

PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education and Scientific Research
Medea University
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Module of :

Wood and Foams

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Chapter 1: Wood Structure

The Forest

Forests are important ecosystems that are rich in plants and animals. They provide homes for many species and help maintain biodiversity. Forests also offer space for people to relax, enjoy nature, and do recreational activities such as hiking or camping. In addition to their ecological value, forests can play an important economic role in our country. They provide wood and other forest products that are used for construction, furniture, paper, and fuel. The annual wood production of a forest is the amount of wood that grows each year from the natural growth of trees. This growth depends on factors such as climate, soil quality, tree species, and forest management. Well-managed forests can produce wood sustainably while preserving the environment.



Production of Raw Materials, and Economic Development



Recreation, Sports, Tourism



Biodiversity, Air Quality, Landscape, Climate Regulation



The Tree

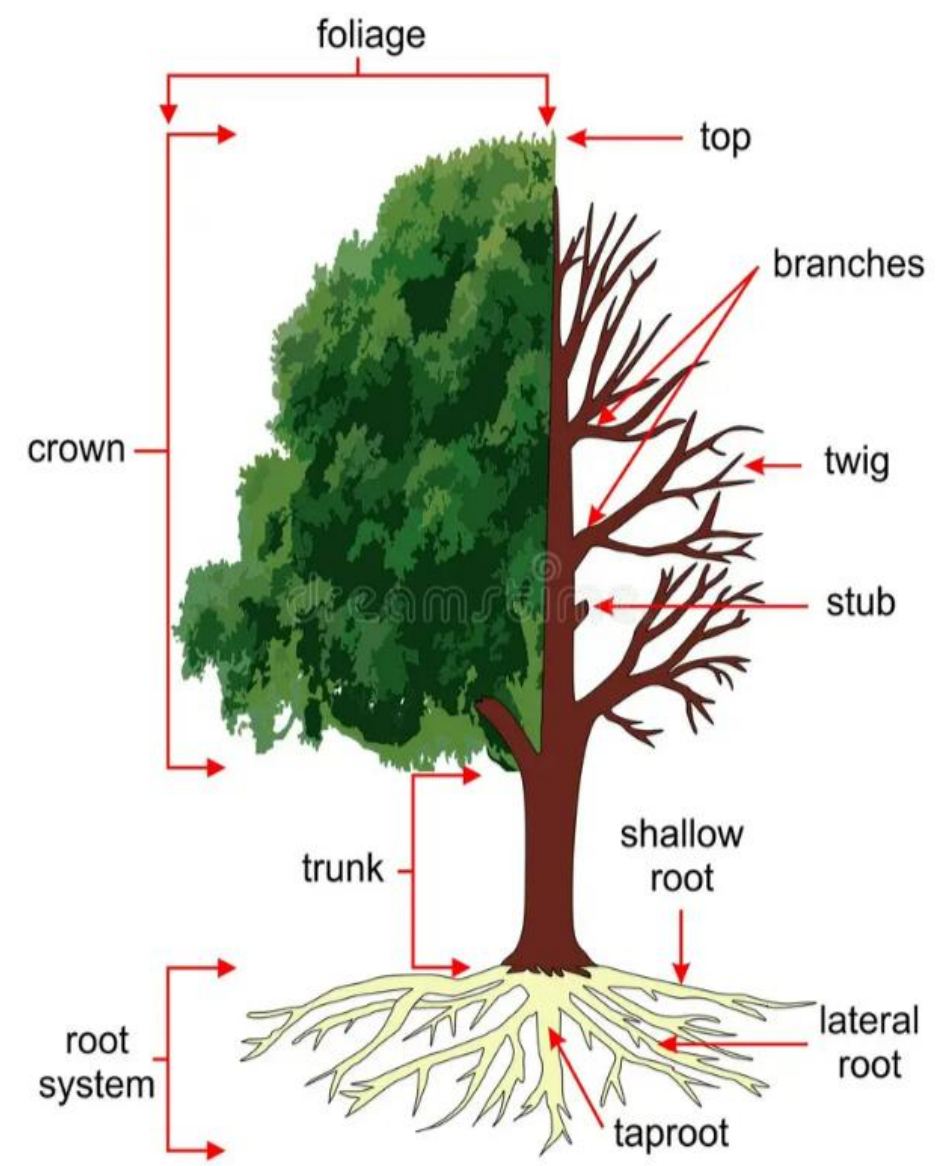
The tree is a fundamental element of the natural environment. Humans have used the tree as a productive plant that plays an important economic role. Trees provide raw materials for many industries, including chemical industries, paper industries, and wood-processing industries. In addition, trees contribute to environmental protection by producing oxygen, absorbing carbon dioxide, improving air quality, and helping to regulate the climate. Trees also protect the soil from erosion and provide habitats for many living organisms.

The physical structure of a tree includes several main parts, each with a specific function.

- **Foliage:** leaves of the tree
- **Top :** The upper part of the tree.
- **Large branch:** A thick branch used for secondary wood cutting.
- **Twig:** small branch
- **Stub:** short part of a branch or trunk
- **Crown:** The area where the main branches grow from the trunk,
- **Trunk:** main stem of the tree

• **Root system**

- **Shallow root:** root near the soil surface
- **Lateral root:** side root growing from the main root
- **Taproot:** main central root growing downward



Roots: Underground part through which the tree is anchored in the soil and absorbs nutrients.

Bark: The protective outer covering of the trunk that surrounds the whole tree.

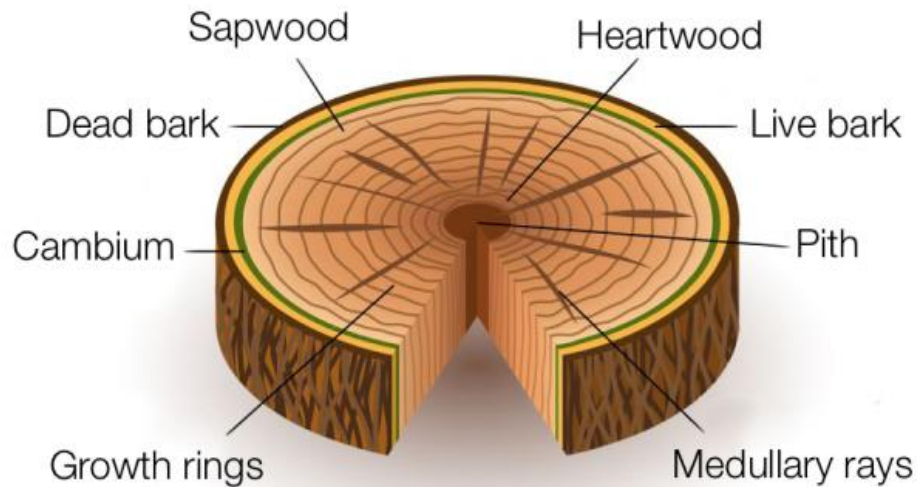
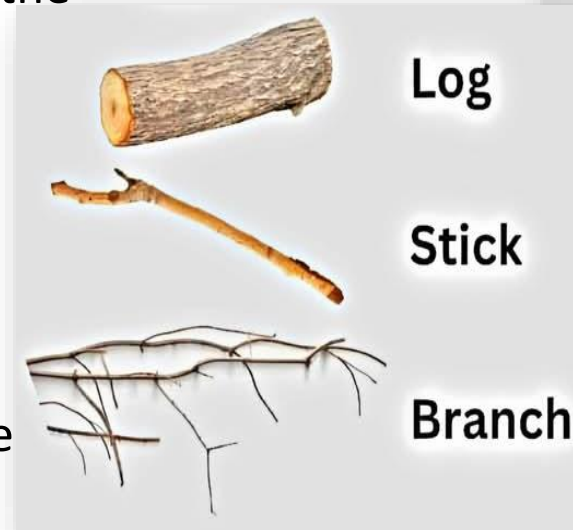
Stump: The base of the trunk together with the large roots attached to it.

Trunk: The lower part of the main stem.

Log: The trunk of a tree after it has been cut and branches removed.

Stick: A long, thin piece of wood; a small branch or slender piece cut from a tree.

