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Special building materials

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Foreword

This handout is intended for first-year students of the LMD Master's degree in Civil Engineering materials and engineering students.

Based on the rich documentation available in the field, we have developed this work, presented as a support for the special building materials course. The course handout defines the building materials as well as their different types. It illustrates the basics of special building materials as a primary discipline in the field of civil engineering, where materials play a key role in every stage of the life of any structure from earthworks to final completion. By then defining the different physical and mechanical characteristics that allow the classification of these special materials taking into account these various parameters.

This document is a checklist for the student or practitioner, designer, builder or inspector to easily grasp the definitions and formulas useful for simple applications and to get a feel for the main concepts and also covering the main part of materials identification and classification.

The interested party is then invited to deepen their knowledge of the various concepts by consulting a bibliographic list proposed at the end of the document. The pedagogical, scientific and relational interests will be among the immediate benefits of this document.

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Chapter 1: Wood

1.1. Introduction

Wood has always been one of the most widely used materials for human needs, and with the progress of civilization and industry, its uses have become more and more varied and important. It owes these various uses to its technical properties. But it may, for various reasons, present defects which restrict its use.

Flexible and light, mechanically and chemically resistant, wood has many qualities that make it an excellent building material. These characteristics allow it to adapt to the most disparate fields of application. Its use has ecological, aesthetic, technical and economic advantages.

1.2. Description

Wood is a plant tissue, similar to a composite material, made up of cells, square or circular in shape, composed mainly of cellulose.

Chemically, wood almost always consists of 50% carbon, 42% oxygen, 6% hydrogen, 1% nitrogen, and 1% miscellaneous elements.

The cross-section of a tree trunk reveals three, sometimes four, concentric parts, from the outside to the inside:

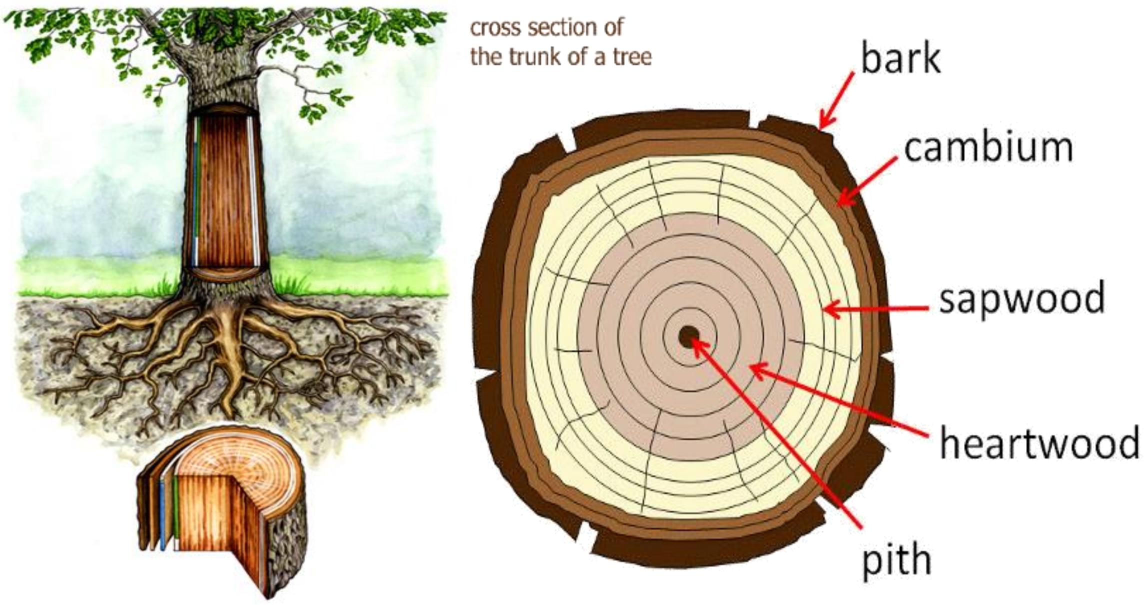


Figure 1.1: A tree cross-section

- ✓ **Bark: forms** the outer shell
- ✓ **The sapwood:** a thin, light-colored layer corresponding to the growing part (young wood)
- ✓ **Heartwood:** denser and harder main part, darker in color than the sapwood
- ✓ **Pith (sometimes!):** soft part, small in diameter, located in the center

Wood-yielding plant species are divided into two main groups

1.2.1. Deciduous trees (hardwood)

Are trees that produce well-developed leaves. Examples: oak, mulberry, poplar.

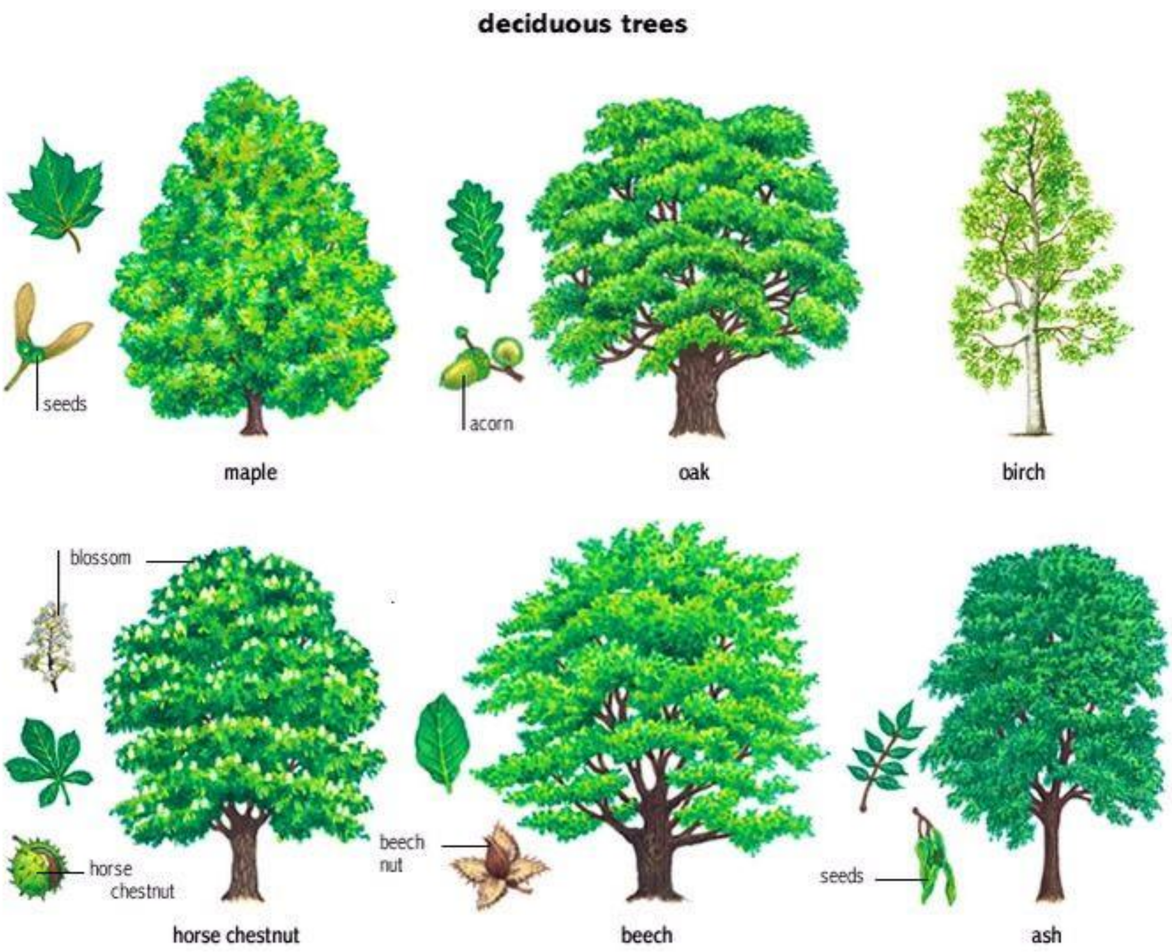


Figure 1.2: Deciduous trees (hardwood)

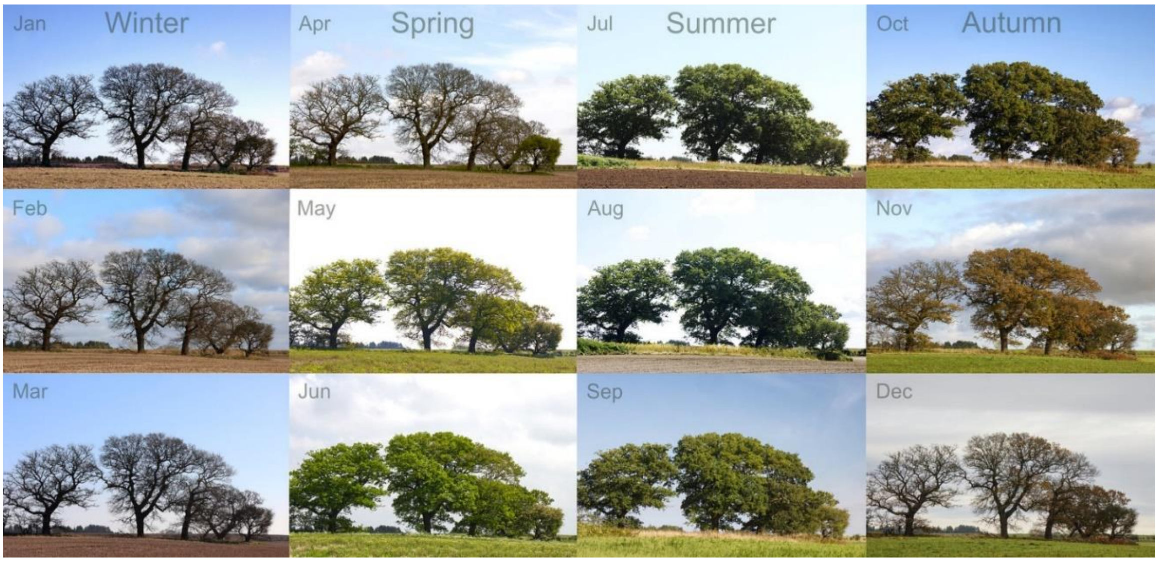


Figure 1.3: A year in the life oak trees

1.2.2. Coniferous trees (softwood)

Are trees whose leaves are mostly narrow and evergreen.

It is the dark green needles that give a dark color to the sides of the mountains. Shape of a cone.

Figure 1.4: Coniferous trees (softwood)

In the study where reconnaissance of a wood and observations must be made according to three perfectly defined plans:

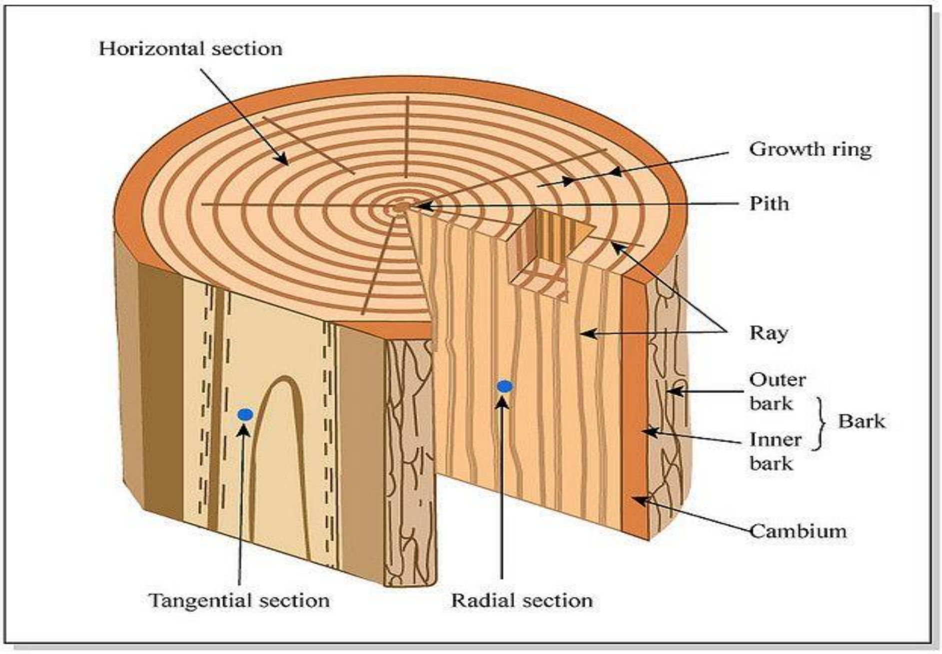


Figure 1.5: Different plans to adopted to observe a tree

- ✓ **the transverse plane (L),** perpendicular to the axis of the tree (standing wood);
- ✓ **the radial plane (R),** parallel to the axis passing through the structural center of the tree;
- ✓ **the tangential plane (T),** tangent to the growth rings.

Wood is a multi-layered composite material. This structure gives the material an anisotropic and heterogeneous character.

It results from this orthotropy that the complete characterization of wood in the mechanical sense is based on the determination of:

- ✓ 3 moduli of elasticity: E_L, E_R, E_T
- ✓ 3 Shear Modules: G_{LR}, G_{LT}, G_{RT}
- ✓ 6 Poisson coefficients : ν_{RT}, ν_{LT}, ν_{LR}, ν_{TR}, ν_{RL}, ν_{TL}.

1.3. Mechanical properties

As wood is a composite material, its strength depends on:

- ✓ The direction of the efforts exerted
- ✓ Of its water content
- ✓ Of its density
- ✓ Of course, by its nature

Wood is tested at 15% moisture content (take into account the actual moisture content: the higher it is, the lower the strength of the wood)

The higher the density, the stronger the resistance of the wood

Behavior of the wood in tension and Compression in the longitudinal direction:

- ✓ Weakness in tension
- ✓ Ductile Character in Compression

In compression, the tubular elements (L-direction) are subjected to micro-buckling explaining the differences in tensile / compressive strength.

