic, meaning it exchanges water vapor with surrounding air through adsorption (moisture gain) and desorption (moisture loss). This process continues until wood reaches Equilibrium Moisture Content (EMC)—the MC at which wood is in balance with surrounding air humidity and temperature.

4.1 Green Wood Moisture Content

Green wood has high MC, affecting:

- Weight of logs
- Transportation cost
- Handling and processing

Hardwood vs. Softwood

- **Hardwoods:** Small difference between sapwood and heartwood MC
- **Softwoods:** Sapwood MC often **three times** higher than heartwood
- As trees age, sapwood percentage decreases, reducing overall MC

Tip for survival: Heartwood of softwoods burns better than green hardwood due to lower MC.

5. Shrinkage and Swelling of Wood

Wood shrinks when it loses **bound water** (below FSP) and swells when bound water is regained. These dimensional changes are **reversible** in small, stress-free specimens but often **not fully reversible** in commercial products due to internal stresses or manufacturing processes.

5.1 Mechanism of Shrinkage and Swelling

- Bound water is held between cellulose and hemicellulose molecules.
- When bound water leaves:
    - Cell wall polymers move closer
    - Volume decreases → **shrinkage**
- When water is absorbed:
    - Polymers move apart → **swelling**

5.2 Dimensional Change Equations

$$\text{Shrinkage (\%)} = \frac{\text{Wet dimension - Dry dimension}}{\text{Wet dimension}} \times 100$$

$$\text{Swelling (\%)} = \frac{\text{Wet dimension - Dry dimension}}{\text{Dry dimension}} \times 100$$

5.3 Longitudinal, Radial, and Tangential Shrinkage

- **Longitudinal shrinkage:**
    - Generally **0.1–0.2%**, rarely exceeds 0.4%
    - Negligible for most applications
    - In abnormal or reaction wood, may reach up to **3%**
- **Radial vs. Tangential:**
    - Tangential shrinkage > radial shrinkage
    - Ratio ranges from **1.5:1 to 3:1**
    - Due to:
        - Ray tissue morphology
        - Pitting pattern

        - Summerwood dominance
        - Variation in cell-wall material distribution

5.4 Variability in Shrinkage

Shrinkage variability depends on:

1. **Size and shape** → grain orientation affects uniformity
2. **Density** → denser wood shrinks more
3. **Drying rate**
    - Fast drying induces internal stresses → lower final shrinkage
    - High-temperature drying can cause excessive shrinkage in some species

6. Student Activity

Students will perform the following:

1. **Moisture Content Measurement**
    - Select a green wood sample
    - Determine wet weight
    - Oven-dry at 103 ± 2°C
    - Calculate MC using the oven-dry formula
2. **Use of Electrical Moisture Meter**
    - Measure MC at different depths using insulated-pin resistance meter
    - Apply temperature and species corrections
3. **Dimensional Change Study**
    - Measure dimensions before and after drying
    - Calculate radial, tangential, and longitudinal shrinkage
4. **Environmental Influence Experiment**
    - Condition dried samples at different relative humidities
    - Record weight gain over time
    - Determine EMC of each sample

7. Learning Outcomes

1. Accurately calculate moisture content of wood using both oven-dry and electrical methods.
2. Explain how environmental conditions influence wood moisture through adsorption and desorption.
3. Distinguish between green wood, EMC, and oven-dry conditions.
4. Understand mechanisms and factors controlling shrinkage and swelling.
5. Measure dimensional changes and relate them to moisture fluctuations.
6. Evaluate differences between tangential, radial, and longitudinal shrinkage in wood samples.
7. Apply moisture measurement techniques in wood processing, quality control, and product design.

Practical 10. Moisture Movement during Drying and Kiln Drying Methods

1. Introduction

Drying is one of the most critical steps in wood processing, significantly influencing dimensional stability, strength, durability, and service performance. Moisture in wood moves during drying either as liquid water (mass flow) or as water vapor/bound water (diffusion). The mechanism depends on the moisture level, wood structure, temperature, and permeability of the species. This practical introduces the principles of moisture movement, diffusion, permeability, and kiln drying methods used in industry.

2. Mechanisms of Moisture Movement

Moisture moves through wood in two primary ways:

2.1 Mass Movement of Liquid Water

- Occurs **above Fiber Saturation Point (FSP)**.
- Wood behaves like partially filled tubes; water evaporates from the surface and is replaced by liquid flow from within.
- Driven by **capillary forces** and **surface drying**.
- Dominant during early drying stages.

2.2 Diffusion of Water Molecules

Diffusion occurs when water moves from **high concentration to low concentration** across cell walls.