Branch: A large side growth from the trunk.



• **Sapwood:** The outer living layers of the tree that carry water and nutrients from the roots to the leaves.

• **Dead bark:** The outer bark that no longer grows.

• **Cambium:** The layer where new cells are produced; it forms wood on the inside and bark on the outside.

• **Growth rings:** Rings in the wood showing yearly growth.

• **Heartwood:** The central, hard part of the tree that supports the trunk but does not carry nutrients.

• **Live bark:** The inner bark that transports nutrients.

• **Pith:** A small, soft, dark center in the middle of the trunk.

• **Medullary rays:** Radial lines in wood that transport nutrients sideways.

Pith

A small and often pulpy core running up the center of the trunk

Heartwood

Sapwood that has been clogged with resins, gums and other extractives; supports tree

Growth ring

A concentric ring divided into earlywood and latewood indicating the amount of wood added to a tree's diameter in one growing season

Ray

Carries nutrients laterally through the wood; also stores nutrients

Bark

Insulates tree against temperature extremes; keeps sapwood and phloem from drying out

Phloem

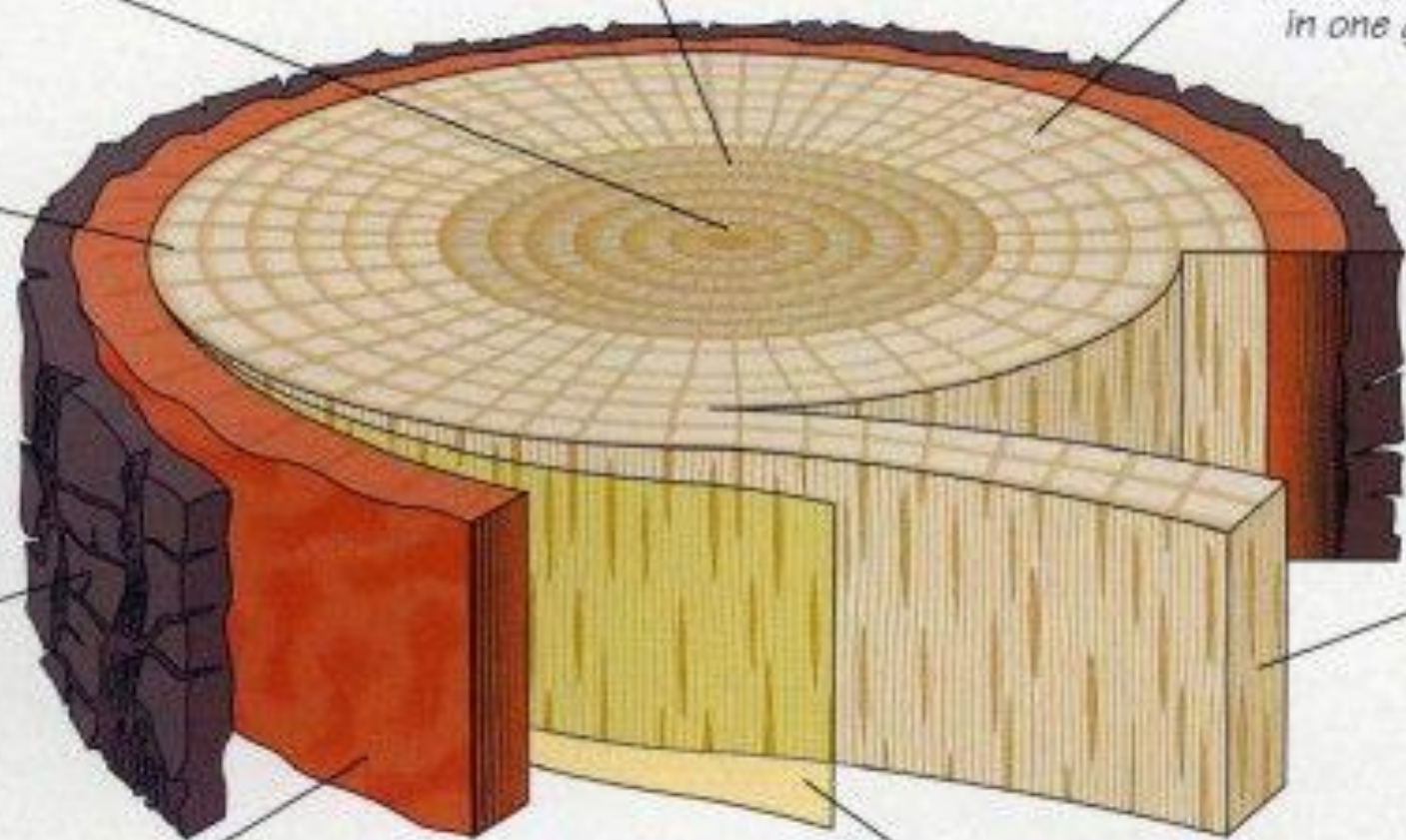
A thin, spongy layer of tubes that carry dissolved sugars and growth hormones from the leaves to other parts of a tree

Cambium

A thin reproductive layer that forms new tissue, adding to the phloem and sapwood to increase a tree's girth

Sapwood

Active part of the tree's wood through which water and minerals are conducted from the roots to the leaves; also stores nutrients and helps to support the tree



- **Butt:** The swollen lower part of the trunk near the roots, where the wood has special structural characteristics.
- **Top end:** The upper end of the trunk.
- **Butt end / Base end:** The lower end of the trunk.
- **Billet / Slab:** A log that has been sawn into pieces and prepared for drying.
- **Rhytidome:** The outermost part of the bark that protects the tree from insects, drying, and injuries.
- **Phloem:** The inner part of the bark that transports sap made of glucose; damage can slow growth.
- **Annual rings:** Yearly marks in the wood showing trunk growth.
- **Stem:** The main axis of the tree.
- **Bole:** The straight, branch-free part of the trunk.
- **Fork:** The place where the trunk splits into two stems.

Macroscopic observation of a trunk (Fig) is carried out along three directions: longitudinal (L), radial (R), and tangential (T).