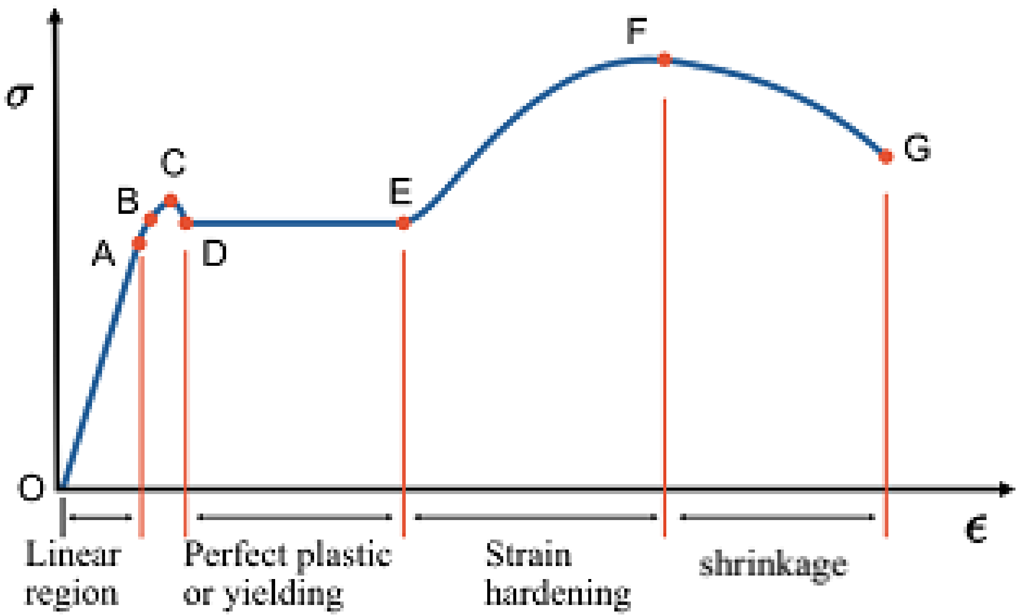


Figure 1.6: Stress-strain diagram for woods

The mechanical strength of the wood is classified according to the direction of the load

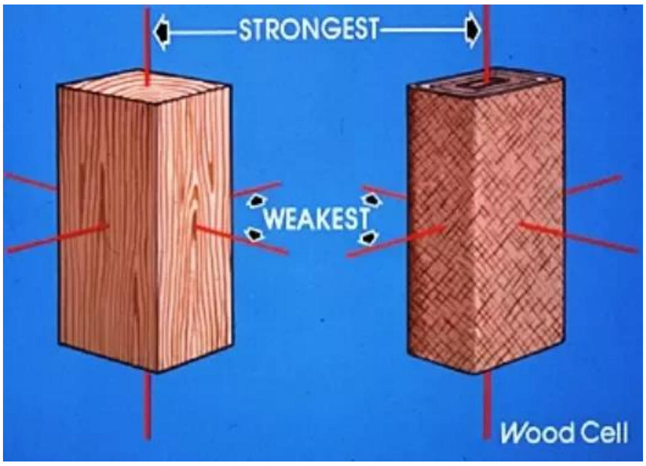


Figure 1.7: Load direction in the wood

Table 1.1: Mechanical resistance of wood.

Direction in relation to fibers	**Resistance**	
	Compression	**Traction**
longitudinal	Good	Very good
transverse	Weak	Almost non-existent

Permissible constraints for sizing wooden parts:

- ✓ Axial compression Ca
- ✓ The axial tension Ta
- ✓ Static bending F
- ✓ Longitudinal Shear C
- ✓ Transverse tension (without shear) Tt
- ✓ Transverse compression Ct

Resistance in the direction of the fibers:

- ✓ Wood resists 2 to 3 times better in tension than in compression
- ✓ In compression, the fibers move away from each other and tend to buckle

Resistance in the direction perpendicular to the direction of the fibers

- ✓ Wood does not resist tensile or compressive forces Modulus of elasticity of wood
- ✓ Is higher in tensile than in compression
- ✓ Decreases as temperature rises
- ✓ Decreases as humidity increases
- ✓ The deflection increases and can double in value when the wood is humid and hot
- ✓ The wood is resistant to shocks and vibrations   Use in seismic areas.

1.3.1. Comparison of the mechanical properties of wood with those of other building materials:

- ✓ Load-bearing poles
- ✓ We are looking for the lightest material (ease of processing), resistant to compression and buckling at limit load F, causing buckling

$$F = k\pi^2 \frac{EI}{L^2}$$

- ✓ For a straight cross-section geometry of the column, starting from the density d, the mass of the column takes the form:

$$m = k' \frac{d}{\sqrt{E}} L^2 \sqrt{F}$$

- ✓ This expression is equivalent to looking for a minimum m, √E/d ratio that is maximal. This ratio is then the quality criterion for a material used in the form of a pole.

Table 1.2: Material Performance Criteria

Material	**Elastic modulus E (MPa)**	**Density**	**Material Performance Criteria √E/d**
Steel	210 000	7.8	58
Aluminum	75 000	2.6	105
Concrete	11 500	2.6	41
Artificial composite material	75 000	1.5	182
Deciduous trees (hardwood)	10 000	0.4	250
Coniferous trees (softwood)	13 000	0.7	162

1.4. Physical properties

1.4.1. Humidity

This is the amount of water contained in the wood.

Humidity levels $H = \frac{Wh-Ws}{Ws} * 100$ % (Wh: wet mass; $W_{S:}$ dry mass)

The reference humidity level is 15%.

Depending on the temperature and, above all, the humidity of the ambient air, the wood stabilizes at an equilibrium humidity, known as hygroscopic equilibrium:

- ✓ At 20°C and 70% relative humidity (RH), which corresponds to a wood hygroscopic balance of approximately 13%
- ✓ Between 0 and 5 °C and 85% RH, which corresponds to a hygroscopic balance of the wood of the order of 19%.
- ✓ A wooden structure located outdoors (windows, shutters, etc.) will see its humidity tend towards 13% in summer, and towards 19% in winter
- ✓ In order for the dimensional variations of the wood to be minimal, its working humidity must be between 15 and 16%.

Table 1.3: Standardized qualifications of wood according to moisture content (NF B51-002)

Humidity	Qualification
Above fiber saturation point (30%)	Green wood
From 30 to 23%	Semi-dry wood
From 22 to 18%	Commercially dry
From 17 to 13%	Air-dried wood
Below 13%	Desiccated
0%	Anhydrous

In order to prevent the wood from shrinking after installation, it is essential to dry it before any machining and construction use and to use the wood as close as possible to what will be its equilibrium moisture.

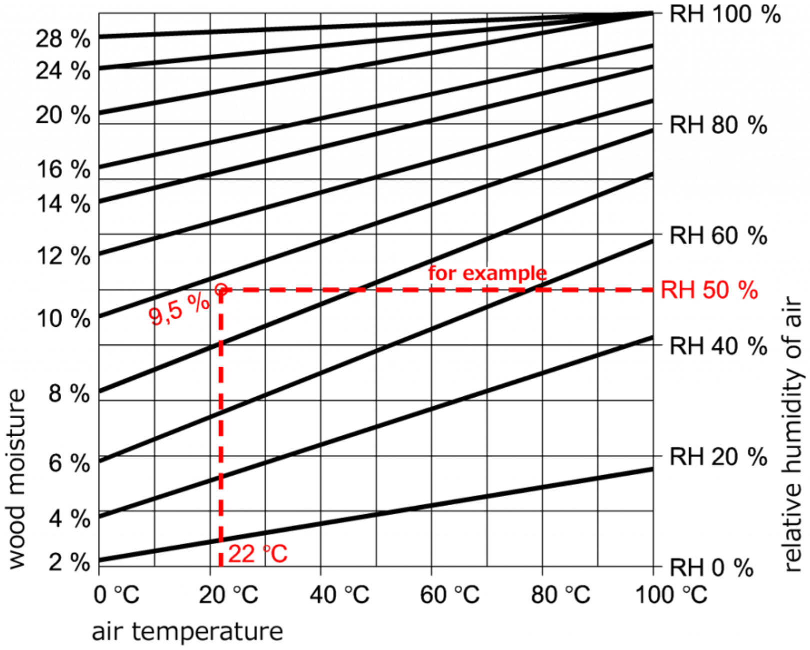


Figure 1.8: Moisture content in the wood as function of temperature and relative air humidity

This curve is used to determine the moisture content of the wood as a function of the temperature and humidity level of the ambient air

1.4.2. Density

This is the most important parameter for characterizing a wood

Wood is a relatively lightweight building material, compared to common building materials

The density of wood varies greatly depending on its degree of moisture; it depends on the type of wood. It is normally expressed for a moisture content equal to 15%

- ✓ It varies for hardwoods (deciduous trees) from 400 to 900 kg/m^3
- ✓ It varies for softwoods (coniferous trees) from 350 to 900 kg/m^3

1.4.3. Temperature

Wood is all at once:

- ✓ A combustible material,
- ✓ Poor thermal conductor,

- ✓ Low thermal expansion
- ✓ Highly safe mechanical behavior in the event of a fire in buildings

1.4.3.1. Thermal expansion's coefficient

The coefficient of linear thermal expansion characterizes the relative increase in the length of an element at a temperature of 1 °C

In the case of wood, the thermal expansion is in any case lower than the shrinkage due to the loss of moisture (it does not play a role in the structures)

1.4.3.2. Thermal conductivity

Since wood has a low thermal conductivity, it is a very good thermal insulator.

Table 1.4: Thermal conductivity of woods in comparison with other materials

Alu	Steel	Granite	Concrete	Plaster	Oak	Fir	Cork	Balsa	Glass Wool
230	52	3.5	1.75	0.5	0.23	0.12	0.10	0.054	0.04

1.5. Behavior and resistance of wood to fire

Contrary to popular belief, wood has advantages in the event of a fire:

- ✓ It doesn't deform,
- ✓ Does not emit toxic gases,
- ✓ It burns slowly, allowing the necessary time for people to evacuate

In fact, its fire behavior is completely predictable. It is important to know that:

- ✓ Wood is the preferred material for firefighters,
- ✓ The thermal expansion of wood is 3 times lower than that of steel and concrete (under the action of heat, a metal structure tends to deform or even collapse. A timber frame does not deform or deforms only slightly and continues to perform its load-bearing functions)
- ✓ The thermal conductivity of wood is low. It is 12 times more insulating than concrete, 350 times more than steel, 1500 times more than aluminum.

The carbonized layer, which has an even lower thermal conductivity, protects the inner layers and slows down the advance of the fire.

The behavior of wood in fire is defined according to several criteria:

- ✓ Calorific value,
- ✓ Reaction to fire,
- ✓ Combustion speed,
- ✓ Fire resistance

1.5.1. The calorific value of wood

The calorific value of a material is the energy released by the complete combustion of the unit mass of that material.

By convention, the calorific value of wood and its derivatives is 17 MJ/kg (4000 kcal/kg) and varies little from one species to another.

This notion of calorific value is interesting when wood is used as fuel, but does not affect the behavior of the wood used during a fire.

1.5.2. The wood's reaction to fire

Reaction to fire is defined as the ability of a material, under specific conditions, to ignite and spread the fire through its own flames. Building materials are classified into 5 classes with regard to their reaction to fire:

Table 1.5: Fire classification of materials

Fire Class	**Material's behavior**
M0	Non-combustible
M1	Non-flammable
M2	Hardly flammable
M3	Moderately flammable
M4	Highly flammable

Wood and wood-based panels are always classified as M3 or M4. Fireproofing processes on the surface (varnish or paint) make it possible to achieve an M2 or M1 classification.

When burning a piece of solid wood, the formation of a surface layer of charcoal with very low thermal conductivity, protects the core of the section and prolongs the mechanical characteristics.

1.5.2.1. What is the difference between M1 and M0?

The M1 classification characterizes a material that does not give off any flame when burned. In this case, although combustible (a black spot corresponding to the charred area is spreading), it does not participate in the spread of the fire and does not create panic among the occupants of the place where it develops. (materials for shops, museums, theatres, etc.)

The M0 classification "non-combustible" can never be achieved by wood or derived materials because their calorific value is higher than the threshold of 2.5 MJ/kg required for the M0 classification.

M0 materials: Glass, concrete, brick, plaster, iron, cast iron, steel, aluminum, copper, zinc, lead, ceramic products

1.5.3. Wood burning speed

An important concept in the field of fire safety is the rate of combustion of the materials used. The rate of combustion corresponds to the thickness of the material, which is degraded, over a given period of time, by the action of heat and no longer exhibits mechanical strength.

Table 1.6: Wood burning speed

Wood	**Combustion rate**
Lumber (construction wood)	
Natural wood (fir, spruce, Scots pine, oak, etc.)	0.7 mm/min
Glued laminated timber	0.7 mm/min
Interior carpentry wood	
Hard species (oak, … etc.)	0.5 mm/min
Other deciduous or coniferous species	0.6 mm/min

1.5.4. Wood resistance to fire

The fire resistance of building elements refers to their ability to maintain their insulating or load-bearing role during the time required for evacuation, rescue and firefighting. The classification is assigned according to the length of time (1/4 hour, 1/2 hour, 3/4 hour,…etc.) during which the element has maintained its properties according to three criteria:

- ✓ Mechanical resistance,
- ✓ Flame and hot or flammable gas tightness,
- ✓ Thermal insulation

These concepts apply to different types of building elements, such as structures, door assemblies, or wall elements; The following characters are defined as:

- ✓ Fire stable: retains its mechanical strength for the specified time.
- ✓ Flame shield: fire-resistant and impervious to flames and flammable hot gases
- ✓ Firewall: in addition to the two previous properties, it has the character of thermal insulator

1.6. Sustainability and preservation

The structure of the wood (cellulosic) exposes it to attacks by certain living organisms (insects and fungi). However, it is important to know that:

- ✓ Wood is only affected when it is used in an enclosed place, without ventilation, and the hygiene and maintenance conditions are defective
- ✓ No fungus can attack dry wood, (wood with a moisture content of less than 22%)
- ✓ It is always preferable to avoid permanent contact of the wood with moisture
- ✓ Wood contains two distinct parts: sapwood (the outer part of the tree) and perfect wood (the inner part of the tree). While the sapwood of all woods is perishable, the perfect woods of certain species are very resistant. Removing the sapwood allows these woods to be used without any treatment, even outdoors. This is referred to as sapwood purged wood.

1.6.1. Degradation agents

There are two types of biological wood degradation agents:

- ✓ Fungi,
- ✓ insects.