Key Requirements

- A moisture gradient **or** vapor pressure gradient across the cell wall.
- Temperature influences rate (higher temperature = faster diffusion).

- Diffusion occurs **only below FSP**, because only then do concentration differences exist in cell walls.

Diffusion Coefficient

- Quantifies how easily moisture diffuses.
- Influenced by:
    - Species characteristics
    - Temperature
    - Wood density
- As per Stamm (1964), raising temperature from **50°C to 120°C** increases diffusion rate more than tenfold.

3. Permeability and Species Effects

Some woods allow water to flow easily (permeable), while others resist water movement (impermeable).

3.1 Causes of Impermeability

- Presence of **tyloses**
- **Aspirated pits**
- **Extractive deposition** on pit membranes

3.2 Examples

- **Impermeable heartwood:** redwood, white oak, walnut
- **Permeable sapwood:** generally all species
- **Species with wet pockets:** aspen, western hemlock
    - Prone to drying defects without careful control.

3.3 Treatments to Increase Permeability

Several experimental methods exist:

- **Freezing** lumber (improves drying of redwood)
- **Hygroscopic chemicals** (urea, NaCl, $CaCl_2$)
- **Pre-steaming**

However, none have universal commercial success due to side effects such as increased hygroscopicity.

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4. Methods of Drying Lumber

4.1 Kiln Drying

Most lumber is dried in **kilns** that control:

- Temperature
- Relative humidity (RH)
- Airflow via fans

Kilns may operate:

- **Conventional temperature:** ambient to ~100°C
- **High temperature:** above boiling point of water for rapid drying

Heating methods include:

- Steam coils
- Direct-fired gas/oil burners
- Wood-residue burners

4.2 Drying Process and Kiln Schedules

Drying proceeds through controlled stages:

Early Stage:

- Gentle conditions
- Free water removed

Later Stage:

- Higher temperature and lower RH
- Promotes diffusion and bound water removal

Types of Kiln Schedules

- **Hardwoods:** MC-based schedules
    - Conditions change when MC reaches set levels
- **Softwoods:** Time-based schedules
    - Conditions change after specified time intervals

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5. Student Activity

1. **Observe Moisture Movement**
    - Take small samples of green wood.
    - Measure surface moisture loss over time at room temperature.
    - Note differences before and after reaching FSP.
2. **Diffusion Experiment**
    - Oven-dry a sample to below FSP.
    - Condition it at different temperatures and measure rate of weight gain.
    - Relate to diffusion coefficients.
3. **Permeability Observation**
    - Compare water uptake in heartwood vs. sapwood of different species.
    - Record which species show impermeable characteristics.
4. **Kiln Schedule Study**
    - Study standard kiln schedules for hardwood and softwood provided in lab.

- Identify changes in temperature and RH at each stage.
- Plot a kiln drying curve.

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6. Learning Outcomes

By completing this practical, students will be able to:

- Explain mechanisms of moisture movement: mass flow and diffusion.
- Understand conditions under which diffusion occurs and its dependence on temperature.
- Identify species differences in permeability and drying behavior.
- Describe how kiln drying works and how kiln schedules are structured.
- Observe and analyze effects of moisture gradients during drying.
- Apply theoretical knowledge to practical drying control and defect prevention.

Practical 11. WOOD PRESERVATION

1. Introduction

Wood is a biodegradable material and is naturally susceptible to deterioration caused by fungi, insects, bacteria, and marine borers. Wood preservation refers to treating wood with suitable chemicals to increase its durability and life span, especially for non-durable species. Preservatives penetrate wood and render its cellulose, hemicellulose, lignin, starch, and extractives unavailable to destructive organisms. When applied properly, wood preservative treatments can extend service life by **five to ten times**, reduce economic losses, and ensure safe performance in structural and outdoor applications.

Wood preservatives are often toxic and hazardous, but when used responsibly, they provide long-term protection under varying environmental conditions. The effectiveness of wood preservation is determined not only by the chemical used but also by the treatment method, penetration depth, retention level, and post-treatment handling.

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2. Objectives

- To understand the need and importance of wood preservation.
- To familiarize students with various **wood preservative chemicals** used in practice.
- To study **non-pressure and pressure treatment methods**.
- To learn the operational steps of **Full Cell, Empty Cell, Boulton, and diffusion processes**.
- To observe the effect of chemical preservatives on sapwood and hardwood.
- To enhance knowledge of post-treatment handling, safety requirements, and field applications.