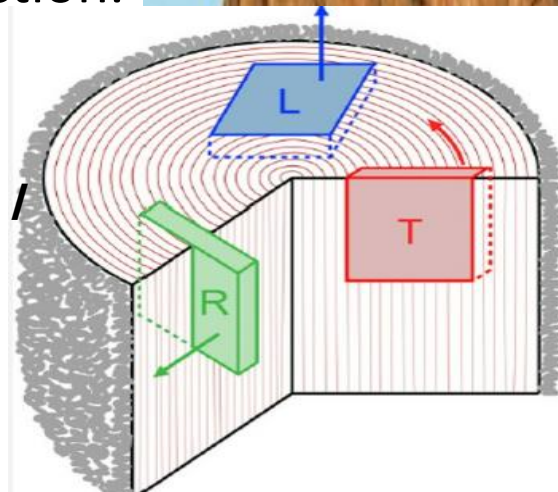
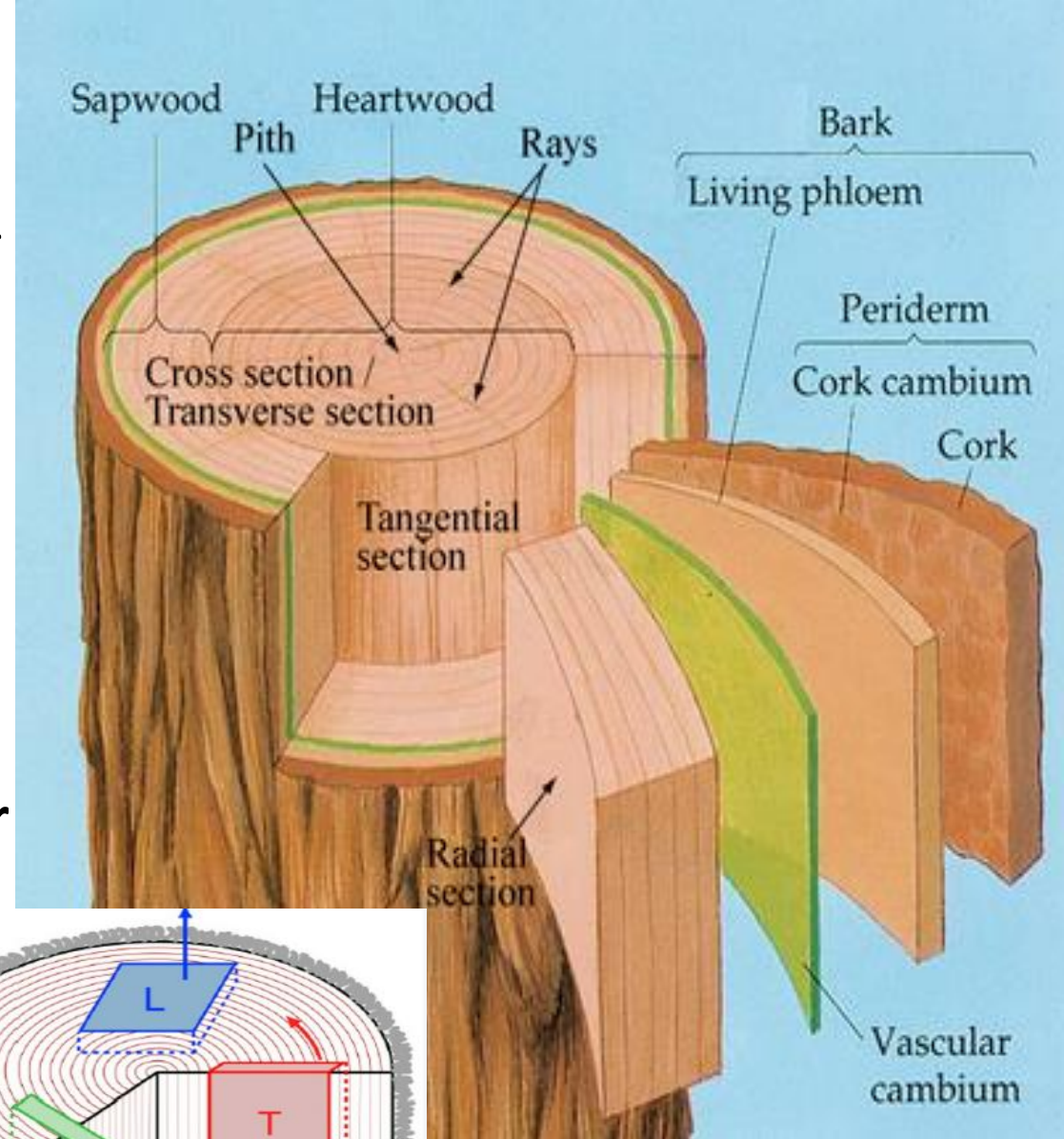
- The **longitudinal axis** is parallel to the main direction of the trunk, where **primary growth** occurs.
- The **radial axis** passes from the bark through the pith, where **secondary growth** occurs.
- The **tangential axis** is perpendicular to the plane defined by the first two axes.

The material is **anisotropic**, meaning its properties are not the same in all directions. For example, the swelling of a piece of wood due to moisture absorption is **greater in the radial direction** than in the longitudinal direction.

1/ Longitudinal – growth in height (upwards)

2/ Radial inward – growth toward the center, forming **xylem / wood**

3/ Radial outward – growth toward the outside, forming **phloem / inner bark**



Wood

Wood comes from trees and forms the trunk and branches. Only the trunk wood is used for building, including the butt, top, log, and billet. The trunk has several layers, from the bark on the outside to the pith in the center, including sapwood and heartwood. Every year, the tree grows a new layer of wood, creating growth rings that show its age and strength.

Classification of Wood

Solid wood consists of pieces obtained by shaping wood cut directly from the tree.

Categories of Wood

White Wood (Bois blancs):

1. Light-colored, generally soft wood
2. Easy to work with; often used for furniture, interior items, packaging, paper, and turning

Softwood / Resinous Wood (Bois résineux)

1. Comes from conifer trees like pine, spruce, fir
2. Light, fast-growing, easy to work, used in construction, carpentry, flooring, and paper

Fine Wood (Bois fins) :

1. Soft, smooth-grained wood with good finishing properties
2. Used for furniture, sculpture, drawing instruments, and fine tools

Durable / Hard Wood (Bois dur):

1. Strong and dense wood from broadleaf trees like oak, beech, chestnut, and walnut
2. Durable; used in furniture, bentwood, plywood, and heavy construction

Exotic Wood (Bois exotiques):

1. Comes from tropical or foreign trees, often hard, dense, and colorful
2. Used for luxury furniture, fine carpentry, veneers, and shipbuilding



Categories of Wood

Types / Examples

Uses

<i>Categories of Wood</i>	<i>Types / Examples</i>	<i>Uses</i>
White Wood (Bois blancs):	Poplar, Lime, Birch, Aspen, Plane, Maple, Alder	Packaging, turning, matches, paper, furniture, carpentry
Softwood / Resinous Wood (Bois résineux)	Fir, Pine, Spruce, Larch, Pitch Pine	Carpentry, construction, flooring, paper
Fine Wood (Bois fins) :	Oak, Beech, Hornbeam, Chestnut, Elm, Acacia, Walnut	Carpentry, bentwood, plywood, turning, furniture, posts, rails
Durable / Hard Wood (Bois dur):	Cherry, Wild Cherry, Walnut, Pear, Apple, Service Tree, Boxwood, Olive	Furniture, sculpture, drawing instruments, planes, measuring tools
Exotic Wood (Bois exotiques):	Mahogany, Ebony, Rosewood, Okoumé, Satinwood, Teak	Luxury furniture, fine carpentry, shipbuilding

Category *Density*
(g/cm³) *Examples*

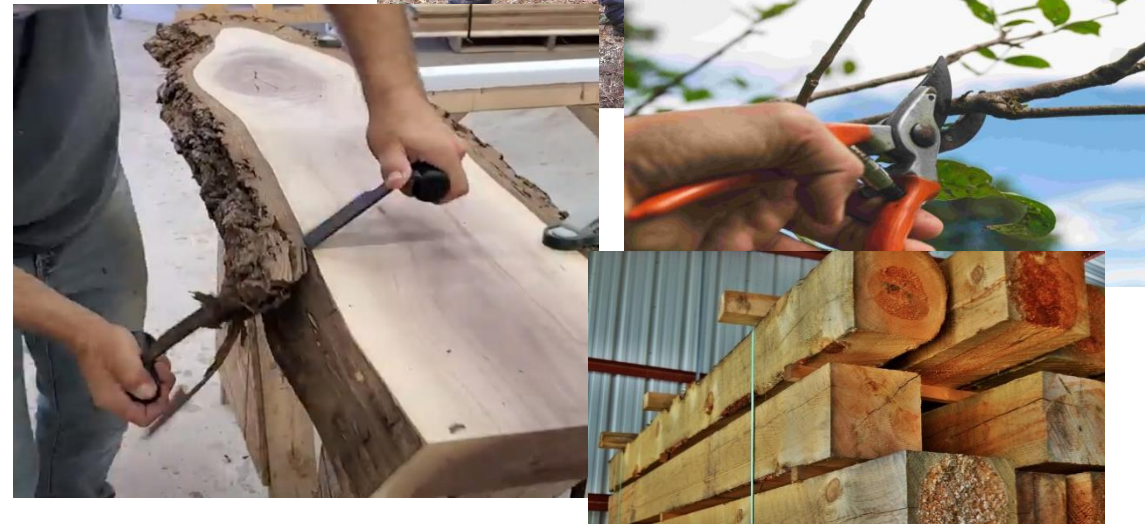
Very Light Wood	0.4 – 0.5	Poplar, Willow, Lime
Light Wood	0.5 – 0.65	Alder, Birch, Aspen
Medium-Heavy Wood	0.65 – 0.8	Chestnut, Oak, Maple, Ash, Beech, Walnut, Pear
Heavy Wood	0.8 – 0.95	Boxwood, Holm Oak, Dogwood, Rowan

Wood Production Operations

Before a tree can be turned into usable wood for construction, furniture, or other products, it must go through several production operations. These processes prepare the raw wood by removing unwanted parts, shaping it, and making it suitable for further use.