1.6.1.1. Fungi

Can only attack wood with a moisture content greater than 22% The most common fungi are:

- ✓ Mold, discoloring agents that only cause aesthetic damage

Figure 1.9: Wood damaged by mold

- ✓ Scalding and rotting that cause structural damage to the wood.

Figure 1.10: Cube-rot

The presence of fungi can be indicated by the following clues:

- ✓ Loss of wood structure,
- ✓ Abnormal discoloration
- ✓ A characteristic smell,
- ✓ A change in the appearance of the wood (softening)
- ✓ The presence of felting and/or filaments
- ✓ A hollow sound when you hit the wood

1.6.1.2. Insects with wood-boring larvae

The insects develop in the following cycle:

- ✓ A female comes to lay eggs in the woods,
- ✓ The eggs hatch and develop into larvae. **These are the larvae that feed on the wood and dig tunnels in it.**
- ✓ The larvae develop into insects. These insects only live for two weeks. They do not feed, but mate and in turn lay eggs in the wood

Termites constantly flee light. Their main food is cellulose. It is the adult termites which degrade the wood and not the larvae.

1.6.2. Wood treatment

There are three groups of products for treating wood:

- ✓ Products based on synthetic organic substances. These are the most toxic and commonly used.
- ✓ Products based on water-soluble salts. Silicofluorides, arsenates and chromium salts, which are highly toxic. Boron salts, used as a preventive measure, are not very toxic and are not air diffused.
- ✓ Natural oily resin-based products that allow the pores of the wood to be clogged and reduce the possibility of attack. No risk to health.

Method of curative treatment of wood by injection	
Wood cleaning (dust removal)	Prepares the wood to receive the treatment product (the cleaner the wood, and the better the penetration rate of the product).
Logging	Removal of sapwood or worm-eaten wood.
	
Drilling	It allows the wood to be probed. Placement of an injector through which the treatment product is injected.
	
Spraying (injection)	A sustained injection is performed. It helps prevent new eggs and kills the larva that has become adult when it emerges from the wood, thanks to the high penetration rate of the product.
	
Surface Application	A double spray is carried out over the entire surface of all the wooden pieces of the frame. It will help protect the pieces of wood from new insect spawning and eliminate larvae close to the surface of the wood.
	

1.7. Use of wood in construction

1.7.1. Solid wood

1.7.1.1. Woodworking

Solid wood is essentially shaped by material removal, although it may be bent. In addition to finishing machines (sander), the main machines used are:

- ✓ The jointer;
- ✓ The thickness planer;
- ✓ The circular saw;
- ✓ The band saw;
- ✓ The Sensitive Drill;
- ✓ The tour;
- ✓ The spinning top.

1.7.1.2. Solid wood construction

Solid wood construction is when natural wood is used on either side of the panels used.

Joints are used to join wooden planks. The joints can be screwed, dowled or glued. These systems may or may not be combined.

The following three assemblies (shown as examples) are usually glued.

Figure I.11: Joints used in solid wood

1.7.1.3. Structural timber

For structural or framing elements, wood is always used in the length of the fiber.

Figure 1.12: Structural timber

1.7.1.4. Exterior cladding wood

Exterior cladding is the element fixed to the frame, and directly exposed to the weather, whose function is to protect the building from bad weather.

Figure 1.13: Exterior cladding wood

1.7.1.5. Interior cladding wood

Parquet

Stairs

Floor slabs / Wall panels

Figure 1.14: Examples of interieur cladding wood

1.7.2. Wood products

The purpose of the manufacture of wood products is to:

- ✓ to use wood with a small cross-section that is easy to produce,
- ✓ use waste from the wood industry
- ✓ materials derived from sawing: glued laminated
- ✓ Like a giant mille-feuille, laminates combine several strips of solid wood (3.5 - 4.5 cm thick) by gluing flat and with parallel threads
- ✓ It is known for its technical performance, which is often superior to that of solid wood
- ✓ They are found in beams with long spans

Figure 1.15: Glulam wood

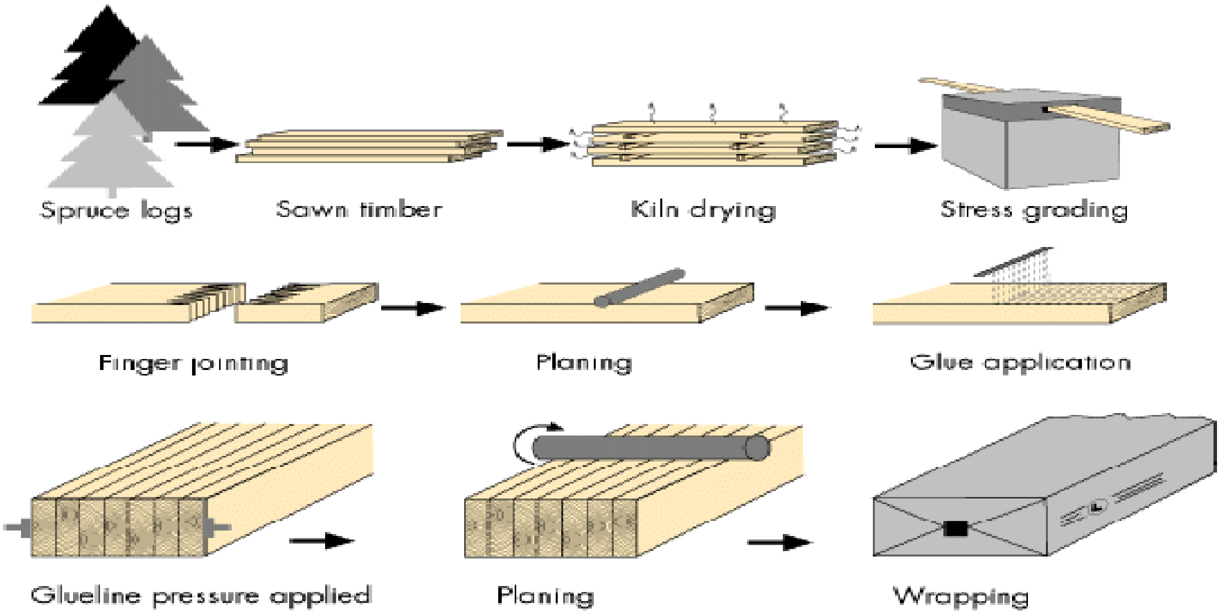


Figure 1.16: Glulam wood manufacturing process

1.7.2.1. Materials derived from peeling or slicing wood

These are panels obtained by gluing a certain number of veneers together. Their numbers and orientations vary according to the products desired.

These include plywood or oriented stranded panels.

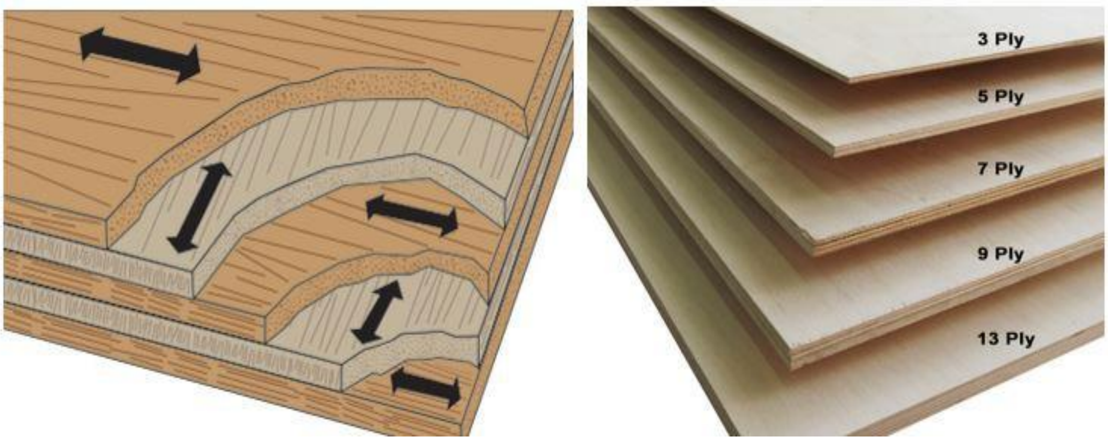


Figure 1.17: Plywood

1.7.2.2. Materials derived from crushing

These panels are obtained by gluing and pressing wood chips and particles.

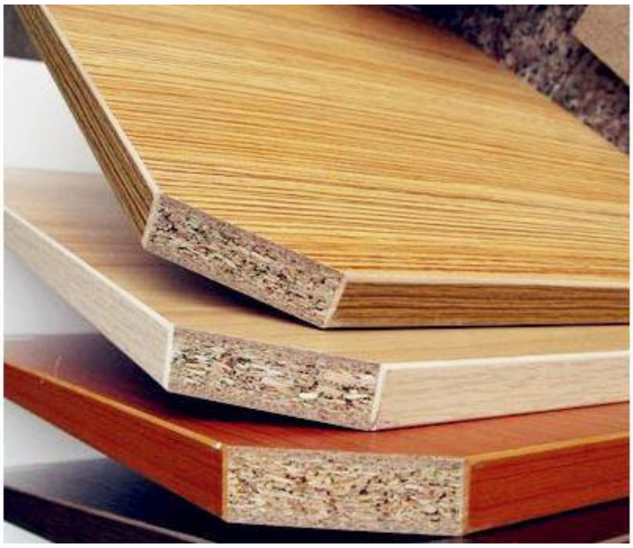


Figure 1.18: Particle Board

1.7.2.3. Composite Products

This family includes many products that combine wood with other materials (metal, wood-based materials)

Examples: triangulated or thin composite beams, prefabricated floor elements, insulating panels for roof supports

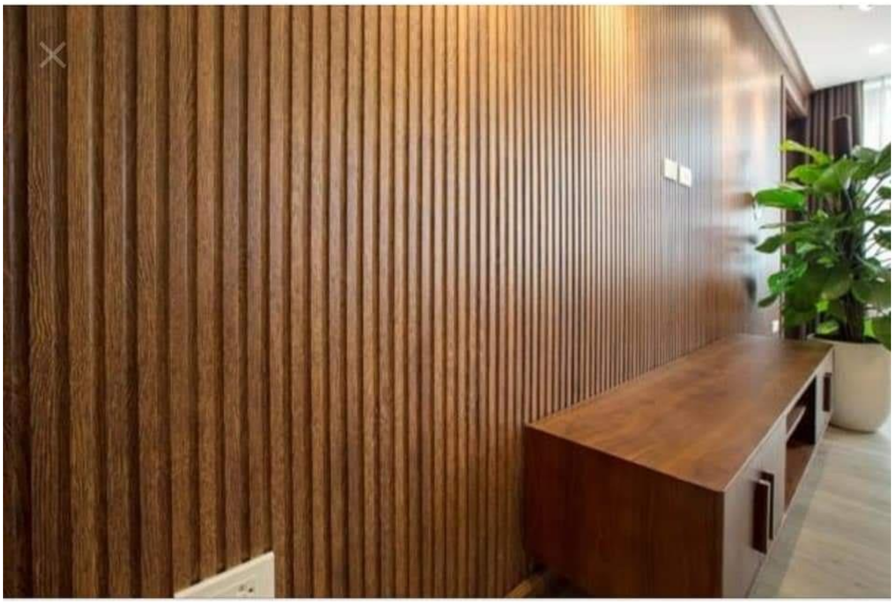


Figure 1.19: Wooden plastic composite wall panel

Chapter 2: Glass

2.1. General composition

Some elements such as silicon and boron can form a glass by their combination with oxygen (oxide of, etc.) and by heating them to a very high temperature. These oxides are called "forming" oxides because they form the backbone of the glass.

They are combined with other so-called "modifiers" which are:

- ✓ – "Fluxes" that lower the melting temperature of the forming oxides (silica = 1730°C).
- ✓ – "Stabilizers" that modify the physical properties of the glass.

Silicon is the most abundant element in the Earth's crust after oxygen, accounting for 25.7% of its mass. It does not exist in a free state, but in the form of compounds: in the form of silicon dioxide (SiO2), silica (in sand, quartz, cristobalite, etc.) or other silicates (in feldspars, kaolinite, etc.)

Boron is abundantly found in nature in the form of borax. Borax ore is usually found in old, dry lakes where water has evaporated.

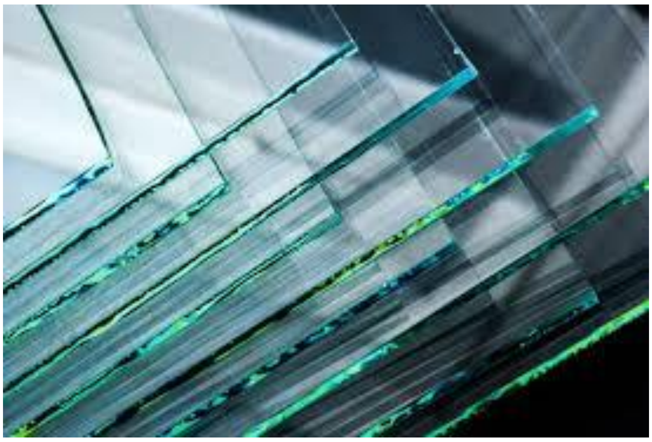


Figure 2.1: Glass sheets

2.2. Glass dyes

2.2.1. Direct Coloring

Color is given by adding mixtures of metal oxides that absorb certain wavelengths of light. Iron oxide, for example, absorbs red and gives green. The tone and intensity of a color depends on the nature and quantity of the dyes as well as the composition of the glass itself.

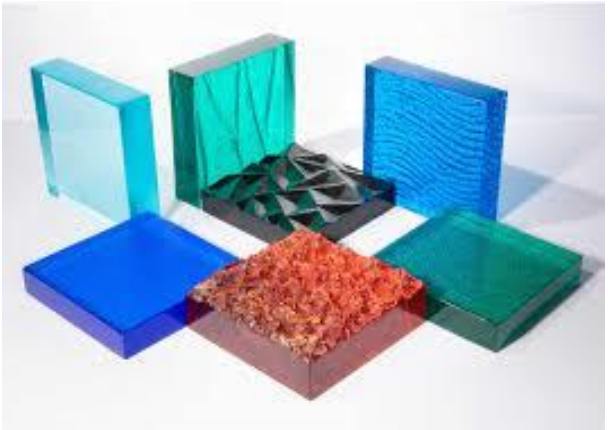


Figure 2.2: Colored Glass

2.2.2. Indirect Coloring

Some oxides are suspended in the vitreous mass during melting. The coloring appears when the glass is heated to around 600°C. The heat causes the particles to expand which highlights the color in the desired wavelength.