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3. Principle

Wood preservation operates on the principle of **impregnation** of toxic chemicals into the cellular structure of wood. These chemicals create an environment unsuitable for biological degradation by blocking nutrients, inhibiting enzymes in fungi and insects, and reducing moisture availability. Treatment can be done through:

- **Non-pressure methods** (brushing, spraying, dipping, soaking, diffusion, hot-cold bath).
- **Pressure methods** (Full Cell, Empty Cell, Lawry, Rueping, Boulton).

Better penetration is achieved in sapwood, green timber, and when the air content in wood is reduced through vacuum or steaming.

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4. Materials and Equipment Required

- Wood samples (sapwood and heartwood of selected species)
- Preservatives: CCA, ACC, CCB, ACZA, Boric acid/Borax, Creosote
- Measuring jars, chemical containers
- Brushes, spray bottles
- Dipping/soaking tank
- Hot and cold bath tanks with heating system
- Pressure cylinder (Autoclave) with vacuum and pressure gauges
- Personal protective equipment: gloves, masks, goggles, apron
- Moisture meter, weighing balance, measuring scale

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5. Methods / Procedures

A. Non-Pressure Methods

1. Brushing/Spraying

- Clean and surface-dry the wood sample.
- Apply preservative solution uniformly using a brush or sprayer.
- Allow drying for 24 hours.
- Repeat the coating if necessary.

2. Dipping

- Immerse wood samples in preservative solution for 2–10 minutes (temporary protection).
- Remove and air-dry under shade.

3. Soaking/Steeping

- Submerge wood samples for **24–48 hours** to improve penetration.
- Use for water-soluble preservatives like borates or $ZnCl_2$.

4. Diffusion / Osmotic Process

- Apply paste of borates or CCB on **green timber**.
- Wrap with polythene to prevent evaporation.
- Allow diffusion for **7–21 days** based on wood thickness.

5. Hot and Cold Bath

- Heat the wood in a preservative tank at **100°C for 2–4 hours**.
- Immediately transfer to a cold preservative bath.
- Vacuum created during cooling draws preservative deep into the wood.

B. Pressure Methods

1. Full Cell (Bethel Process)

- Load debarked and conditioned wood into cylinder.
- Apply **initial vacuum** to remove air from wood.
- Introduce preservative while maintaining vacuum.
- Apply pressure **3.5–12.3 kg/cm²** until refusal.
- Drain solution and apply final vacuum to remove excess chemicals.

2. Empty Cell Process

- Carried out to achieve **maximum penetration with minimum absorption**.
- Final vacuum is applied at the end to force excess preservative out.
- Includes:
    - **Lawry Process** – No initial vacuum; saves ~40% preservative.
    - **Rueping Process** – Initial air pressure (1.75–5 kg/cm²) before preservative entry; saves ~60%.

3. Steam-cum-Vacuum (Boulton Process)

- Suitable for green timber.
- Steam under **1.41 kg/cm²** to expel air and moisture.
- Apply vacuum followed by preservative under pressure.

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6. Observations to be Recorded

- Moisture content of samples before treatment.
- Type and concentration of preservative used.
- Duration of treatment and depth of penetration.
- Changes in color, odor, and surface characteristics.
- Drying time and retention levels (kg/m³).
- Comparison between sapwood and heartwood penetration.

7. Precautions

- Always use PPE: gloves, masks, goggles.
- Avoid direct skin contact with preservatives.
- Do not heat flammable preservatives (e.g., organic solvents).
- Do not use CCA-treated wood for residential or food-related purposes due to arsenic leaching.
- Never burn treated wood or scraps in open air.
- Store treated wood under shade to prevent checking and chemical loss.
- Maintain proper ventilation in treatment area.

8. Post-Treatment Handling

- Allow treated wood to season properly, especially water-borne treatments.
- Avoid mechanical damage that may expose untreated areas.
- Label treated wood clearly with chemical type and date of treatment.
- Ensure safe disposal of waste chemicals.

9. Student Activity

- Treat a sapwood sample using **dipping** and another using **Full Cell process**.
- Measure penetration depth by cutting cross-sections.
- Prepare a comparative chart of **water-borne vs. oil-borne preservatives**.
- Demonstrate safe handling techniques using PPE.

10. Learning Outcomes

- Understand the role and importance of wood preservation in forestry and timber utilization.
- Identify different preservatives and their properties.
- Distinguish between non-pressure and pressure treatment methods.
- Operate basic wood preservation equipment safely.
- Evaluate penetration and retention quality of treated wood.
- Apply appropriate post-treatment handling practices.

Practical 12. Wood Drying and Seasoning

1. Aim

To study the principles, methods, advantages, and challenges of wood drying and seasoning, and to understand the practical aspects of preparing timber for safe, durable, and efficient utilization.