The operations include :

- 1. Felling:** Cutting the tree while it is standing.
- 2. Trimming (Blanching):** Removing the peripheral wood of the felled tree, including branches and outgrowths.
- 3. Bark Removal (Debarking):** After visual and electronic inspections (checking for ferrous metals), the bark, sand, and stones are removed.
- 4. Washing:** Longitudinal sawing is performed to expose the surface of the wood.



Wood Production Operations

5. Squaring: The log is squared on four sides to form a rectangular prism, slightly pyramidal along its length.

6. Cutting / Pre-Cutting: Users of wood material need pre-cut elements. A first longitudinal cut is made in the sawmill. This includes sawing, peeling, and slicing.



Flat sawing



Sawing around



Cant sawing



Quarter sawing

7. Splitting: Cutting a piece in a way that separates the fibers longitudinally, without sawing.

8. Sawing: Cross-cutting perpendicular to the wood fibers.

9. Sap Removal: Elimination of sap and water reserves using saturated steam.

10. Floating: Immersing wood in water to preserve it or facilitate transport.

11. Steaming: Sterilizing the wood using saturated steam.

12. Drying: The drying of wood depends on internal physical phenomena (water in the wood material) and external factors (air humidity). It is the process of partially removing water from the wood.

After the initial sawing, the wood is classified by **thickness into thin sheets, medium planks, and large beams**, depending on its intended use.

Wood as a Naturally Prestressed Material !!!

Wood is considered a **prestressed material** because it contains **internal stresses** that develop **without any external load**, during the tree's growth.

The stresses in wood come from **two main components**:

$$\text{Growth stress} = \text{Support stress} + \text{Maturation stress}$$

✓ a) Support stress

- Caused by the **self-weight of the tree**
- Due to external actions (wind, gravity)
- Similar to stresses in conventional structures

✓ b) Maturation stress

- Caused by the **formation of new wood cells**
- Specific to wood material
- Main source of prestressing

Each year, a new layer of wood is formed, and its cells tend to shrink (maturation strain). However, this shrinkage is restrained by the older layers, creating internal stresses: the new outer layers are in **tension**, while the inner core is in **compression**. This natural stress distribution improves the tree's strength and stability but can cause deformation or cracking when the wood is cut.

Wood properties

Wood has three main types of properties:

- 1/ Physical properties** – how wood looks and behaves, like **density, moisture, shrinkage, swelling, and heat conduction.**
- 2/ Chemical properties** – what wood is made of, which affects **durability and resistance to insects or decay.**
- 3/ Mechanical properties** – how strong and stiff wood is. Wood is **directional**: it behaves differently along the **grain, across the radius, or tangentially.** Strength also changes with **species, age, growth conditions, and location in the tree.**

1/ *Physical Properties*

The structure of wood is influenced by **water**, which affects its **consistency** and **swelling**.

—————→ *Moisture Content (Hygroscopicity)*

All solid wood objects **change shape**: they **shrink when drying** and **swell when absorbing water**.

Best practice: Use wood that has been stored in a room with **the same humidity** as where the finished furniture will be used.



Example: Outdoor wood (windows, shutters, siding) has moisture around **13% in summer** and **19% in winter**.

•To **minimize changes**, the wood moisture should be around **15–16%**, the average of this range.

Forms of water in wood

1/ Free water: Moves easily in the wood; fills the cell cavities.

2/ Bound water: Also called **impregnation or saturation water**; it is inside the cell walls. Its loss is the **main cause of wood shrinkage**.

3/ Constitutional water: Part of the chemical structure of the wood; disappears only when the wood is destroyed (e.g., charcoal).

Equilibrium Moisture Content

- The wood's moisture level **stabilizes** depending on **temperature** and **air humidity**.
- When stable, the wood is in **hygroscopic equilibrium** with the air.

Moisture content (MC %) = mass of water in wood ÷ dry mass of wood × 100

Calculation methods:

a/ Weighing method:

$$\text{MC\%} = (m_{\text{wet}} - m_{\text{dry}}) / m_{\text{dry}} \times 100$$

where:

- m_{wet} = wet mass of wood
- m_{dry} = dry mass of wood

b/ Electrical method:

- Water affects **wood's electrical resistance**.
- More water → better conductivity.
- Measure by inserting two electrodes in the wood, passing a current, and measuring resistance.

Wood Shrinkage (Retractability)

Wood shrinkage is the ability of wood to change its size and volume when its moisture content changes. It is defined by the relation:

$$B(\%) = \frac{V_1 - V_2}{V_2}$$

- **V1**: volume in saturated state
- **V2**: volume in oven-dry (anhydrous) state

Wood contains two types of water: free water (inside the cell cavities) and bound water (inside the cell walls). The fiber saturation point is about 30%. Above this value, wood only loses free water and does not change its dimensions. Below 30%, the loss of bound water causes shrinkage and deformation.

From 100% to 30% moisture content, wood loses weight but does not deform. From 30% to 0%, wood continues to lose water and begins to shrink; this is called shrinkage.

Shrinkage depends on the direction of the wood fibers. It is very small in the longitudinal direction (about 0.1%), moderate in the radial direction (about 5%), and highest in the tangential direction (about 11%). Tangential shrinkage is about 1.5 to 2 times greater than radial shrinkage.

Wood species can be classified according to their shrinkage:

- ✓ high shrinkage (15–20%) such as oak and beech,
- ✓ medium shrinkage (10–15%) such as most softwoods,
- ✓ low shrinkage (5–10%) such as sipo, iroko, walnut, poplar, and mahogany.

Wood is also a hygroscopic material, meaning it exchanges moisture with the surrounding air until it reaches an equilibrium moisture content, which depends on temperature and air humidity.

Freshly cut wood (green wood) contains a high amount of water, usually between 35% and 50% of its weight. After cutting, wood gradually loses water, which leads to shrinkage and a reduction in its dimensions.

Wood Swelling

Wood swelling is the opposite of shrinkage. When wood absorbs water, its moisture content increases and the wood expands in size.

Swelling happens until the fiber saturation point (about 30%). Above this level, the wood shows dimensional changes.

Swelling is not the same in all directions. It is:

- ✓ very small along the fibers (length)
- ✓ much larger across the fibers (width)

For example, wood changes only about 0.1% in length but about 8% in width.

Wood is therefore an anisotropic material, meaning its properties depend on direction. It always contains some moisture and swells when it absorbs humidity from the air, especially in the transverse direction.

Density and Hardness of Wood

Wood density is the mass of wood per unit volume. It varies depending on the species, usually between **350 and 1100 kg/m³**, and even within the same species it can change by about **±15%**.

There is a clear relationship between density and hardness. In general, **dense wood is hard**, while **light wood is soft**. This means that heavier woods are usually stronger and more resistant to wear, while lighter woods are easier to cut and shape.

Table 3. Wood Classes by Density and Hardness

Density & Hardness Class	Density (kg/m ³)	Hardness (Chalais-Meudon)	Examples
Very heavy & very hard	> 0.85	~ 9	Azobé, Ipé
Heavy & hard	0.70 – 0.85	5 – 9	Hornbeam, Movingui, Hard oak
Medium (moderate)	0.56 – 0.70	2.5 – 5	Chestnut, Soft oak, Pine
Light & soft	0.45 – 0.55	1.25 – 2.5	Framiré, Douglas fir, Spruce, Fir
Very light & very soft	< 0.45	~ 1.25	Western red cedar, Sequoia, Poplar

Thermal Conductivity of Wood

The **thermal conductivity** of wood is **moderate** and depends on:

- ✓ **Species** of the wood
- ✓ **Density**
- ✓ **Moisture content**
- ✓ **Temperature**

When the **air in the pores decreases** (for example, when moisture increases), the **thermal conductivity improves** (heat passes more easily).

2/ Chemical Properties

The composition of wood varies depending on its type. Wood is mainly made up of the following constituents:

• **Cellulose (40–50%)** – The main structural material of wood. Its chemical formula is $(C_6H_{10}O_5)_n$. Cellulose makes up about 40–50% of wood.