Figure 2.3: Different colors of Glass

Table 2.1: Different colors of the lenses depending on the additive used.

ADDITIVE	COLOUR
Cobalt 0.025 to 0.1%	Blue
Manganese	Eliminates the green tint produced by amethyst iron
Selenium	Fades the red tint
Tin oxide, Antimony oxides Arsenic oxides	Opaque white (imitation Venetian porcelain)
Copper oxide (2 to 3%)	Turquoise
Metallic Copper	Very dark red, opaque golden ruby
Nickel	Blues, purples, or even blacks
Titanium	Yellow-brown
Metallic Gold (0.001%)	Currant ruby
Uranium (0.1 to 2%)	Fluorescent yellow or green
Silver-based compounds, silver nitrate	Orange-red to yellow

2.3. Classification of glasses according to their composition

2.3.1. Soda-lime glasses (Most Common)

Figure 2.4: Soda-lime Glass

Composition: Silica (72%) + soda (13%) + lime (5%)

Softening temperature = 700°C.

Coefficient of expansion from 0 to 300°C: 86 x 10-7 (high)

- ✓ Characteristics: Good chemical stability but susceptible to thermal shock.
- ✓ Use: Flat and hollow glasses, light bulbs and bottles.

2.3.2. Borosilicate glasses

Figure 2.5: Borosilicate glasses

Composition: Silica (80%) + boric anhydride (13%) + soda (4%) + alumina (3%)

Softening temperature = 820°C.

Coefficient of expansion from 0 to 300°C: 32 x 10-7 (low)

- ✓ Features: Good resistance to thermal shock.
- ✓ Use: Laboratory and kitchen utensils (resistance to heat and chemical agents), insulation (glass fibers), storage of radioactive waste.

2.3.3. Leaded glass

Figure 2.6: Leaded glass

Composition: Silica (62%) + Lead Oxide (21%) + Potash (7%)

If lead oxide > 24% you will get the Crystal

Softening temperature = 630°C.

Coefficient of expansion from 0 to 300°C: 90 x 10-7 (very high)

- ✓ Characteristics: Crystal clear, sonorous, highly resistant to devitrification.
- ✓ Use: Art tumblers and glassware, televisions and electronics, X-ray protection (high lead content).

2.3.4. Silica Glass

Figure 2.7: Silica Glass

Composition: Minimum 96% silica.

Softening temperature = 1700°C.

Coefficient of expansion from 0 to 300°C: 5.6 x 10-7 (very low)

- ✓ Characteristics: High purity (optical transparency), high resistance to high temperatures, corrosion and thermal shock.
- ✓ Usage: Halogen lamp tubes, optical elements.

2.3.5. Glass-ceramics (crystalline vitro)

Figure 2.8: Glass-ceramics

Composition: Silica (75%) + Alumina (15%) + Titanium Salt (5%) + Lithium Oxide (3%)

- ✓ Features: High breaking strength, highly resistant to thermal shock.
- ✓ Use: Fire-resistant culinary glassware (hobs), optical.

2.4. Chemical properties of glasses

- ✓ Glass is a material with a very high chemical inertness.

However, hydrofluoric acid is one of the only known liquids (along with a few alkaline products) capable of dissolving glass, which consists mainly of silica.

Hydrofluoric acid is a highly corrosive and toxic aqueous solution of hydrogen fluoride.

Hydrofluoric acid is used to deeply etch glass.

- ✓ Fire has no chemical effect on glass: it is non-combustible.
- ✓ The water acts on the silicates which, as they decompose, form a deposit on the surface that gradually becomes opaque; The glass loses its transparency.
- ✓ The carbonic acid in the air reacts with the alkali silicates, resulting in a whitish deposit on the surface of the glass.
- ✓ When exposed to light and ultraviolet light, some glasses become colored or discolored.

2.5. Physical properties of glasses

1) Density ρ =2700 kg/m³
2) Density (depends on components) 2.7 (1 m³ weighs 2.7 t, 1 m² x 1mm sheet weighs 2.7 kg)
3) Hardness (on Mohs scale) 6.5, Glass is a hard material but "fragile" in the brittle sense. Only diamonds and tungsten carbide can scratch it. The hardest is that of Bohemia, the softest is the crystal.
4) Waterproofing, Although extremely waterproof, glass remains porous for certain liquids, such as kerosene. However, a porous texture can be created by shaping (inclusion of gases): this is foam glass.
5) Resilience (Impact Resistance) 1500 to 2500 Pa, (energy required to produce the rupture of a sample). We speak of "safety glass" when it reduces the risk of injury, in the event of breakage (laminated, tempered, reinforced glazing).
6) Compressive strength > to 1000 MPa (very high), To break a cube of 1 cm on each side, the load required is 10 t.
7) Transparency, Glass is transparent, but it has a refractive index equal to 1.5.

2.6. Mechanical properties of glasses

1) Elasticity, Glass is a fragile material, because if you apply increasing force to it, it breaks suddenly. Its mechanical properties are highly dependent on its level of deterioration. It is perfectly elastic since it does not show permanent deformation.
2) Young's modulus E (or modulus of elasticity): $7x\ 10^5$ daN/cm² = 70 GPa. This modulus expresses the theoretical tensile force F for lengthening a glass specimen to twice its initial length.
3) Poisson's ratio ν 0.20 to 0.22. This coefficient characterizes the narrowing of the cross-section of a specimen subjected to elongation. This is the relationship between shrinkage and elongation.
4) Very high compressive strength, much higher than tensile strength.
5) Resistance to mechanical shocks, This is a weak point of glass (toughness is quite low).
6) Viscosity. What more accurately defines a "glass" is its physical state and the process that leads to it.

In thermodynamics, glass is considered to be obtained from a supercooled liquid phase solidified at the glass transition point. The viscosity of a material characterizes its ability to flow.

Viscosity is certainly the most important property of glass, in terms of its melting, manufacturing and annealing.

Namely that glass, even heavily heated, is never fluid, it gradually becomes malleable, then from 1000° to 1400°C, it becomes viscous.

In the opposite direction, as it cools, the material becomes less and less viscous, it becomes plastic again, (it can be deformed because it is still deformable) and then it finally becomes solid and rigid again.

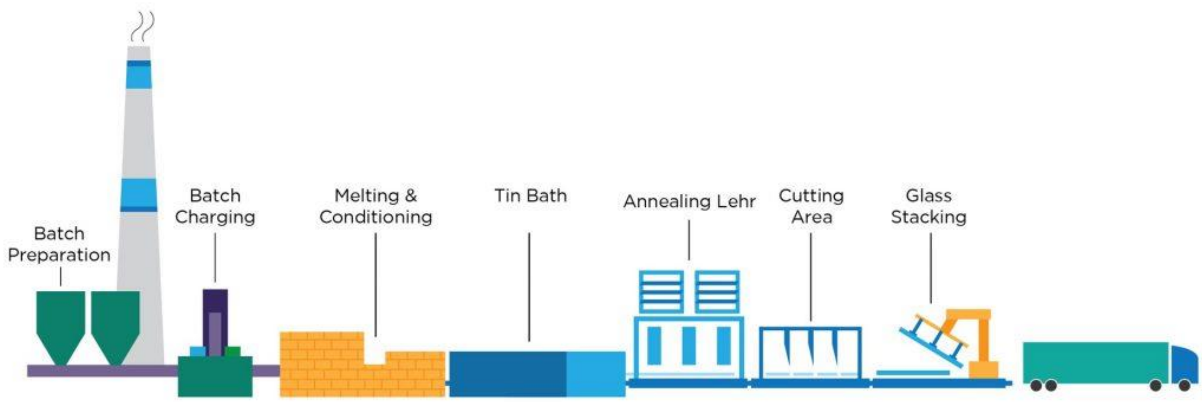
7) Viscoelasticity. In the glass transition range (glass gradually becomes more viscous and changes from liquid to solid state), the behavior of the glass is viscoelastic.

2.7. Principle of glass manufacturing - float-glass process

In 1959, the English firm Pilkington developed a revolutionary float glass process, which made it possible to obtain glass and glass of exceptional size and quality.

It is the most widely used manufacturing method (automotive, building, glazing, mirroring, etc.).

This process is based on the use of molten tin, which is the only liquid that can support glass without reacting with it and has a sufficiently low vapor pressure.



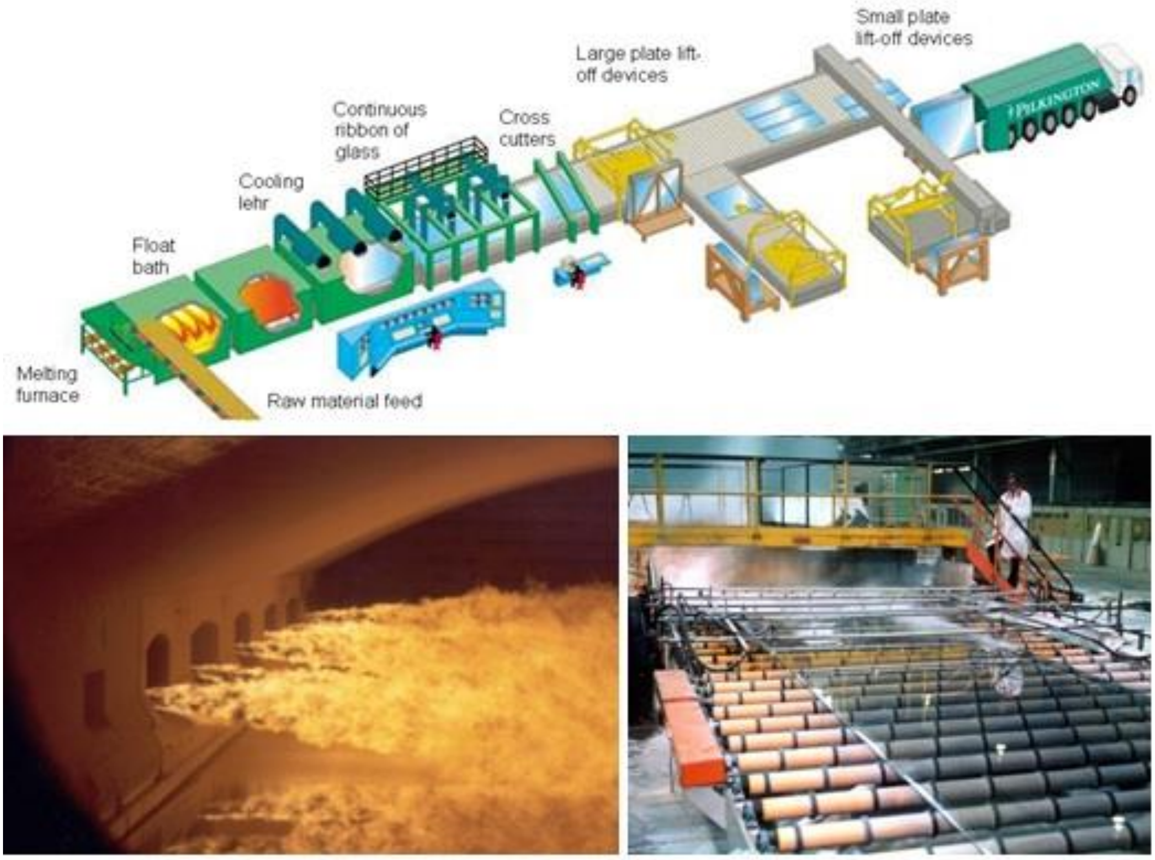


Figure 2.9: Float-glass process

2.7.1. Preparation of the composition

The first step is to dose and mix the raw materials for smelting.

Pieces of recycled glass, cullet, from the plate cutting system are added to the composition of raw materials. Each batch contains about 10 to 30% cullet.

2.7.2. Melting in the furnace

The composition is heated by natural gas burners to about 1650°C. The raw materials are first melted, the raw glass paste is then degassed and then mechanically homogenized and finally cooled slowly in the downstream part of the furnace called the working basin.

The chemically and thermally homogeneous glass then leaves the furnace and pours with a controlled flow into the tin bath to take on its geometrical characteristics.

2.7.3. The Tin Bath

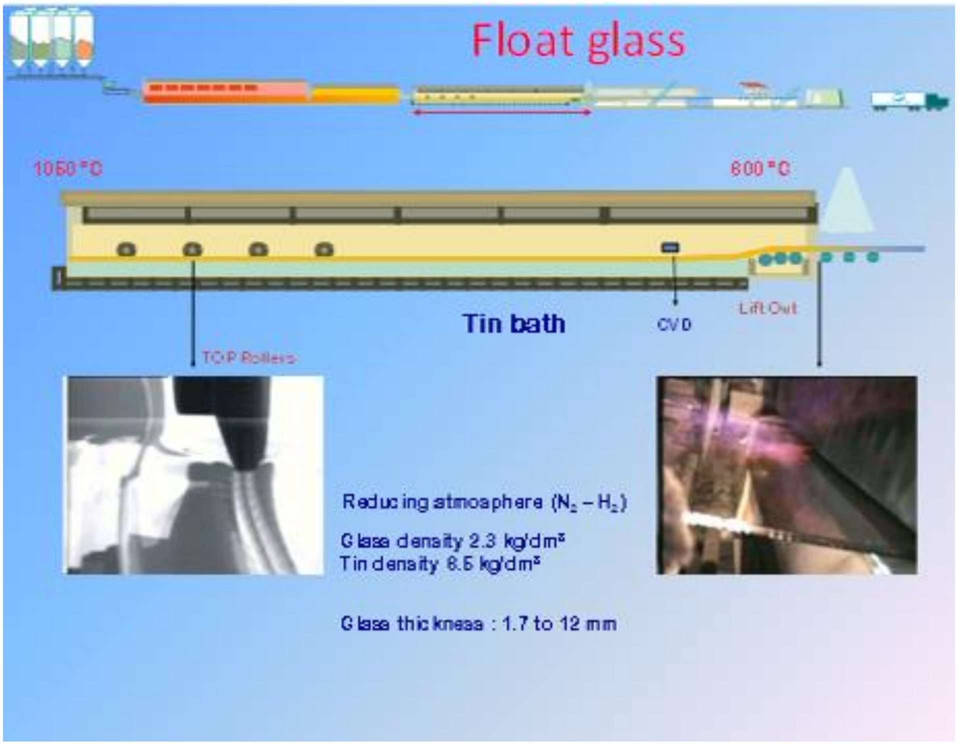


Figure 2.10: Tin Bath

When it comes out of the furnace, the molten glass is directed into a channel from where it flows over a bath of molten tin.