2. Introduction

Wood drying is the process of reducing the moisture content of timber to a level that is in equilibrium with the atmospheric conditions of its place of use. Freshly converted wood contains free water in cell lumina and bound water in cell walls. Removing both systematically enhances wood quality and prevents post-use defects. Seasoned wood is lighter, stronger, more stable, and more durable against decay organisms. Drying can be achieved naturally (air seasoning) or artificially (kiln seasoning), each method having distinct advantages and limitations.

3. Objectives of Wood Drying

- To reduce fungal and insect attacks by lowering moisture content.
- To minimize warping, cracking, and other seasoning defects.
- To reduce weight and facilitate transportation and handling.
- To improve strength, dimensional stability, and working properties.
- To enhance preservative and adhesive treatment efficiencies.
- To improve electrical and thermal insulation properties of wood.

4. Principles of Wood Drying

Drying occurs because moisture moves from the interior to the wood surface due to a moisture gradient. The surface loses moisture quickly by evaporation, leading internal water to migrate outward until equilibrium is achieved.

Factors Affecting Drying Rate

1. **Temperature** – Higher temperatures accelerate evaporation and diffusion.
2. **Relative Humidity** – Lower RH increases drying rate; high RH slows drying.
3. **Air Circulation** – Faster air movement increases drying rate.
4. **Wood Characteristics** – Species, initial moisture content, density, grain direction, and thickness influence drying behavior.

5. Seasoning Behaviour of Wood

Wood species respond differently during drying:

- **Highly refractory woods** – Dense, prone to defects (e.g., *Shorea robusta*, *Diospyros*, *Syzygium*).
- **Moderately refractory woods** – Moderate density; fewer defects (e.g., *Dalbergia sissoo*, *Gmelina*, *Tectona grandis*).
- **Non-refractory woods** – Low density; tolerate rapid drying (e.g., *Bombax ceiba*, *Populus*, *Deodar*).

Understanding these classes is essential for planning the correct method and schedule.

6. Methods of Wood Drying

A. Air Drying (Seasoning)

Air drying uses natural atmospheric conditions. It requires 6–12 months depending on species and climate. Temperature, relative humidity, and wind cannot be controlled.

Key practices:

- **Stacking/Piling** is the most critical operation.
- Ensure sanitation by clearing weeds.
- Build foundations 30–45 cm above ground using piers spaced 120–150 cm.
- Orient refractory woods parallel to prevailing winds; non-refractory perpendicular.
- Sort timber according to length and thickness.
- Stack height ≤ 3 m; width ≤ 1.5 m.
- Place crossers (2.5×4 cm or 4×5 cm) aligned vertically layer-to-layer.

Types of stacking:

- **Horizontal stacking** – Used for most sawn lumber (close crib or open crib).
- **Vertical stacking** – For non-refractory woods requiring rapid surface drying.

Seasoning time guidelines:

- Highly refractory – End of rainy season
- Moderately refractory – End of winter
- Non-refractory – Beginning of summer

B. Kiln Drying

Kiln drying is controlled drying inside a chamber where temperature, RH and air velocity can be regulated. Most commercial timber is kiln-dried.

Advantages:

- Requires only 2–5 weeks.
- Produces uniformly dried timber with fewer defects.
- Suitable for large-scale continuous operation.

Types of kilns:

- **Steam kiln** – Heated by steam coils; airflow via fans.
- **Furnace kiln** – Direct or indirect heating through hot gases.
- **Dehumidification kiln** – Uses refrigeration coils to condense moisture.
- **Electrical kiln** – Uses electrical heaters.
- **Solar kiln** – Uses solar heat, cost-effective for small operations.
- **Progressive kiln** – Timber moves through temperature zones.
- **Compartment kiln** – Timber remains stationary; most commonly used.

C. Special Seasoning Methods

- **Salt seasoning** – For refractory timber; salt maintains favorable RH at surfaces.
- **Chemical seasoning** – Uses $CaCl_2$, molasses, and sugars to control surface RH.

7. Advantages and Disadvantages

Aspect	Air Drying	Kiln Drying
Investment	Very low	High capital cost
Time required	6–12 months	2–5 weeks
Quality control	Limited	Excellent
Defects	Higher probability	Fewer, better controlled
Seasonal constraints	Dependent on climate	Independent of climate

8. Challenges in Drying Wood

- Wood shrinks unevenly, creating defects if dried incorrectly.
- High energy is required in artificial drying.
- Skilled operation is needed to prevent tissue damage.