• **Lignin (10–30%)** – A hard and colored substance. Cellulose and lignin together form the cell walls of wood, especially the **fibers**, giving wood its rigidity.

• **Soluble or insoluble substances (20–25%)** – Includes gums, oils, resins, sugars, tannins, starch, etc.

• **Mineral matter (ash) (0–10%)** – Small fraction of inorganic components present in the wood.

Table 1. Proportions of Chemical Components of Wood (Dry Mass)

Chemical Component	Cellulose	Lignin	Hemicellulose	Mineral Matter
Proportion (%)	40–50	10–30	20–25	0–10

The percentage chemical composition of dry wood varies little, as shown in Table 2:

Table 2. Composition of Dry Wood

Component	Carbon	Oxygen	Hydrogen	Nitrogen	Mineral Matter (Ash)
Content (%)	50	42	6	1	1

3/ *Mechanical Properties*

Wood is a **heterogeneous and anisotropic material**, which means its strength depends on the **direction of the applied force** (longitudinal, radial, or tangential).

Mechanical properties vary depending on:

- **Species** (texture, density, moisture)
- **Age and growth conditions**
- **Environment and surroundings**
- **Position within the tree**

Wood behaves differently in each direction:

- **Longitudinal (along the grain)**: strong, stiff, and resistant
- **Tangential (across the grain)**: more flexible, less resistant

Wood has **high strength along the grain**, but it can **split easily in the radial direction**. Because of this, the cutting direction is important depending on the use.

There can be large variations in results (even double) for the same type of stress, mainly due to differences in **density**, which is the most important factor.

Before use, wood must be **cut and dried** to remove moisture and avoid deformation. Its mechanical behavior is tested under different loads such as **tension, compression, shear, and indentation**, and results vary with direction and wood quality.

Compression and Tension Strength

Wood has **high strength in compression and tension** when the force is applied **along the grain (longitudinal direction)**.

However, it is **much weaker across the grain (transverse direction)**.

Bending Strength

Bending strength, or **modulus of rupture**, depends on the type of load and the **direction in which it is applied** to the material. Compression strength is higher in the **longitudinal direction** than in the radial or tangential directions.

A bending test is used to bend the material. In the case of a beam, this involves bringing its two ends closer together by placing a **load at the center**. Bending at the center of the beam is achieved by distributing the load over two supports.

Several factors influence bending strength:

- **Density**
- **Moisture content**
- **Presence of knots**

The **grain slope** is the angle between the fiber direction and the main axis of the beam. As this angle increases, the strength decreases because the connections between the fibers are stressed more than the fibers themselves. Bending strength increases as the **density of the wood increases**.

Moisture has a special influence on wood: water is present both in the **cell cavities** and in the **cell walls**. The cell walls absorb water first; when they are saturated, the cavities start to fill. This transition occurs at a certain moisture level called the **fiber saturation point (FSP)**, which is between **20 and 30%**.

Knots come from the growth of branches in a direction different from that of the trunk. They represent **weak points** in the mechanical behavior of wooden beams because of the change in fiber direction (live branches) or even the discontinuity (dead branches) of the material around them.

Modulus of Elasticity

The **elastic modulus**, or **Young's modulus**, is the constant linking **strain** to the **stress applied** to a material. Whatever the type of load (tension, compression, bending), there is a stress range within which the material behaves **elastically**.

Factors affecting the **elasticity of wood** are the same as those affecting the **modulus of rupture**. Under normal temperature and pressure conditions, wood behaves **perfectly elastically** in all directions when **small loads** (up to 30% of the breaking load) are applied. This means the deformation is **proportional to the applied load**.

Impact Strength

Impact strength is measured by the **work needed to break a bar of given cross-section**. It indicates the wood's **resilience**, and therefore its **brittleness**, which is an important property. This parameter is affected by **fiber deviations** and **irregular growth** in the wood.

Hardness

The **hardness** of a local wood surface under compression can be measured using different methods. The **Brinell method** is the most common. It measures the **imprint of a steel ball** pressed into the wood under a given load.

The **spherical shape of the ball** combines resistance to compression **parallel and perpendicular to the grain**, with a ratio that changes as the ball penetrates the wood.

Although Brinell values are not directly comparable with **unidirectional measurements**, they are useful for evaluating the **suitability of a wood species**, for example, for **flooring**.

4/ Durability (Resistance to Decay)

Durability is the **ability of wood to resist damage** from destructive organisms such as **fungi, insects, and other pests**.

It depends on:

- ✓ **Natural protective substances** in the wood
- ✓ **Artificial antiseptics** added to the wood
- ✓ **Presence of nutrients** that attract organisms

To protect a wooden structure from fungi, it is important to **assess the risk**:

- ✓ Lower risk in **sheltered areas**
- ✓ Higher risk when wood is **exposed to weather or in contact with the ground**
- ✓ Moisture near the wood increases the risk
- ✓ **Testing Durability**

Durability tests involve exposing a **wood sample to decay agents** and measuring the **weight loss (WL)**:

$$WL = 100 \times \frac{ms1 - ms2}{ms1}$$

Where: **ms1** = dry mass of the sample before exposure **ms2** = dry mass after exposure

The **mass lost due to fungal attack** is used to assign a **durability class**, showing how resistant the wood is to fungi.

Wood Treatments

→ Thermo-Hydro-Mechanical Treatments

Thermo-hydro-mechanical treatments are techniques that modify wood, such as **drying, bending, compression, friction welding, and heat treatment.**

a) Drying:

Water content in wood starts to decrease immediately after the tree is cut, naturally in open air, and is often accelerated in **drying kilns** to reach **10–20% moisture**. Dried wood has many advantages over green wood:

- Less vulnerable to **fungi and insects**
- **Less deformation**
- **Lighter**
- **Better mechanical properties**
- **Better support for paint and varnish**

b) Bending:

This shows the combined effect of **water, heat, and mechanical forces** on wood. Bending permanently shapes wood **without breaking it.**

c) Compression/Densification:

Some **chemical treatments** fill wood cells to reduce water absorption. Wood can also be **densified by compression**, which **improves its mechanical properties.**

→ Thermal Treatment of Wood

Thermally treated wood is a modified material with different properties than natural wood:

- Slower degradation**
- Slightly more fragile**

Thermal treatment affects **durability** and **mechanical performance**, ensuring product quality and optimizing the treatment cycle.

Wood is thermally modified by heating it to **140–250 °C** for **12–100 hours** under **low oxygen conditions**, which changes the **cell wall composition** and **physical properties**. Exact conditions vary depending on the **species of wood** and **desired final properties**.

Thermally treated wood can be used **indoors and outdoors**:

- Indoors**: darker tones than untreated wood, expanding design options
- Outdoors**: better durability and dimensional stability for **cladding, decking, furniture, and crafts**

→ *Defects and Enemies of Wood*

Wood has advantages and defects that must be considered during shaping and especially during assembly, even for small objects:

- Low cost
- Easy to work with

Defects

Wood can have **anomalies** that change its properties. Structural anomalies include:

- ✓ **Knots:** occur where a branch joins the trunk
- ✓ **Inbark (between-bark):** bark included in the wood mass
- ✓ **Frost cracks and splits:** longitudinal cracks on a radial plane caused by alternating freezing and drying
- ✓ **Ring shakes:** circular cracks caused by the separation of two annual rings

Deformation Due to Shrinkage

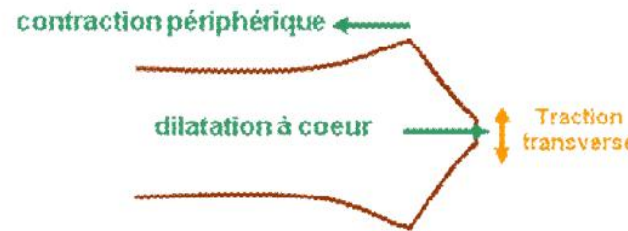
a) **Logs (round wood):**

- ✓ Outer layers dry first and shrink more because they contain more water.
- ✓ Inner layers dry slowly and shrink less.
- ✓ This uneven shrinkage causes **radial cracks**.

b) Sawn wood:

- ❑ **Tangentially cut boards:** the parts farthest from the heartwood shrink more than the parts closer to the center due to uneven water distribution. The board **bows**, with the convex side toward the heart, which shrinks less. This is called “**wood pulling to the heart**”.
- ❑ **Radially cut boards:** both faces rich in water shrink equally. The **middle plane** does not deform. Width and thickness decrease, more noticeable at the edges than in the center.
- ❑ **Lengthwise shrinkage:** the ends dry faster than the center, causing cracks.
- ❑ **Prevention:** limit cracks by
 - ✓ nailing wooden blocks (tasseaux)
 - ✓ using S-shaped hooks hammered into the wood
 - ✓ avoiding too rapid drying

At the workshop, when a **thick piece of wood is cut**, cracks at the new end can be **prevented by gluing a sheet of paper** on the freshly cut surface.