The bath is a sealed system with a controlled atmosphere composed of nitrogen and hydrogen.

The bath is approximately 60m long by 8m wide with a scroll speed of up to 25m/min. The bath contains almost 200 tons of pure tin, melted at an average temperature of 800°C.

Glass floats on tin because its density is lower than that of metal (hence the name of the process). This is a long, continuous ribbon.

The result is a sheet of glass with parallel faces because there is no external constraint. Fire polishes the top side while molten pewter polishes the bottom side. The thickness of the sheets varies between 1.1 and 19 millimeters.

The tin bath has 3 zones (heating zone, fire polishing, cooling zone) and each zone corresponds to a temperature that is important for the quality of the glass.

The cooling area is important because, at the exit of the tin bath, the glass must be hard enough to be handled by the bearings without the bearings leaving marks on the underside.

The tin bath must therefore be long enough for the temperature of the entire glass ribbon to decrease from 1050°C to 600°C.

The tin bath should also be smooth and flat so that the glass ribbon has parallel faces. Otherwise, imperfections form in the glass that deteriorate its quality and make it brittle. This is why the atmosphere inside is neutral or weakly reducing to prevent tin oxidation. The surface tension must also be constant because the thickness of the sheet depends on it.

2.7.4. Annealing and Controlled Cooling

Figure 2.11: Annealing and Controlled Cooling

The glass ribbon leaves the bath at a temperature of 600°C at which it is strong enough to be transported on rollers. However, it cannot be cooled freely in the open air without the differential cooling between the outer surfaces and the core of the ribbon causing stresses that can lead to its spontaneous breakage. It is therefore necessary to reduce the temperature of the glass ribbon to room temperature, in a gradual and controlled manner (annealing) depending on its thickness.

This is done in a tunnel about 120 m long and 6 m wide called a drying rack. Heating resistors and fans allow precise control of the temperature profile across the entire width of the glass ribbon. The glass is transported on rollers driven by a mechanical system.

2.7.5. Cutting and Packaging Line

Figure 2.12: Cutting and Packaging Line

When the glass leaves the drying rack, it goes through an in-line inspection system to detect any defects. The edges of the tape are then detached and the ribbon is automatically cut into plates of different sizes. The unused glass, the cullet, is recycled into the composition. The glass plates are treated so that they can be stored without damage before being lifted and then stacked. The glass plates placed on easels are then transferred to the storage warehouse or for shipment to the customer.

2.7.6. The advantages of the process

The flotation technique makes it possible to obtain perfectly flat and transparent sheets while avoiding the smoothing and polishing operations necessary with other processes.

This is a significant financial gain as these operations are costly in terms of equipment, raw materials and energy. This also accelerates the manufacturing process, as the output speed is between 5 and 10 times higher than in the case of stretching.

It is therefore a very efficient process and that is why it has so quickly become the standard for the manufacture of flat glass.

2.8. Tempering glass

Flat glass shatters easily when subjected to bending stresses.

A flat glass becomes a safety product when it undergoes a tempering process. This makes it five times more resistant to bending and thermal shock.

There are two treatment options: 1) thermal tempering, 2) chemical tempering.

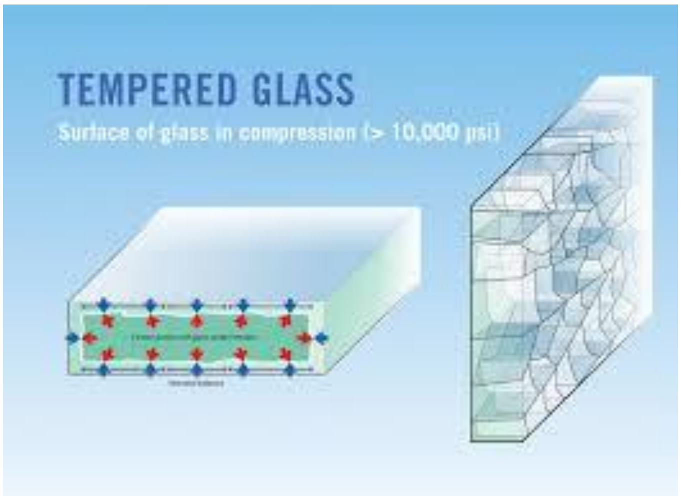


Figure 2.13: Tempered glass

2.8.1. Thermal tempering

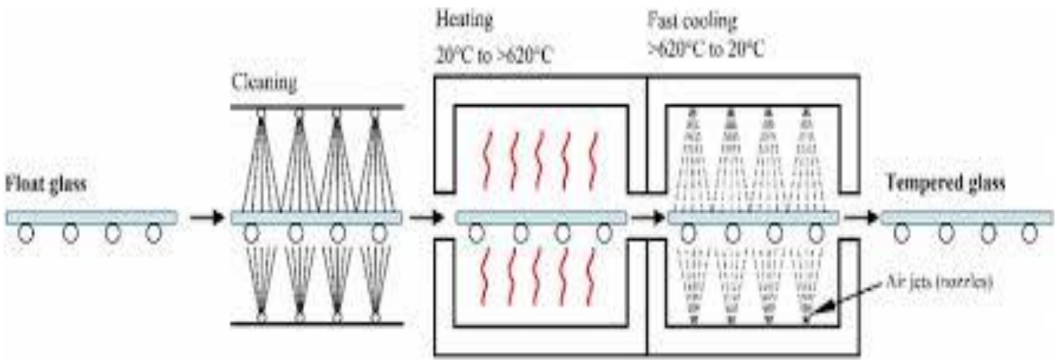


Figure 2.14: Thermal tempering process

The glass volume is heated up to 700°C (the temperature at which the molecules can move) and then cooled very quickly and evenly to 300°C by jets of cold air.

When the inner regions contract, they "pull" on the surface and create a residual compressive tension.

The process creates permanent tensions in the thickness of the glass.

There are three layers of tension that compensate for the reverse stresses suffered by a possible impact, by bending.

Flexural strength is significantly increased. An 8 mm glazing resists a 500g steel ball falling from a height of 2 meters while a height of 30 cm would be enough to break untempered glass.

The glass shatters into a multitude of small, non-sharp shards when broken.

The risk of breakage due to thermal shock is considerably reduced. If non-tempered glass is not heated evenly (from a temperature difference of 30°C between two points), internal stresses can cause it to break. Tempered glass, on the other hand, is resistant to temperature variations of 200°C. It can be exposed to a temperature of up to 250°C.

Its density decreases.

It can no longer be cut or pierced at the risk of shattering.

It is possible to soak it by "annealing" it (heating up and then cooling slowly).

2.8.2. Chemical tempering

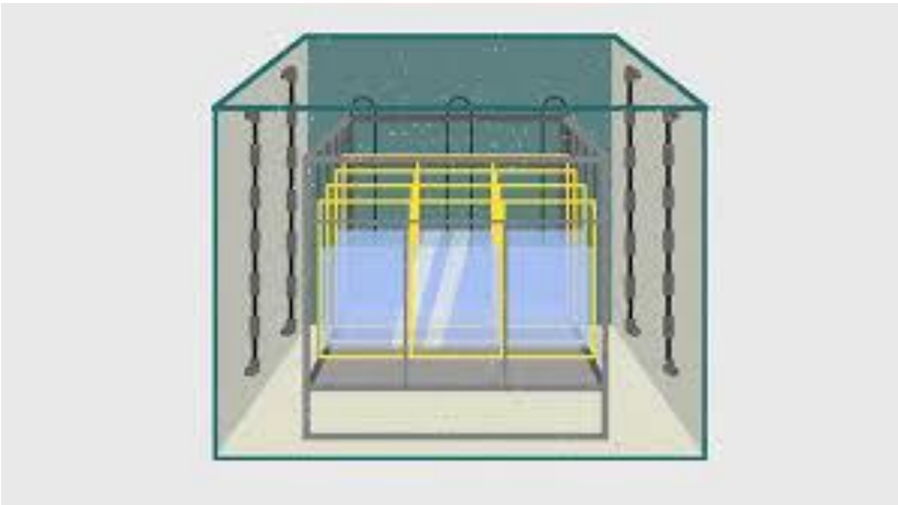


Figure 2.15: Chemical tempering process

It is easier to control than thermal tempering, but it is more expensive and reserved for special glasses (aircraft window).

The glass is immersed in a salt bath (molten salt of potash or potassium nitrate) at 400°C for a period of 12 to 36 hours (or more depending on the desired resistance). Very high compression on a very thin surface thickness.

Glass is much stronger than thermally tempered glass.

As it is a superficial treatment, chemically tempered glass has the typical fragmentation of normal glass when broken.

Chemical tempering allows the processing of thin sheets (2-3 mm) that cannot be tempered with the thermal process.

2.9. Glass products in the building industry

2.9.1. Window glass

- ✓ Classic building works.
- ✓ Tempered glass is used for lighting workshops, offices and buildings.

Figure 2.16: Window glass

2.9.2. Glass

- ✓ For shop installations, in large building façade panels
- ✓ It can be transparent, tinted, reflective, filtering, etc.
- ✓ Tempered glass or glass is used for doors (framed or unframed), interior partitions, frameless windows, stair treads, etc.

Figure 2.17: Façade panels

2.9.3. Bricks, paving stones and tiles

There are solid bricks, hollow bricks, for the manufacture of interior or exterior vertical partitions, horizontal slabs, floors

Translucent concrete is a combination of glass and mortar

Figure 2.18: Glass blocks

2.9.4. Profiled or corrugated glass

Profiled glass is manufactured, often in a U-shape and can be reinforced

Corrugated glass plates: one side can be smooth and the other ridged. They are used in roofing, shedding and cladding. They are connected to sheet metal.

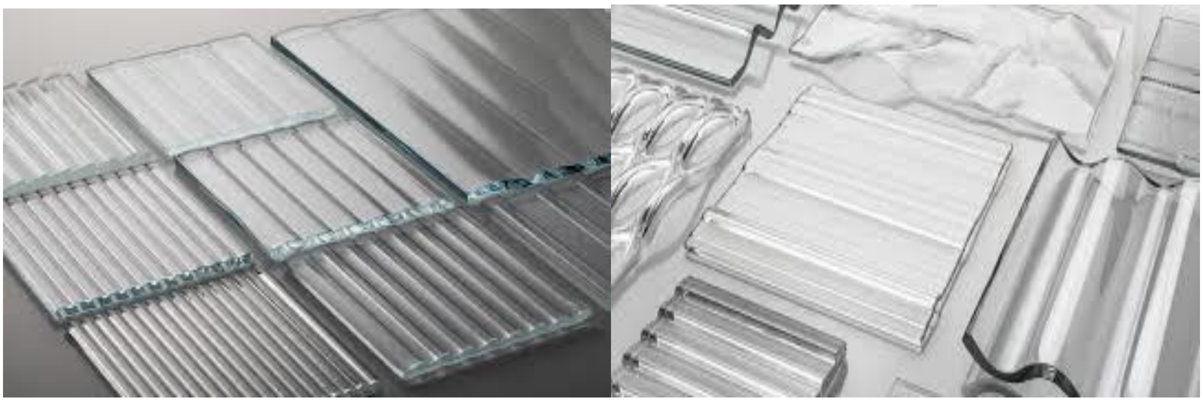


Figure 2.18: Profiled and Corrugated glass panels

2.9.5. Composite Products: Glazing

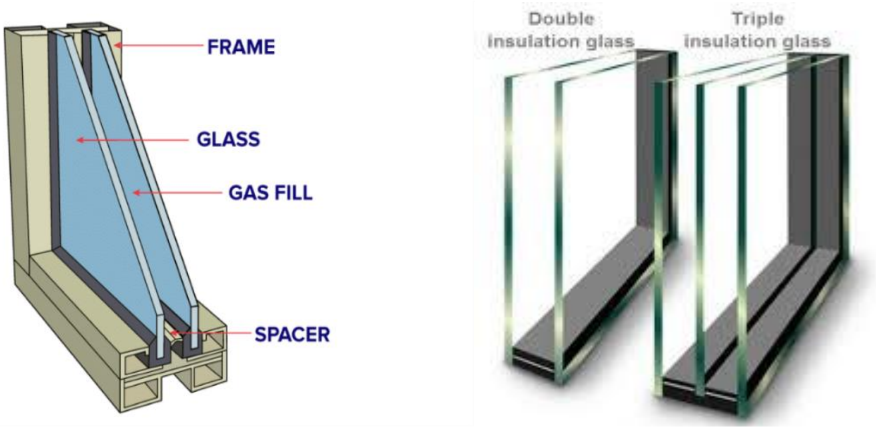


Figure 2.19: Insulated glass

By combining 2 or more glasses, insulating glazing (thermal or acoustic) is made. A 6 to 12 mm air gap separates the glazing and plastic or metal joints ensure the seal.

Air can be replaced by:

- ✓ Argon is used frequently and performs better than air
- ✓ Krypton and xenon perform better than air and argon

The whole is held together by a peripheral frame (made of mild steel, aluminum, etc.)

Insulating glass must meet two essential conditions:

1. Being transparent
2. Being Insulated

2.9.6. Glass Wool

They are mainly used for thermal insulation (roofs, floors, walls, etc.). Fiberglass is obtained from sand (silica) and additives (alumina, carbonate of lime, magnesia, boron oxide).