9. Common Drying Defects

1. **Warping, cupping, bowing, twisting, spring** – Dimensional changes due to shrinkage.
2. **Checks and splits** – Caused by rapid, uneven drying.
3. **Honeycombing** – Internal cell collapse from severe drying.
4. **Casehardening** – Surface becomes stiff while interior remains moist.

Defects can be minimized through appropriate control of temperature, RH, and airflow—best achieved in kilns.

10. Practical Activity

- Visit the air-seasoning yard to study stacking arrangement.
- Observe kiln controls: temperature, RH, vents, and fans.
- Measure moisture content of samples using a moisture meter.
- Identify at least three drying defects from seasoned boards.
- Prepare a comparative note on the performance of air-seasoned vs kiln-seasoned samples.

11. Learning Outcomes

Students will be able to:

- Explain the principles and importance of wood drying.
- Differentiate between air seasoning and kiln seasoning.
- Identify species-specific drying behavior.
- Recognize common drying defects and their causes.
- Design safe and effective stacking systems.
- Demonstrate moisture content measurement techniques.

Practical 13. Mechanical properties

Objectve-To study and understand the major mechanical properties of wood—hardness, strength, durability, elasticity, flexibility, and feasibility—and their significance in determining wood performance for different end uses.

1. **Hardness (Soundness)**
   - ✓ Resistance to indentation or penetration
   - ✓ Depends upon nature of grains, presence of silica content, wood elements
   - ✓ Softest wood – *Bombax ceiba, Cryptomaria japonica*
   - ✓ Hardest wood – *Acacia catechu*
   - ✓ Extremely hard wood – *Schleichera oleosa, Messua ferra, Shorea robusta, A. catechu, Xylia dolabriformis*
   - ✓ Hard wood – *Chukrasia tabularis, Lagerstroemia spp., Albizia lebbeck, Tectona grandis, Adina cordifolia*
   - ✓ Moderately hard – *Mangifera indica*
   - ✓ Soft wood – *Lannea coromandalica, Cedrus deodara, Toona ciliata, Abies pindrow*
   - ✓ Extremely soft wood – *Bombax ceiba, Cryptomeria japonica, Pinus roburghii, Boswellia serrata, Picea smithiana*
2. **Strength**
   - ✓ Ability to resist to external forces tending to the alter its shapes
   - ✓ The change in size , shape, or both due to the force acting on a unit per area is called '**Stress'** and the deformity per unit area is known as '**Strain**'.
   - ✓ **Tension** – Pulling of the fibres apart from wood $\perp$ to the grains eg. Building materials

Pulling of the fibres apart from wood $=$ to the grains eg. Structural materials

   - ✓ **Compression** – Pushing of the fibre of wood parallel to the grains is stronger than perpendicular
   - ✓ Neutral axis – No tension or compression on central axis

- ✓ **Shear strength** –Differ from the tensile or compression and due to slipping of wood elements.
- ✓ **Torsion** – Resistance to twisting forces in opposite direction.
- ✓ Strongest wood – *Mesua ferra, Schleichera trijuga, Shorea robusta, Xylia dolabriformis*
- ✓ Strong wood – *Anogeisus acuminata, Acacia nilotica, Grewia tiliaefolia, Terminalia alata, Tectona grandis, Terminalia bellerica*
- ✓ Moderately strong – *Adina cordifolia, Cedrus deodara, Chukrassia tabularis, Mangifera indica*
- ✓ Weak wood – *Picea smithiana, Cedrela toona, Pinus wallichiana, Lannea coromandalica, Boswellia serrata*
- ✓ Weakest wood – *Hymenodictylon excelsum*, *Bombax ceiba, Cryptomaria japonica*

3. Durability

- ✓ It is the indices of service life of the wood
- ✓ It enables the wood to be useful for a long time and resistance against disease, decay, insect attack etc.
- ✓ Teak is used as a standard wood for strength, stiffness, shock resistant, shear.

4. Elasticity

- ✓ Capacity of wood to bend out of shape freely without rupture. As a rule elasticity increases with specific gravity.
- ✓ Resistant to bending is stiffness
- ✓ Coppice shoots are more flexible than seedlings.
- ✓ Climbers are more flexible because of long straight loosened fibres.
- ✓ Very elastic – *Grewia tiliaefolia, Anogeisus latifolia, Acacia catechu, Mesua ferra, Dendrocalamus strictus*.
- ✓ Elastic – *Mimusops elengi, Chloroxylon swietenia, Shorea robusta, Xylia dolabriformis, Acacia nilotica, Dalbergia sissoo, Dalbergia latifolia*.
- ✓ Moderately elastic – *Mangifera indica, Tectona grandis, Cedrus deodara, Tona ciliate, Syzygium cumini, Chukrasia tabularis*.