Eucalyptus



Fente en bout chez le hêtre

Figure 11 : Les fentes et leur propagation dans le sens de la longueur

Enemies of Wood

Fungi: Wood can be attacked by **plant parasites (fungi)**, which can **change the chemical composition**, consistency, and color of the wood. **Rot caused by fungi** reduces the wood's **mechanical, physical, and chemical properties**. Some fungi only **change the color** without affecting the wood's strength.

The dry rot fungus (Merule):

- ✓ The most common parasitic fungus
- ✓ Attacks **old wood used in buildings**
- ✓ Appears in different forms
- ✓ Growth is favored by:
 - **High moisture (22–35%)**
 - **Darkness**
 - **Poor air circulation**

WOOD DERIVATIVES (Engineered Wood Products)

One of the current concerns is to remedy the defects of wood, particularly its deformations under the influence of moisture.

1 – A first solution

consists in preventing deformation by gluing several veneer sheets together with crossed grain directions. Fibers that are less deformable in the longitudinal direction help restrain the fibers of adjacent layers placed in the transverse direction.

This process results in laminated wood, also known as plywood.

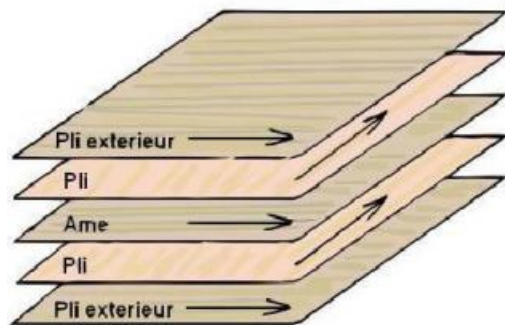
Bonding is carried out under pressure using synthetic resins.

1.1 – Multi-ply plywood:

It is made up of layers called “plies” arranged at 90° to each other (referred to as multi-ply). The manufacturing of plywood consists of peeling tree trunks to obtain thin sheets of wood called plies. These layers are glued together with alternating grain directions. The layers are bonded in an odd number, with the inner layer forming the core.

Thin plywood panels are thus obtained, which are then placed in a mold of the desired shape and pressed. The panel then takes the shape of the mold, which can be curved or rounded. It is then heated for 5 to 10 minutes at 90°C.

- The crossing of successive plies and the characteristics of the adhesive provide improved performance compared to the original wood structure;
- Transverse properties are significantly enhanced;
- These mechanical properties lead to interesting applications.



1.2 – Blockboard Plywood (Plywood Panels):

It consists of veneer plies and a core made of wooden strips with widths ranging from 7 to 30 mm. The solid panel (blockboard) is composed of a core formed by softwood slats (usually fir) glued side by side. The two outer faces are made of veneer sheets glued with crossed grain directions.



Main characteristics of plywood panels:

- Strength:** Plywood is relatively resistant to water and offers high mechanical performance. This makes it preferable to MDF or particleboard for manufacturing transport crates or for structural applications. Due to the cross-laminated plies, it provides excellent resistance to creep and impact.
- Dimensional variations:** Plywood panels exhibit very good dimensional stability. Their dimensional changes are lower than those of solid wood, around 0.15% in width or length between the dry state and the fully saturated state.

However, since the fibers are mainly arranged flat in layers, the panel properties differ through the thickness. These dimensional variations make plywood one of the most stable wood-based products, with changes of about 0.5 to 1 mm per linear meter.

To prevent the release of volatile compounds from the edges of reconstituted wood panels:

- seal the edges with a coating;
- choose panels with an integrated surface finish.



2 – A second solution

Another approach consists in eliminating the porosity of wood caused by the presence of vessels through which moisture penetrates. Wood can be compressed to transform it into a compact, non-deformable mass. This technique produces compressed wood under high pressure, reducing its thickness to about two-thirds of the original thickness.

Wood can also be made impermeable by filling its vessels with a hardenable and waterproof substance. This process produces impregnated wood. The materials used for impregnation may have specific properties such as water resistance (hydrophobic), fire resistance (fire-retardant), and protection against insects (insecticidal).

Low-melting-point metals (such as lead, tin, and antimony) and synthetic resins are commonly used.

The combined use of these two techniques results in compressed and impregnated wood. The products obtained have interesting applications in aeronautical and naval construction. They are hard, insensitive to humidity variations, and particularly suitable for manufacturing models.

2.1 – Wood Fiber Panels

In the category of wood fiber panels, we find medium-density fiberboard (MDF), which is made from defibrated lignocellulosic materials (wood), mixed with a synthetic binder and hot-pressed. MDF panels are usually brown in color, although the shade may vary depending on the type of wood used. This type of panel is one of the heaviest wood-based products. Among its main characteristics:

Homogeneity: Wood fiber panels have a fine and uniform composition, and both surfaces are smooth, which facilitates machining. They do not present issues related to grain direction, knots, or surface irregularities. However, the surface density is higher than that of the core.

Dimensional variations: MDF panels exhibit good dimensional stability. When relative humidity changes from 35% to 85%, dimensional variations are much lower than those of solid wood, around 0.3% in width or length. Since the fibers are arranged in flat layers, the panel properties differ through the thickness. Thus, when relative humidity varies from 35% to 85%, dimensional changes can reach about 6% in thickness. Moreover, when in contact with water, MDF panels swell and lose their mechanical properties.

Warning: Cohesion is weaker through the thickness, and fasteners driven into the edges may cause panel delamination. It is recommended to pre-drill and increase the penetration depth of fasteners into the edges to compensate for the lower withdrawal resistance in these areas.

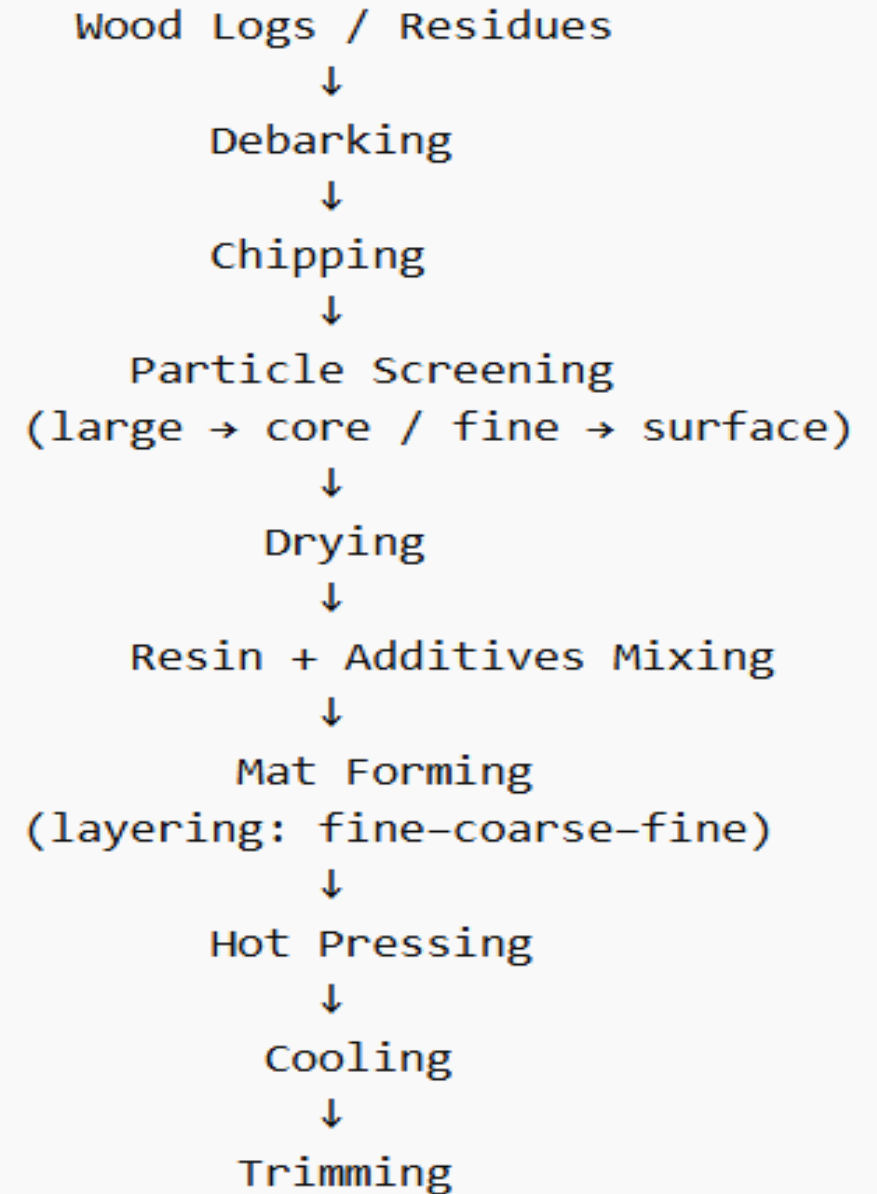
In addition, these panels are less rigid than solid wood and can be compared to high-density cardboard that remains somewhat plastic and may deform over time.