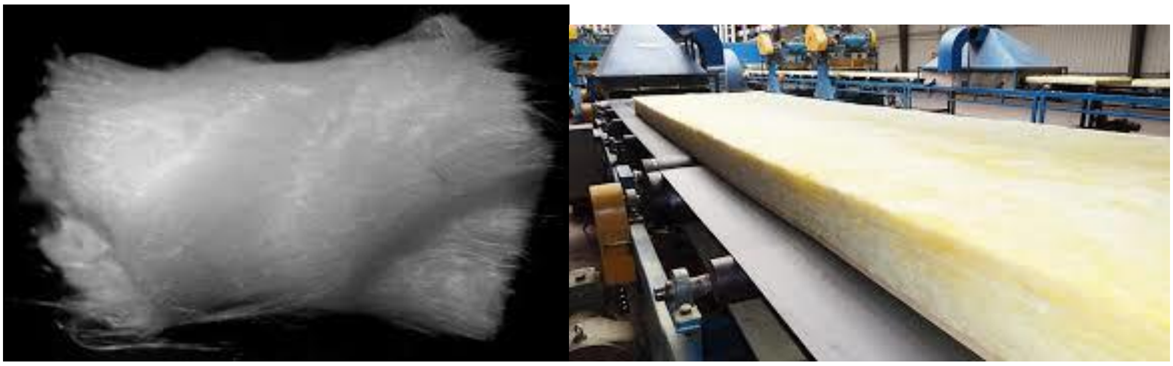


Figure 2.19: Glass Wool

Chapter 3: Ceramic materials

3.1. Definition

The term "ceramics" (ceramic product) generally refers to inorganic materials (which may have a certain organic content), permanently transformed by firing. In addition to clay-based materials, ceramics today encompass a multitude of products that contain a low proportion of clay or are completely clay-free.

Ceramics can be varnished or matte, porous or glassy.

The firing of ceramic pastes produces a "time-temperature" transformation of the minerals that compose them, usually resulting in a mixture of new minerals and vitreous phases.

The characteristic properties of ceramics are their high mechanical strength, wear resistance and durability; Chemically inert, they are non-toxic, resistant to heat and fire, and usually have insulating properties and sometimes also specific porosity.

Figure 3.1: Examples of ceramics

3.2. History of ceramics

The term "ceramics" is derived from the Greek word "keramos" which means "terracotta" and is used to refer to materials used in the pottery industry. Recent studies reveal that the transformation of clay began around 19000 B.C. The oldest pottery, discovered in Japan, is dated between 8000 and 9000 B.C. As early as 4000 B.C., baked brick was already used to build temples, palaces and fortifications. More than two thousand years ago, the Romans spread the brickmaking technique to vast areas of Europe. In Egypt, glazed ceramic plates were used as wall decorations for the pyramids and in China, the art of porcelain was known as early as 1000 BC. J.C.

Figure 3.2: Ceramics used in pottery

3.3. Classification of ceramic products

The methods and basic steps of the manufacturing processes differ only slightly in the manufacture of the various ceramic products, apart from the fact that for the manufacture, for example, floor and wall tiles, tableware and decorative objects (domestic ceramics), sanitary ware and technical ceramics, a multi-stage firing process is often used. This is one of the reasons why the different ceramics sectors are traditionally classified into two groups: the "coarse" or "construction" ceramics group, which includes the bricks and tiles, stoneware pipes, refractory products and expanded clay aggregates sectors, and the "fine ceramics" or "traditional and industrial ceramics" group, which includes floor and wall tiles, ornamental ceramics, sanitary ware, technical ceramics and inorganic abrasives. However, the technical implementation can be extremely different, depending on the specific criteria of the products and the characteristics of the raw materials used. For example, there are different continuous (e.g. tunnel furnaces) and periodic (e.g. intermittent furnaces) furnaces that are used to fire the same or different ceramic products.

Ceramics can be classified according to their application, firing temperature, method of production and final form, and chemical composition:

3.3.1. Classification according to their application

Ceramic products traditionally fall into two categories:

1. "Coarse" or "construction" ceramics, which include bricks and tiles, stoneware pipes, refractory products and expanded clay aggregates.
2. "Fine ceramics" or "traditional and industrial ceramics", which includes the sectors of floor and wall tiles, ornamental ceramics, sanitary ware, technical ceramics and inorganic abrasives

3.3.2. Classification according to their firing (cooking) temperature

Ceramics are classified according to the firing temperature (still incorrectly called "melting" or "cooking" temperature)

- ✓ High melting: 1289 to 1390°C
- ✓ Medium melting: 1090 to 1260°C
- ✓ Low melt: 870 to 1065°C
- ✓ Very low melt 660 to 780°C.

3.3.3. Classification according to chemical composition

- ✓ Feldspar ceramics
- ✓ Vitroceramic
- ✓ Ceramics or rather hydrothermal glasses
- ✓ Aluminous ceramics
- ✓ Zirconium oxide (zirconia) ceramics

3.4. Manufacture of ceramic products

The manufacture of ceramic products generally involves three stages (Table 3.1).

Table 3.1: Steps in the manufacture of ceramic products according to the family of ceramics.

Ceramics family	Step 1	Step 2	Step 3
Traditional & Technical Ceramics	Powder	Formatting	Heat treatment
Glasses	Powder	Heat treatment	Formatting
Concretes / Cements	Heat treatment	Powder	Formatting

3.5. Raw materials

The ceramics industry uses a wide variety of materials to adapt to the diversity of its product range. It uses both natural and synthetic materials, many of which are made locally but some of which are imported. The needs are not the same from one sector to another.

The formulas (or pastes) of clay-based ceramics can consist of a single clay or several, mixed with mineral, so-called "non-plastic" modifiers, such as quartz powder and feldspar.

Figure 3.3: Clay examples

3.6. Some Ceramic Products

3.6.1. Bricks and tiles

Brick products are manufactured in large quantities and are used as materials in many branches of building and construction. Most often, bricks and tiles have a name that designates not the shaping technique used, but the use for which they are intended:

- ✓ Building bricks (e.g. clay blocks, facing bricks, Dutch bricks (clinker quality) and light bricks)
- ✓ Tiles (e.g. extruded tiles, pressed tiles)
- ✓ Paving bricks
- ✓ Chimney bricks (e.g. chimney flues).

Figure 3.4: Bricks and tiles

3.6.2. Sandstone pipes

Sandstone pipes and fittings are used for drainage channels and sewers, but also for acid tanks and for products for animal buildings.

Figure 3.5: Sandstone pipes

3.6.3. Refractory products

Refractory products are ceramics capable of withstanding temperatures above 1500 °C. Many refractory products in a wide variety of forms and appearances are used in a wide range of industrial applications in the steel, iron, cement, lime, glass, ceramics, aluminum, copper and petrochemical industries, in incinerators, generators and home heating systems. especially night-time storage heater blocks. They are essential for high-temperature processes and are resistant to all types of stresses (mechanical, thermal, chemical) such as erosion, creep deformation, corrosion and thermal shock

Figure 3.6: Refractory products

3.6.4. Expanded clay aggregates

Expanded clay aggregates are porous ceramic products that have a uniform porous structure composed of fine closed cells and have a firm, densely sintered outer shell. They are made from raw materials containing clay minerals. The raw material is prepared, moulded and then subjected to a firing process at temperatures between 1100 and 1300 °C, which causes a significant increase in volume by expansion.

These products can be manufactured in any quantity and with a grain size and characteristics that can be precisely adjusted to meet extremely varied technical requirements in many areas of application.

They are used as a loose material or as a cement-bonded material in the construction industry (e.g. for loose embankments, lightweight concrete, precast lightweight concrete blocks and other elements, structural lightweight concrete for in situ treatments) and also as a soft material for landscaping (e.g. backfill in road construction, supports for green roofs, filtering and draining backfills).

Figure 3.7: Expanded clay aggregates

3.6.5. Tiles for floors and walls

Ceramic tiles (see EN 14411) are thin slabs made of clays and/or other inorganic materials and are generally used to cover floors and walls. Ceramic tiles are usually shaped by extrusion or dry pressing at room temperature, then dried and finally fired at temperatures sufficient to develop the required properties.

The most common tile shapes are squares and rectangles, but there are also other polygonal shapes (hexagon, octagon, etc.). As for the dimensions, they range from a few centimeters on each side (mosaics) to slabs of 60 to 100 cm on each side. The thickness varies from about 5 mm for wall tiles to more than 25 mm for some extruded tiles.

Figure 3.8: Tiles for floors and walls

3.6.6. Ornamental ceramics (domestic ceramics)

Figure 3.9: Ornamental ceramics

The manufacture of domestic ceramics includes tableware, artificial and fancy objects made of porcelain, earthenware and fine stoneware. Typical products are plates, dishes, cups, bowls, decanters and vases.

The total production volume is low compared to other major industrial ceramics products. Tableware and decorative objects have a completely different ratio between value and mass.

3.6.7. Sanitary ware

Ceramic products used for sanitary purposes are all collectively referred to as "sanitary ware". Typical ceramic products are toilet bowls, bidets, washbasins, cisterns and fire hydrants. These products are mainly made of vitreous porcelain (imitation porcelain) or earthenware.

The total production volume is small compared to other major industrial ceramics products such as bricks or refractory products. Sanitary ware has a completely different value-to-mass ratio than bricks or refractory products.

Figure 3.10: Sanitary ware

3.6.8. Technical ceramics

Technical ceramics are used in many industries and concern both established products, such as insulation, and new applications. They supply components for the aerospace and automotive industries (engine parts, catalyst mounts), electronics (capacitors, piezoelectrics), biomedical products (bone replacement), environmental protection (filters) and many other areas.

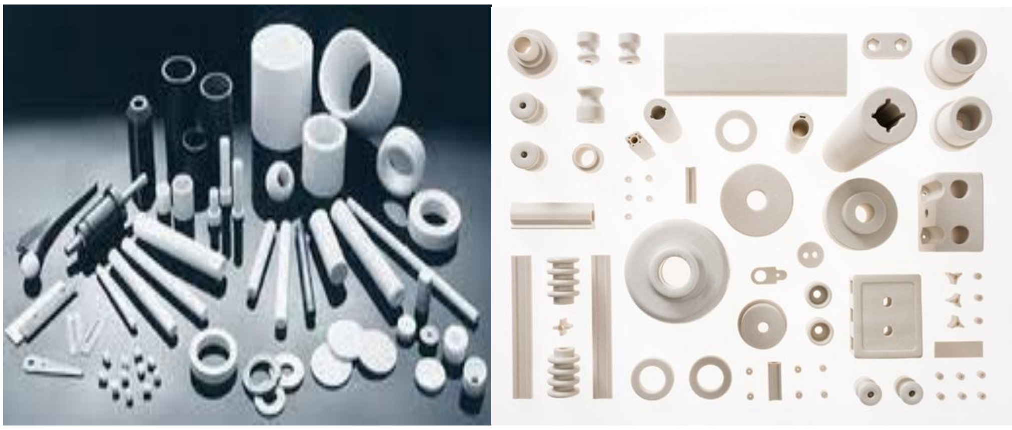


Figure 3.11: Technical ceramics

3.6.9. Inorganic Abrasives

One of the main characteristics of grinding - one of the oldest known manufacturing processes - is the effect of many unoriented cutting materials in the workpiece. Abrasive products that apply this main characteristic are commonly used tools to work with all kinds of materials: not only for grinding, but also for cutting, polishing, straightening, sharpening, etc. metals, plastics, wood, glass, stones, etc.

Basically, a distinction can be made between bound abrasives ("grinding wheels") and applied abrasives ("abrasive paper and fabrics"). In addition, there are free abrasives that do not have a solid bond with a substrate (e.g. abrasion pastes)

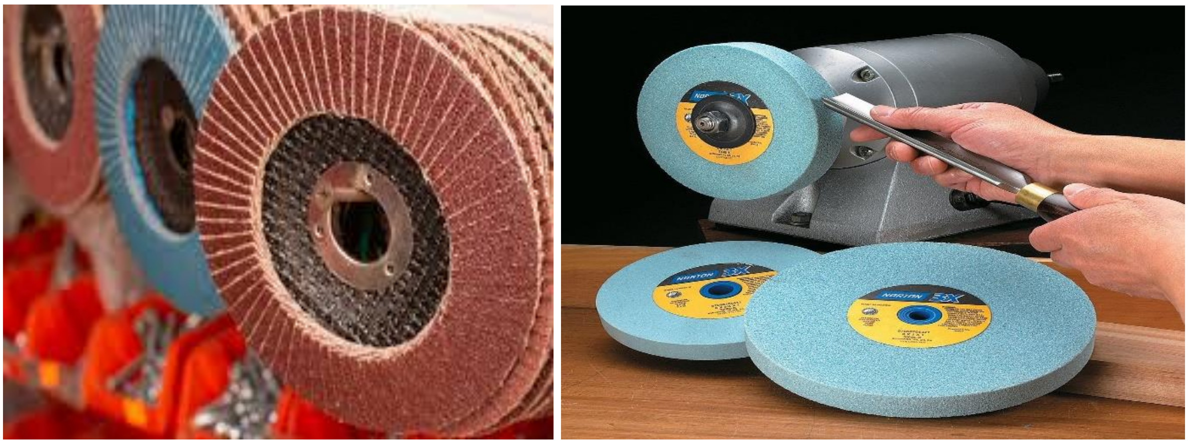


Figure 3.12: Examples of inorganic Abrasives

Chapter 4: Bituminous materials

4.1. Introduction

Bituminous coatings (Asphalt mixes) consist of a mixture of aggregates (pebbles, sand and fines) and a hydrocarbon binder (usually bitumen) and additives.

Figure 4.1: Bituminous mix

4.2. Asphalt constituents

4.2.1. Aggregates

Aggregates make up almost 95% of asphalt. It is therefore important to characterize them well in order to make an optimal choice when formulating and manufacturing a high-performance asphalt mix. Aggregate is a granular material used in construction or is a set of grains with dimensions between 0 mm and 125 mm, which contributes intimately to the performance and durability of structures.

Figure 4.2: Aggregates

4.2.1.1. Physical characteristics and properties of aggregates

Here are a few laboratory tests that can be used to determine some of the mechanical characteristics of aggregates:

a) *Resistance to fragmentation (impacts):*

It is measured by the "Los Angeles" coefficient. This measurement is intended to assess the resistance of aggregates to fragmentation under the action of traffic.

b) *Resistance to attrition and wear and tear:*

The test used is the Micro Deval in dry conditions or in the presence of water. The purpose of this measurement is to quantify the wear that occurs between the gravel in a seat on the one hand and between the tire and the aggregate on the surface of the pavement on the other. As wear is strongly influenced by the presence of water, the most representative test is the Macro Deval in the presence of water.

c) *Polishing resistance:*

This test is used to quantify the polishing resistance of the gravel used for the surface layers. A drum machine is used on which aggregate support plates are placed.