5. Flexibility

- ✓ Capacity to enable to regain its original shape after stress has produced deformation
- ✓ Elastic wood always flexible but all flexible wood does not elastic in nature.

- ✓ Dry wood is more elastic than moisture wood
- ✓ Elasticity α specific gravity α strength
- ✓ Highest elastic wood – *Mesua ferrea*, *Acacia catechu*

6. **Feasibility**
   - ✓ Capacity of wood for being split along fibre
   - ✓ This property is mainly used for fuel wood material
   - ✓ Extremely feasible wood – Himalayan conifers, *Tectona grandis, Taxus baccata*
   - ✓ Difficult to split – *Dalbergia latifolia*, *Ougeinia oogeinensis*

Students' Activity

1. Identify and classify 10 wood samples based on mechanical properties such as hardness, elasticity, and durability.
2. Perform a simple indentation (hardness) test on available samples and compare resistance levels.
3. Observe fibre orientation and relate it to tension, compression, and shear properties.
4. Demonstrate bending behaviour of dry vs moist wood and record elasticity differences.
5. Prepare a table categorising wood species (provided in the notes) under strongest, weakest, most elastic, and highly feasible groups.
6. Conduct a splitting test on selected wood species to compare feasibility.
7. Prepare a short report on the application of strong, elastic, durable, and flexible woods in construction and wood products.

Learning Outcomes

• Explain key mechanical properties of wood and their influence on wood performance.
• Identify wood species based on hardness, strength, elasticity, and durability characteristics.
• Distinguish between tension, compression, shear, and torsion forces acting on wood.
• Relate wood anatomy (fibres, grain, specific gravity) to mechanical behaviours.
• Conduct basic comparative tests for hardness, elasticity, and splitting feasibility.
• Evaluate suitability of different species for structural, furniture, fuelwood, and engineered wood applications.

Practical 14. Mechanical Properties of Wood – Stress, Strain, Flexure, Shear, and Anisotropy

Objective-Study of Mechanical Properties of Wood: Stress, Strain, Flexure, Shear Strength, and Anisotropic Behaviour

2. Objective

1. To understand the concepts of stress, strain, and elastic deformation in wood.
2. To determine the Modulus of Elasticity (MOE) of a wooden beam using a bending test.
3. To study shear stress and shear failure characteristics parallel and perpendicular to grain.
4. To observe anisotropic behaviour of wood in longitudinal, radial, and tangential directions.
5. To relate specific gravity with the strength properties of wood.

3. Introduction

Mechanical properties describe the ability of wood to resist forces and deformation. These properties are crucial in designing structural members such as beams, rafters, poles, plywood panels, and engineered wood products. Wood behaves differently under tension, compression, bending, and shear forces, and these behaviors are influenced by moisture, density, grain direction, growth characteristics, and defects.

Understanding stress (force per unit area) and strain (deformation per unit length) is fundamental in evaluating wood performance. Elastic deformation occurs immediately upon loading and is recoverable, while time-dependent deformation results from prolonged loads.

Wood is anisotropic—its strength varies in three directions (longitudinal, radial, tangential)—which makes it unique compared to isotropic materials like steel or concrete.

This practical explores these concepts through experiments on bending, shear, and directional mechanical behavior.

4. Theory Summary

4.1 Stress and Strain

- **Stress** = load distributed over an area (psi or MPa).
- **Strain** = change in length / original length (dimensionless).
- Up to the **proportional limit**, stress and strain show a linear relationship.
- The slope of this linear portion is the **Modulus of Elasticity (MOE)** or Young's Modulus.

4.2 Flexure (Bending)

When a beam is bent:

- Top fibers undergo **compression**
- Bottom fibers undergo **tension**
- The central plane with zero stress is the **neutral axis**
- MOE determines stiffness and deflection under load

Formula to calculate MOE in bending:

MOE=PL348IDMOE = \frac{PL^3}{48ID}MOE=48IDPL3

where

P = load (lb),

D = deflection (in),

L = span (in),

I = moment of inertia = bd312\frac{bd^3}{12}12bd3

4.3 Shear Stress

- Shear acts parallel to grain and tends to make wood fibers slide past one another.
- Wood has **low shear strength parallel to grain**, but high shear strength across grain.
- Laminated and plywood structures experience **rolling shear**, important in engineered products.

4.4 Anisotropic Nature of Wood

Wood has different properties along:

- **Longitudinal direction** (strongest)
- **Radial direction**
- **Tangential direction**

Since radial and tangential properties are similar, engineering uses *perpendicular to grain* values.