These products also contain a higher amount of adhesive compared to plywood.

2.2 – Wood Particle Panels:

In the category of wood particle panels, we find non-oriented particleboard (chipboard). This type of panel is made from particles of various sizes, sorted by screening so that larger particles are placed in the core and finer ones on the surface.

As in the manufacture of fiber panels, these particles are bonded with thermosetting resins and hot-pressed. Some types of particleboard are made with particles of similar size to achieve better edge quality during machining. Different panel qualities are produced by varying particle size, distribution, and the type and quantity of resin used.



Main characteristics of particle panels:

- Cost-effectiveness:** Particleboard has become widely used as an economical product.
- Dimensional variations:** Particleboard panels exhibit good dimensional stability. Their variations are similar to those of fiberboards. When relative humidity changes from 35% (dry state) to 85% (humid state), dimensional changes are about 0.3% in length or width, and about 6% in thickness. A particleboard panel may vary by 1 to 2 mm per linear meter. However, when in contact with water, these panels swell and lose their mechanical properties.
- Warning:** The mechanical properties of particleboard are lower than those of plywood. In addition, the edges are particularly fragile and prone to crumbling.

Applications:

Like wood, wood-based products are used for:

- ❑ Manufacturing furniture and transport crates;
- ❑ Storage structures (shelves, etc.);
- ❑ Display cases and picture frames.

Wood chips or plant fibers are bonded using adhesives. These panels are classified according to density, which determines their physical and mechanical properties:

- ✓ Soft: 230 to 400 kg/m³
- ✓ Hard: 480 to 850 kg/m³
- ✓ Extra hard: more than 950 kg/m³

This category also includes fiber panels such as MDF (Medium Density Fiberboard), which are materials manufactured under pressure mainly from wood particles or other fibrous materials. These particles, with no specific shape but a certain granulometry, are obtained by fragmenting wood. They are coated with adhesives (thermosetting resins), then spread and pressed.

These panels can be of several types: single-layer, multi-layer, or three-layer panels with one inner layer and two outer layers (with different particle sizes and densities).

They can also be surface-coated. The most common finishes include melamine-faced, laminated, or wood veneer (beech, oak, cherry, etc.), often varnished.

Melamine-faced or laminated surfaces



Raw (unfinished)



USE OF WOOD

Wood is available in the form of boards of various thicknesses, widths, and lengths. Its use can be divided into three main sectors:

a) Structural wood (timber): used for:

- Construction: frameworks, cladding, terraces, flooring, paneling, and joinery;
- Furniture;
- Packaging.

Structural wood refers to wood that, after harvesting, is sawn, sliced, or peeled.

b) Industrial wood: used for processing. Processing involves breaking down the wood and separating its fibers so it can be used for paper pulp or for the manufacture of particleboards and fiberboards.

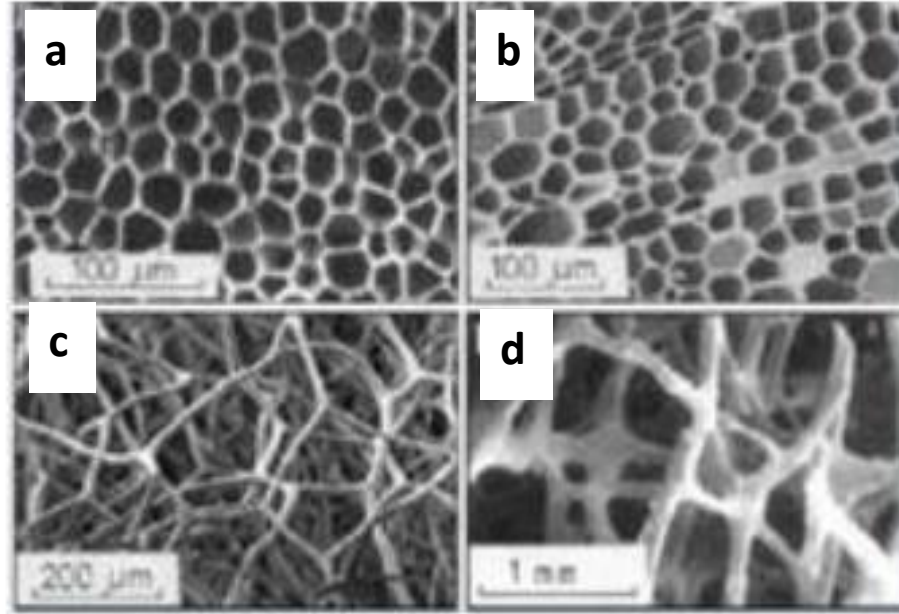
c) Energy wood: like straw, agricultural residues, and black liquor from the paper industry, wood can be used as a source of energy.

Solid Foam

A solid foam is derived from a liquid foam by solidifying the liquid. It can be obtained through different processes depending on the nature of the liquid: solidification, polymerization, or gelation.

Natural materials:

- (a) Cork
- (b) Wood
- (c) Sponge
- (d) Bone



A foam is a collection of “bubbles” ranging from 0.5 to 5 mm in size. Foam is a solid or liquid structure containing cavities (pores). There are two phases: liquid–solid or solid–gas. All foams are at some point in a liquid state, which can vary in viscosity. This liquid foam can then be transformed into a solid foam via solidification (such as during thermal curing), polymerization, or gelation.

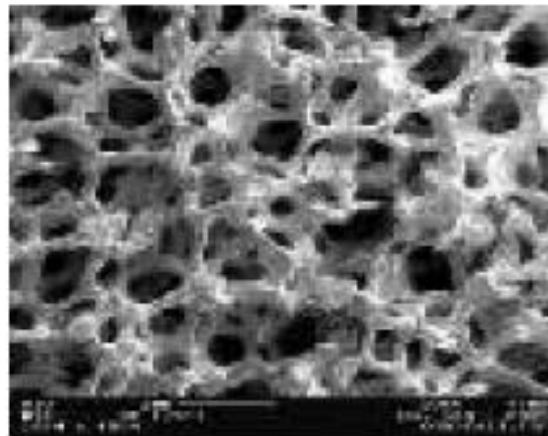
There are **two types of foam**:

- Open-cell foams**: These foams have thousands of broken bubbles, allowing gases and liquids to pass through. This characteristic makes them ideal for applications such as heat exchangers and dissipators, catalysts, acoustic barriers, filters, electrodes, and electromagnetic shields.