4.2.1.2. Classification of aggregates

Aggregates are classified according to the largest dimension "D" and the smallest dimension "d" as shown in Table IV.1:

Table 4.1: Classification of aggregates

Product Class	Dimension in millimeters
Fine	0/D or D ≤ 0.0063
Sand	0/D or D ≤ 6.30
Small Gravel	d/D or d ≥ 2 and D ≤ 31.50
Stones	d/D or d ≥ 2 and D ≤ 820.00
Gravel	0/D or 6.3< D ≤ 31.50

4.2.2. Filler fines

When the content of fines (elements less than 0.08 mm) provided by the crushing or grinding sand used in the composition of asphalt is insufficient, the addition of filler fines must be provided.

In order to characterize the quality of these fines as well as those derived from sand, it is necessary to use the tests defined by the regulations in force and to comply with the minimum values imposed.

4.2.3. Hydrocarbon binders

The hydrocarbon binders used for pavements use a variety of resources: bitumen, tar and bitumen emulsions. A hydrocarbon binder is an organic binder made up of hydrocarbons, that is to say essentially based on carbon and hydrogen, to which oxygen and sulphur are added.

4.2.3.1. Classification of hydrocarbon binders

The set of hydrocarbon binders consists of three main groups:

- ✓ Bitumen and its anhydrous derivatives
- ✓ Bitumen emulsions
- ✓ Tars

1. **Bitumen**

Figure 4.3: Bitumen

These are solid, semi-solid or liquid products including:

- ***Pure bitumen:***
  Obtained by refining petroleum purposes and with no additives
- ***Cutback (Liquidized) bitumen:***
  Bitumen mixed with a more or less volatile diluent, derived from distillation of petroleum
- ***Fluxed bitumen:***
  Bitumen softened by the addition of a low-volatility fluxing oil from the distillation of coal tar.

- ***Mixed fluxed bitumen:***
  Pure bitumen, the consistency of which has been reduced by the incorporation of products from the distillation of petroleum for at least 50% of the additions, and from the distillation of coal tar.
- ***Compound bitumen:***
  Containing at least 50% of bitumen and it is subdivided into:
  1. Bitumen-tar: a mixture of pure bitumen and coal tar.
  2. Bitumen-Coal: mixture of pure bitumen and coal pitch.

  Tars have an equiviscosity temperature (TEV)<60 °C or a softening point (BA)<40°C.
- ***Modified bitumen:***
  Previous bitumens with the addition of mostly macromolecular substances other than mineral fines or adhesive additives.

2. Bitumen emulsions

The bitumen emulsion is a dispersion of bitumen in water formed by the use of a mechanical shear energy of the binder and a mechanical surfactant. The basic binder may be pure or modified bitumen, possibly fluxed fluidified.

Figure 4.4: Bitumen emulsions

3. Tar

Figure 4.5: Tar

They originate from the high-temperature coking of coal, and are obtained by reconstitution from pitch and oil cuts from the processing of coal tar. A distinction is made between:

- ✓ **Pure tar:**
  No additions.

- ✓ **Modified tar:**

  Containing mostly macromolecular substances other than mineral fines or adhesive additives. These include vinyl tars and styrene tars, the former not being subject to specifications.

- ✓ **Compound tar:**

  Containing more than 50% of tar and pure bitumen, and not subject to classification or specification.

4.2.3.2. Origin of bitumen

a) Natural bitumen

Figure 4.6: Natural bitumen

Natural bitumens are extracted from crude oils, completely devoid of light fractions and containing a certain percentage of mineral matter.

The best known is certainly the "Trinidad bitumen" from a bitumen lake located on the island of Trinidad (British West Indies).

We can also mention Gilsonite (Utah, Colorado) which is a pure, very hard bitumen, used not for roads but for paints, accumulators, and asphalt tiles; there is also Elaterite, Albertite (Canada), infusible and extremely hard.

Figure 4.7: Trinidad bitumen lake

b) Artificial bitumen

Figure 4.8: Crude oil

Bitumen is the heaviest fraction of crude oil, made up of the longest hydrocarbon molecules. The schematic composition of a crude oil can be represented as follows:

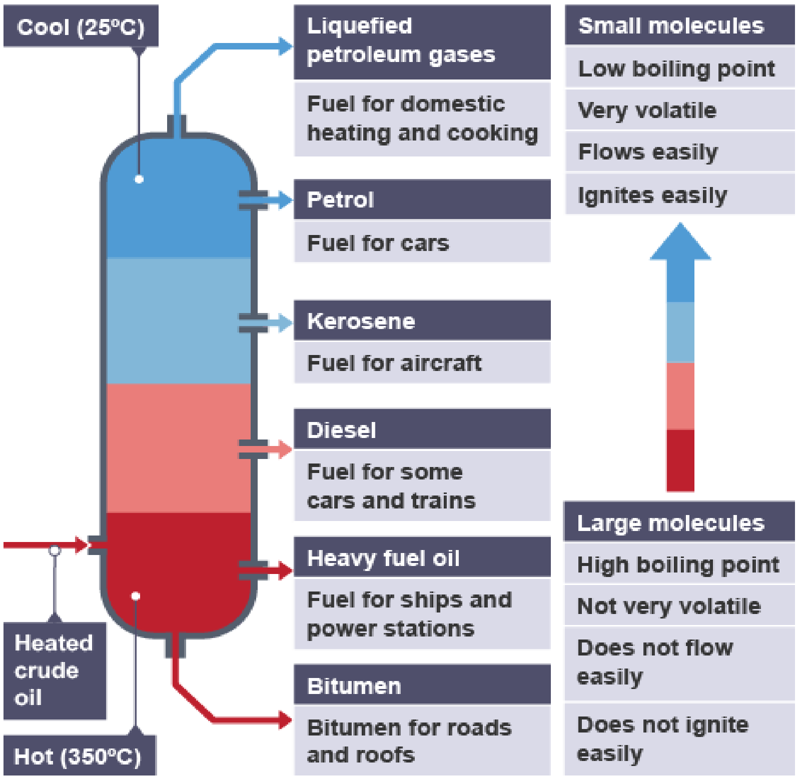


Figure 4.9: Schematic composition of a crude oil

In this composition, the percentage of a bitumen can vary in very large proportions, it can be:

- ✓ Low or even non-existent, which makes its extraction unprofitable from an industrial point of view (the case of Algerian oil and oil from the Middle East).
- ✓ Very high, it can reach 70 to 80% in some oils from Latin America (Venezuela), it can reach almost 100% in natural bitumen.

4.2.3.3. Bitumen Manufacturing

In order to manufacture bitumen of a given specification, the first condition is to choose a crude oil that is sufficiently heavy, this means that which has the highest amount of residue (reduced crude) after atmospheric distillation. It should be noted that of the 1300 crude oils referenced in the world, 10% are capable of producing bitumen that meets the specifications of use.

Depending on the various origins of these oils, special methods of manufacture have been adopted to obtain quality bituminous products. There are four methods of making bitumen:

4.2.3.3.1. Distillation

It is a physical process of evaporation of volatile constituents where the vapor phase is eliminated and condensed, leaving the bitumen at the bottom of the column. There are two distillation processes:

a) Distillation at atmospheric pressure

It is a simple method, but depending on the base, it may require treating high temperatures that can lead to degradation of the products by overheating. This process is only used to remove light products (gasoline, kerosene).

b) Vacuum distillation

This operation is necessary to obtain heavy products, so we start with the distillation under atmospheric pressure of the selected crude. The bottom of the column is then sent to vacuum distillation, which consists of separating the different constituents by playing with the parameters: flow, pressure and temperature.

The reduced pressure inside the tower is intended to continue the physical separation of the constituents without thermally degrading them.

The more distilled the bitumen, the harder the bitumen obtained and the lower its penetrability.

4.2.3.3.2. Extraction (Deasphalting)

This process consists of making bitumen by solubility of the bottom of the vacuum distillation in a solvent (propane and butane), so this process is used as a complement to the distillation. After extraction of the residue under vacuum, we obtain:

- ✓ Bitumen,
- ✓ A high-quality lubricant base.

Bitumen of deasphalting is generally sensitive to temperature.

4.2.3.3.3. Blowing

This operation consists of injecting air into the residue of the vacuum distillation at temperatures between 250 and 300°C. The aim of this process is to obtain harder bitumen with a decrease in temperature susceptibility

In practice, a distinction is made between:

- ✓ Semi-blowing, which consists of treating the bottom of a column under vacuum, which is too soft to make a road bitumen,
- ✓ Blowing a more complex base to obtain industrial bitumen that is very low in temperature (used, for example, in roofing coverings),

4.2.3.3.4. Cracking

Cracking is a treatment of the bottom of the column under vacuum at high temperatures between 450 and 500°C and pressures ranging from 2 to 25 bar. Under these conditions, some large molecules in the heavy fractions crack to form small molecules, while the more stable ones are resistant to treatment. These bitumens have no road application.

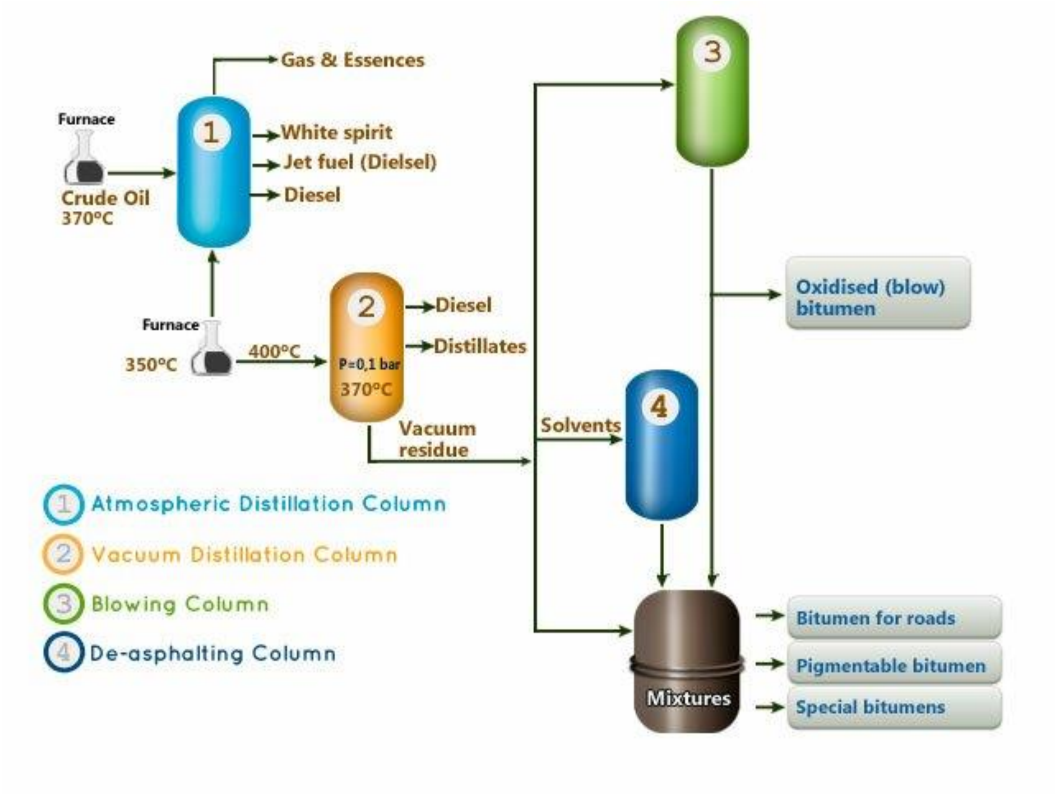


Figure 4.10: Bitumen manufacturing

4.2.3.4. Bitumen characterization tests.

To characterize a bitumen, several tests are used.

4.2.3.4.1. Classic tests

These include:

a) Needle penetrability test (NF T 66-004)

It is the measurement of the penetration (expressed in tenths of a millimeter) into a bitumen sample, after a time of 5 seconds, of a needle whose weight with its support is 100g, and at 25°C. Under these conditions, the harder a bitumen is, the lower its penetration.

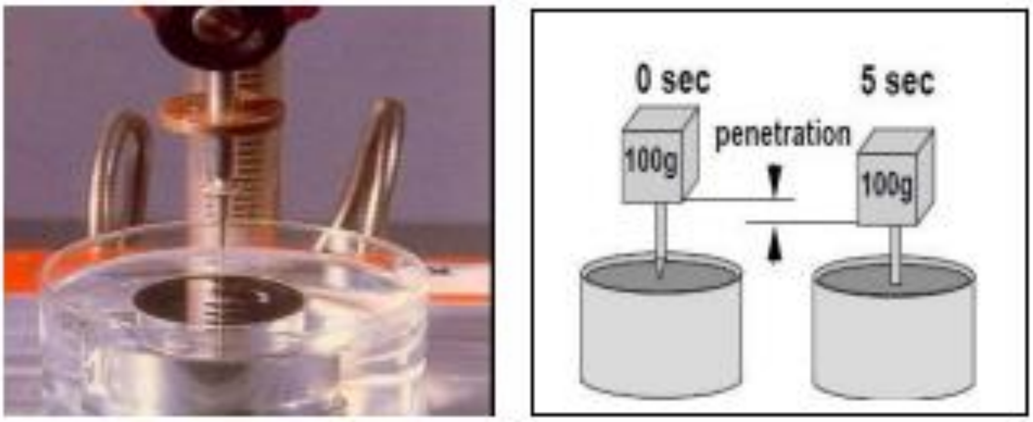


Figure 4.11: Penetrability test for bitumen

b) The ball and ring softening point (NF T 66-008)

The test consists of determining the temperature (denoted **TBA**) at which a normalized steel ball passes through a sample of bitumen held in a metal ring. It characterizes the consistency of the material: the lower the ball and ring temperature, the more likely the bitumen is susceptible.