4.5 Strength and Specific Gravity

Strength is strongly correlated with specific gravity. Higher density generally means higher mechanical strength. This relationship helps estimate properties even when species identification is uncertain.

5. Materials Required

- Clear, defect-free wood specimens (different species if available)
- Universal Testing Machine (UTM) or bending test apparatus
- Dial gauge or deflection sensor
- Vernier caliper
- Weighing balance
- Moisture meter
- Shear test jig
- Measuring tape

6. Experimental Procedure

Experiment A: Determination of MOE by Bending Test

1. **Measure specimen dimensions**

   Record width (b), depth (d), and length.

2. **Set the support span (L)**

   Place the sample on simply supported ends.

3. **Attach dial gauge**

   Position it at the midspan to measure deflection.

4. **Apply load gradually**

   Add load incrementally at the beam's center.

5. **Record deflection (D)**

   At each load increment (P), note corresponding deflection.

6. **Plot load vs. deflection**

   Draw the graph and identify the proportional region.

7. **Calculate MOE** using:

MOE=PL348IDMOE = \frac{PL^3}{48ID}MOE=48IDPL3

Experiment B: Shear Strength Test

1. Place wood sample in shear test jig.
2. Apply load parallel to grain.
3. Observe type of failure—sliding, crushing, or rolling shear.
4. Compute shear stress:

τ=PA\tau = \frac{P}{A}τ=AP

where A=b×dA = b \times dA=b×d

5. Compare parallel vs. perpendicular performance.

Experiment C: Anisotropic Behaviour Study

1. Prepare three specimens: longitudinal, radial, tangential.
2. Subject each to a small compression test.
3. Observe variation in deformation and strength behavior.
4. Compare stiffness and failure modes among the three directions.

Experiment D: Relation of Strength to Specific Gravity

1. Determine oven-dry weight and volume of samples.
2. Calculate specific gravity:

SG=WdryV×1 g/cm3SG = \frac{W_{dry}}{V \times 1\,g/cm^3}SG=V×1g/cm3Wdry

3. Compare strength values obtained from bending and shear tests.
4. Observe the correlation between density and mechanical performance.

7. Observations & Data Recording

Students should maintain a detailed table including:

- Dimensions
- Species
- Moisture content
- Load vs. deflection readings
- Calculated MOE
- Shear stress values
- Failure mode observations
- SG and strength correlation

8. Results

Students will:

- Compute MOE for each sample
- Identify samples with higher stiffness
- Determine shear strengths parallel and perpendicular to grain
- Compare directional strength behavior
- Relate density with mechanical properties

9. Discussion

Students should discuss:

1. Why wood shows different MOE values among species.
2. Influence of grain orientation on strength.
3. Why clear, straight-grained samples behave differently from knotty wood.
4. Engineering relevance of shear strength in beams and joints.
5. Practical implications of anisotropy in designing structures.

10. Precautions

- Ensure uniform loading during bending test.
- Avoid samples with surface defects or cracks.
- Zero deflection gauge before each reading.
- Maintain constant loading rate.
- Handle samples carefully to avoid pre-damage.

11. Student Activity

- Students will prepare a comparative chart of MOE for 3 different species.

- Draw stress–strain curves for bending and shear tests.
- Identify structural applications appropriate for species with high vs. low MOE.

12. Learning Outcomes

After completing this practical, students will be able to:

1. Understand and apply fundamental concepts of stress, strain, flexure, and shear.
2. Calculate the Modulus of Elasticity of wood using bending test data.
3. Evaluate wood's anisotropic behaviour and its engineering implications.
4. Relate specific gravity to mechanical strength.
5. Interpret test results to recommend suitable wood species for different structural applications.

Practical 15. Acoustic Properties of Wood

Practical Objective-To study the acoustic and electrical behaviour of wood, including sound velocity, absorption, reflection, resonance, and insulating properties.

Acoustic Properties

- Wood is widely used in musical instruments, auditoriums and specialised buildings due to its favourable sound-transmitting and sound-absorbing nature.
- Velocity of sound in wood depends on elasticity (E) and density/specific gravity (P):

8. $$\mathbf{V = \sqrt{(E / P)}}$$

9. As *E/P* ratio is often similar across species, sound velocity remains comparable in both light and heavy woods.

- Moisture reduces elasticity and increases density → decreases sound velocity.
- Approximate sound velocities (m/s): Wood (longitudinal): **4120,** Wood (radial): **1651**
- Sound absorption and reflection depend on:
  - ➢ Surface roughness/smoothness
  - ➢ Fibre orientation
  - ➢ Cellular structure
  - ➢ Moisture content
  - ➢ Specific gravity
- Sound absorption coefficient (K) indicates proportion absorbed.
- Total absorption: **Q = KA**, where A = area of the material.
- Rough, porous, low-density wood → higher absorption; smooth and dense wood → higher reflection.