- Closed-cell foams**: These foams retain intact liquid films after solidification, resulting in thousands of unbroken bubbles. Consequently, gases and liquids cannot pass through, making them impermeable. Their lightness and waterproof properties are such that some of these foams can float on water. They are very promising for manufacturing structures for transportation vehicles. Applications include building façade panels and impact-absorbing materials inside bumpers.



(a)



(b)

a/ Closed-cell foams

b/ Open-cell foams

Foam Manufacturing Method:

The method of manufacturing foam involves mixing water, a polymer, and a foaming agent, which is then heated. This process creates a cluster of bubbles, which is subsequently cooled, resulting in the formation of the foam.

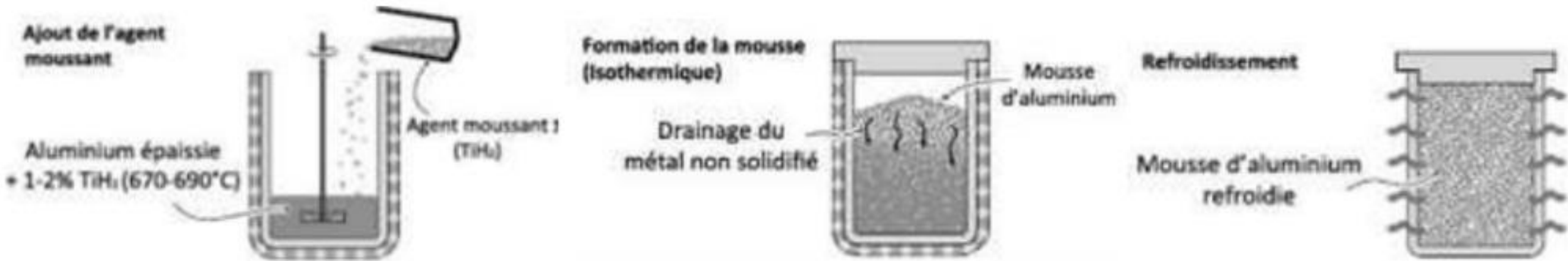
1/ Fabrication of Metal Foam

Metal foam is made from a foaming agent, water, and polymers. By analogy with regular foam, the mixture is heated. The foaming agent releases hydrogen gas, forming bubbles and transforming the material from a liquid to a gaseous state.

Example: Aluminum thickened with a foaming agent forms aluminum foam. After cooling, the aluminum foam solidifies.



To optimize the weight of a component, low-density materials are highly desirable, as they reduce the amount of solid material used while maintaining the desired geometric dimensions. Metal foams have good mechanical properties and a high energy absorption capacity. Their performance can be further enhanced when used in sandwich structures with carbon fibers. Metal foams are produced by introducing a foaming agent into the molten metal following the process described below:



- The foaming agent used is **titanium hydride (TiH₂)**, about 2% by mass. When heated, it releases hydrogen gas, which forms bubbles, while titanium is expelled into the aluminum.
- The resulting aluminum foam then fills the mold in which it is contained. It is important to note that this is a **batch (discontinuous) process**. The pore diameters obtained range from 0.5 to 5 mm. Nickel foams are also produced industrially because of their excellent electrical conductivity, making them suitable for batteries used in portable devices (phones, laptops, etc.).

2.1 – Dental Implants:

The purpose of dental implants made from titanium foam is to replace damaged teeth. Unlike conventional solid titanium implants, titanium foam implants have a **porous structure**. This porous structure closely mimics human bone. The pores allow bone cells to grow into the implant, anchoring it more securely to the jaw. This results in **faster healing** and allows for the use of **smaller-sized implants**.

2.2 – Hip Prostheses:

A hip prosthesis is a device that replaces the hip joint and allows it to function almost normally. *Figure 19* shows a titanium foam hip prosthesis with **open cells**, which imitates the structure of the human joint. The **corrosion resistance**, **biocompatibility**, and **open-cell structure** (promoting tissue integration) of titanium foam make this prosthesis highly effective.

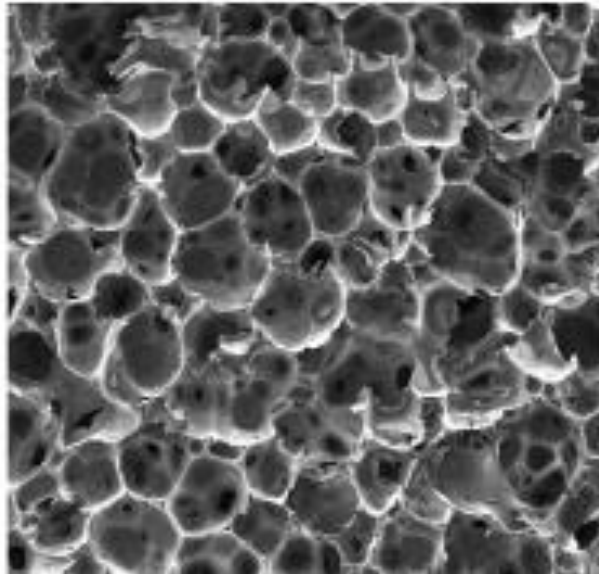
Hip Prostheses



2/ Carbon Foams

Carbon foams are mainly characterized by a **cellular structure** similar to that of a sponge and a **very low density** (less than 0.8 g/cm^3). Their physical properties—particularly **high thermal resistance**, **large specific surface area**, and **good compressive strength**—make them ideal for applications such as **porous electrodes**, **catalyst supports**, and **thermal insulation panels**.

When the chemical composition of the foam contains a high amount of oxygen, the resulting carbon product is **glassy** (RVC: reticulated vitreous carbon). In this type of material, the connections between pores form a network. These foams generally have **very high porosity**, **extremely high permeability**, and **good mechanical strength**.



3/ Foams Used in Furniture

The furniture industry primarily uses foams in the following applications:

- Bedding (mattresses)
- Upholstered seating (sofas, armchairs, sofa beds, BZ beds, etc.)

To a lesser extent, foams can also be found in products such as lightly padded seats and bed bases.

This study focuses on the two main applications: **mattresses** and **upholstered seats**.

Desired characteristics include:

- Comfort
- Durability (minimal height loss, etc.)
- Safety (fire performance)

Manufacturers of **PU (polyurethane) foam** produce polyurethane by reacting **polyols** and **diisocyanates**, both derived from petrochemicals, in the presence of suitable catalysts and additives.

Polyurethane can be produced in either **solid** or **flexible** form, each with distinct applications. In furniture, both flexible and solid forms are used, with solid polyurethane typically reserved for sofa cushions and seating.

Special feature: Production of these foams is generally located close to the markets to avoid transporting **low-weight but high-volume materials** over long distances.

4/ Caramelization

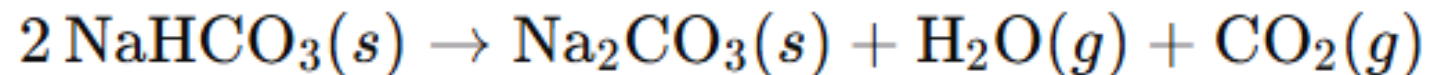
This is a technique that involves **polymerizing the sugar** present in a food so that it develops a **brown color** and a **nutty flavor** without being burned or carbonized.

Table 1. Caramelization Temperatures

Sugar	Fructose	Galactose	Glucose	Maltose	Sucrose
Temperature (°C)	110 °C	160 °C	160 °C	180 °C	160 °C

Sodium Bicarbonate (NaHCO₃):

Sodium bicarbonate is **biodegradable** and **non-toxic** to both the environment and human health. When heated, it **releases carbon dioxide** at 50°C and is converted into **sodium carbonate** at 100°C, according to the reaction:



7/ Sucrose and Sodium Bicarbonate Foam

Take **25 g of sucrose** and **0.5 g of sodium bicarbonate**. Place the sucrose in a container and heat it until it reaches its **boiling point**, at which it melts into a liquid. Continue heating until it **turns brown**, indicating that it has **caramelized** (the sugar molecules polymerize).

To transform the liquid into a **foam**, add a foaming agent—in this case, **sodium bicarbonate**. After **polymerization** and **cooling**, the mixture forms a **solid polymer foam**.