Students Activity

1. Measurement of Sound Velocity: Select two wood samples of different densities.
2. Compare velocities of seasoned vs unseasoned wood.
3. Observation of Sound Absorption & Reflection on smooth-planed wood, rough-sawn wood, plywood, cork.
4. Demonstration of Resonance : Hold a wooden bar at its node point and strike gently.

5. Electrical Resistance Test Measure resistance of: Dry wood and Moist wood
6. Use a megohmmeter or insulation tester.
7. Identification of Instrument Woods

Learning Outcomes

- Ability to measure, observe and interpret acoustic properties of wood.
- Understanding resonance behaviour and its importance in instrument-grade timber.
- Ability to compare electrical insulation properties of different wood conditions.
- Skill in identifying suitable wood species for musical and acoustic applications.

Practical 16. Electrical Properties of Wood

Practical Objective- To study the behaviour of wood under electrical fields, including resistivity, conductivity, dielectric constant, power factor, and the effect of moisture, temperature, grain direction, and frequency on electrical properties.

Introduction

Wood is naturally a good electrical insulator, especially when dry. Its behaviour under electrical influence can be studied under two categories—static electricity and dynamic electricity. Static electricity refers to electrostatic charges, while dynamic electricity involves the flow of current. Dynamic electricity is further divided into Direct Current (DC) and Alternating Current (AC).

This practical focuses on the comparative study of DC and AC properties of wood and factors influencing them.

1. Direct Current (DC) Properties of Wood

Electrical Resistivity

The most important DC property of wood is electrical resistance to current flow**.** The resistivity of a unit cubic centimeter of wood is expressed as:

$$r = \frac{RA}{O}$$

Where:

- r = resistivity (ohm-cm)
- R = resistance (ohms)
- A = cross-sectional area (cm^2)
- O = length (cm)

The reciprocal of resistivity gives **conductivity**, expressed in **mhos cm^{-1}**.

Factors Influencing DC Resistivity

1. *Moisture Content:* Below fibre saturation point, electrical conductivity increases linearly with moisture.
   - Completely dry wood is an excellent insulator.
   - Above 30% moisture, the relationship becomes nonlinear.
   - This principle is used in *electrical moisture meters*.

2. Temperature: Increasing temperature decreases resistivity of oven-dry wood. This makes wood more conductive at higher temperatures.

3. Density: Density has no significant effect on DC resistivity.

4. Grain Direction: Wood offers *less resistance along the grain* than across it. This is due to alignment of cells and pathways facilitating electron movement.

5. Resin Impregnation: Resin-treated wood shows *higher insulation* compared to untreated wood.

2. Alternating Current (AC) Properties of Wood

Unlike DC, **AC reverses direction periodically**. At low frequencies, wood behaves similarly to DC conditions, but at **high frequencies**, especially radio frequencies, its behaviour changes significantly. These properties are important in **radio-frequency heating**, wood drying, and adhesive curing.

Dielectric Constant (Permittivity)

The die- electricity constant of wood which is also known as permittivity is defined as the ratio of capacitance 'C' of a condenser with wood and a die- electric medium to its capacitance.

The dielectric constant (E) is defined as:

$$\text{Die-electric constant (E)} = \frac{Capcitance\ wood}{Capcitance\ vaccum}$$

$$\text{i.e. (E} = \frac{C_w}{C_v}$$

Where:

Cw = capacitance with wood as dielectric

Cv = capacitance in vacuum

Students Activity

1. Measure DC Resistance of dry and moist wood using a megohmmeter.
2. Compare Resistivity along grain vs across grain.
3. Study Effect of Moisture by controlled wetting and drying experiments.
4. Observe Temperature Effects by measuring resistance at room and elevated temperatures.
5. Measure AC Properties using an LCR meter (dielectric constant, capacitance, and power factor).
6. Demonstrate RF Heating on small wood samples (if equipment available).
7. Identify Applications of insulating and impregnated wood products.

Learning Outcomes

1. Understanding of DC and AC electrical behaviour of wood.
2. Ability to measure resistivity, conductivity, and dielectric properties.
3. Knowledge of factors influencing electrical insulation.
4. Awareness of industrial applications of electrical properties in wood processing and drying.