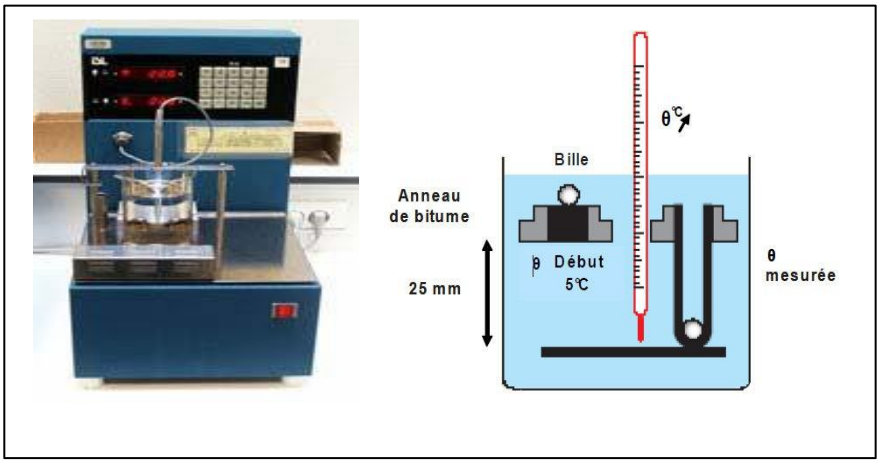


Figure 4.12: Determination of the softening point 3-

c) The RTFOT test "Rolling Thin Film Oven Test" (NF T 66-032)

This assay is used to characterize the aging of asphalt pavement. Indeed, during the manufacture of asphalt, the aggregates heated to around 160°C are brought into contact with the hot bitumen which distributes in a thin film around the aggregate, this contact inducing an ageing of the binder. For the **RTFOT** test, under specific test conditions, the thin-film bitumen is regularly exposed to a flow of hot air whose flow rate is controlled. The usual properties of the binder are then measured: penetrability and ball and ring softening temperature. These values, known as **RTFOTs**, are then compared to the initial values. They are closer to those of the binder extracted from the asphalt than those obtained on the original bitumen.

Figure 4.13: The RTFOT test

d) The PAV test "Pressure Aging Vessel" (AASHTO PP1)

This assay is used to characterize the aging of bitumen in situ. The RTFOT residue is heated and poured into metal trays that make up the PAV test specimens. These trays are stored in a rack that will be placed in a container in the thermal chamber. At the test temperature, an air pressure is applied in the container. slowly (8 to 10 minutes). After a period of twenty hours, the pressure is reduced. The test tube trays are then placed in a furnace at the 163°C for 30 minutes. The usual properties of the binder are then measured: penetrability and ball and ring softening temperature. These values, known as after VAP, are then compared to the initial values and the values obtained after RTFOT.

Figure 4.14: The Pressure Aging Vessel test

e) The fragility point's test FRAAS (NF T 66-026)

It corresponds to the temperature at which a film of bitumen deposited on a steel plank cracks when the plank is bent at low temperatures. It characterizes the brittleness of the binder at low temperatures. The values obtained during these various tests are the basis of the bitumen specifications. These are divided into "classes" corresponding to a given range of penetrability values at 25°C:

- ✓ 10/20 hard bitumen (unnormalized),
- ✓ 20/30 hard bitumen (normalized),
- ✓ 35/50 and 50/70 semi-hard bitumen,
- ✓ 70/100 and 180/220 soft bitumen.

f) Ductility test (NF T 66-006)

The ductility of a bituminous material is the elongation that characterizes it before it breaks, when stretched, at a specified rate and at a given temperature. The speed of the test is 5 cm/min ± 5%.

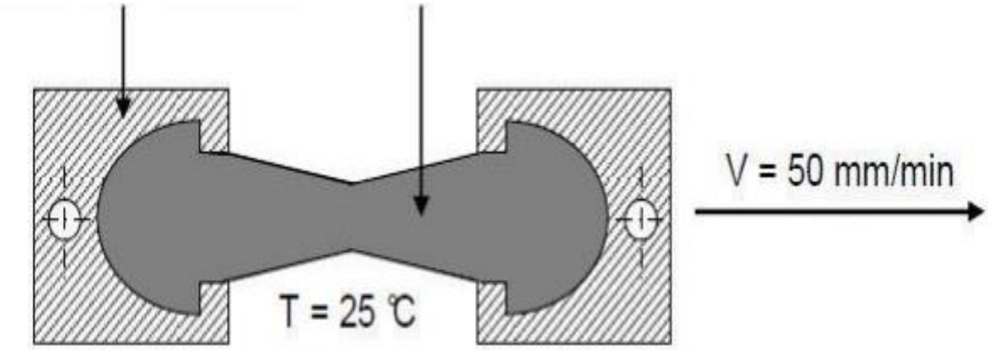


Figure 4.15: Principle of the Ductility Test

4.2.3.4.2. Mechanical Testing

The objective was to be able to link the characteristics of the binders measured in the laboratory to the performance of the binders in asphalt on pavements.

Four tests were selected from this program, these trials are presented in Table IV.4

Table 4.2: Mechanical tests on binders

Type of test	**Purpose of the test**
Dynamic Shear Rheometre (DSR)	Measuring the properties of the binder to High and medium temperatures
Rotational Viscometre (RV)	Measuring the properties of the binder to High Temperatures
Bending Beam Rheometer (BBR) (Beam Bending Test)	Measuring Properties at Low Temperatures
Direct Tensile Test (DTT)	Measuring Properties at Low Temperatures

4.3. Classification of hydrocarbon asphalt

In the very broad field of hydrocarbon asphalt and in view of its possible composition and use, a classification based essentially on method of manufacture and compactness has been introduced.

4.3.1. Based on the manufacturing method.

We distinguish:

- ✓ **Hot mix asphalt:** characterized by passing the aggregates through a dryer drum to heat and dry them. The binder used may be pure, fluxed or cutback bitumen, tar or compound binder, but most often pure bitumen.
- ✓ **Cold mix asphalt:** prepared from aggregates that are not passed through a drum dryer. The binder used can be fluxed or cutback bitumen, tar or emulsion.

4.3.2. Based on compactness.

We distinguish:

- ✓ **Dense asphalt:** In which the percentage of voids is less than 10%. High-quality dense asphalt mixes are characterized by stricter specifications with regard to aggregate quality, binder viscosity, particle size curve, mechanical performance and manufacturing care.
- ✓ **Semi-dense asphalt:** in which the percentage of voids is between 10 and 15%.
- ✓ **Open asphalt:** in which the percentage of voids is greater than 15%.

4.4. Influence of actions applied to the pavement

4.4.1. Traffic Effect

The passage of a vehicle generates tensile and compressive stresses in the different directions of the pavement layers. Each layer of the pavement is likened to a beam that is bent by traffic. The calculation of the forces and strains that occur requires, in the first place, knowledge of the complex modulus and possibly of the Poisson ratio.

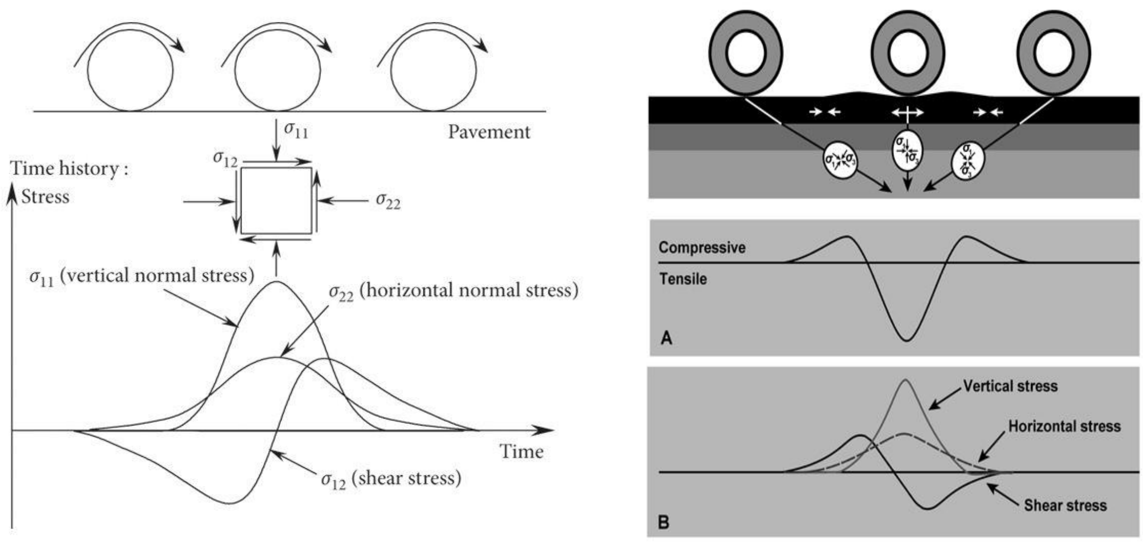


Figure 4.16: Diagram of traffic-induced loads

Repeated pulling at the base of the layers, under the effect of passing vehicles, creates micro-degradations that accumulate and can lead to the ruin of the material. This is the phenomenon of fatigue that is observed for many materials. A crack can also appear and spread into the pavement.

Repeated compressions under the passage of the load can create permanent deformations that sometimes induce rutting on the pavement surface. This rutting can be due to the settling of the bituminous concrete layers but also possibly to the deformation of untreated lower layers.

We can also point out that due to the particular properties provided by the bituminous binder, asphalt mixes have a behavior (i.e. a modulus) that is highly dependent on temperature and loading speed.

4.4.2. Effect of temperature

Pavements are loaded as a result of temperature variations. These thermal variations lead to changes in the stiffness of the mixture: at low temperatures, the bituminous mixture is rigid and brittle, while at high temperatures, the stiffness of the mixture drops and its ductility increases.

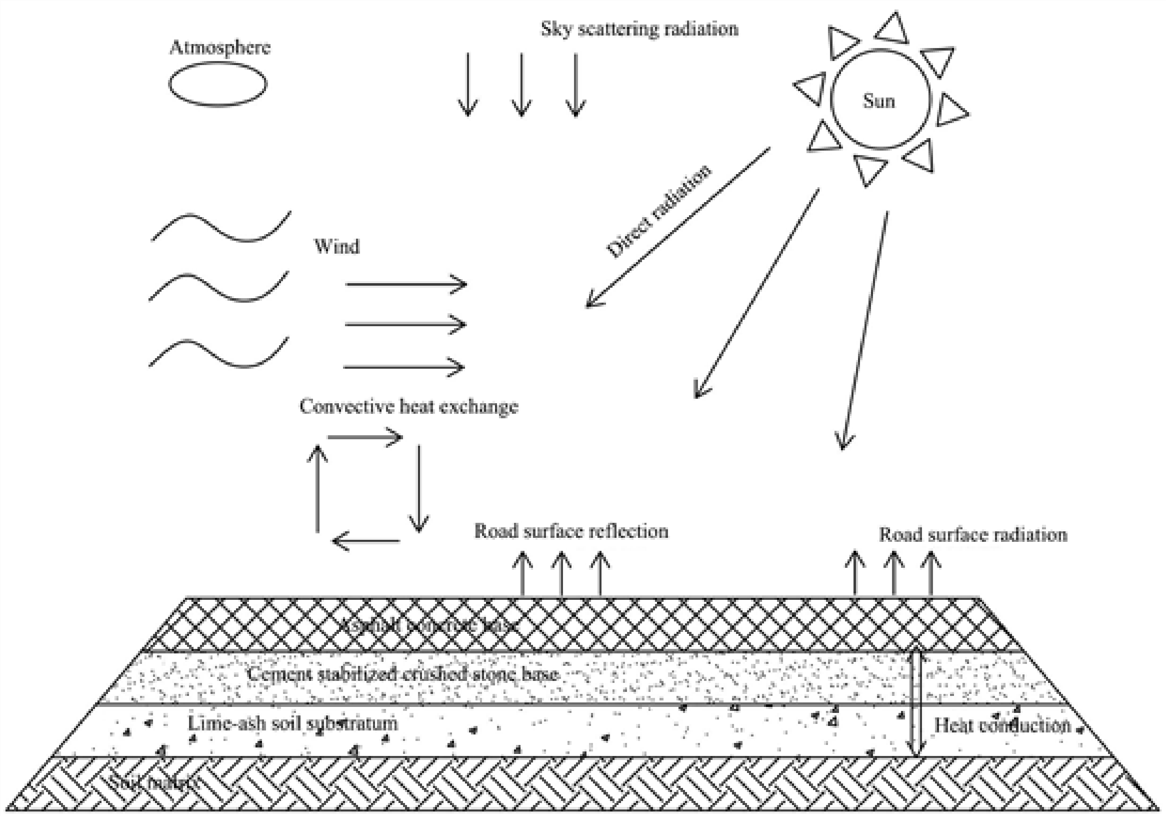


Figure 4.17: Diagram of temperature-induced stresses.

To sum up, in addition to the aging of the material, temperature has two main mechanical effects:

- ✓ Variation of the modulus of the asphalt mix,
- ✓ Creation of stresses and deformations within the material due to thermal expansion-contraction during temperature changes (thermomechanical coupling).

4.5. Required qualities of an asphalt mix

The essential qualities that an asphalt mix must-have are:

4.5.1. Stability

The stability of an asphalt layer is the resistance to permanent deformation of the layer under the effect of static and dynamic loads. Insufficient stability of the layer in the face of heavy traffic leads to creep with depressions, ruts and undulations. Stability increases with the internal friction angle of the aggregates and the hardness of the binder; This explains the current trend towards the use of hard bitumen (20/50) and hard, angular aggregates for the formulation of asphalt mixes for heavy traffic pavements.

4.5.2. Flexibility

It is the ability to admit without cracking, the overall deformations that can be imposed on the asphalt layer by the deflection of the lower layers.

Insufficient flexibility results in cracks in the flooring. Flexibility depends primarily on the ductility of the binder, which must remain acceptable at low temperatures and throughout the life of the asphalt.

The viscoelasticity of the binder leads to a stable and flexible asphalt mix, remaining viscous in summer and not fragile (brittle) in winter.

4.5.3. Insensitivity to water

Insensitivity to water and impermeability are characteristics that asphalt must have. For this purpose, dopes are often used to improve the adhesion between the binder and the aggregates and to allow the asphalt to better resist decoating under the action of water.

Asphalt used in surface layers must have special properties such as resistance to tangential and piercing shear forces, as well as roughness. This requires aggregates that do not polish easily under the action of traffic and that retain edges when in contact with the tires.

4.6. Asphalt Testing

Laboratory tests used on bituminous mixtures include:

4.6.1. Duriez test

This test makes it possible to determine the water resistance of a hot mix asphalt expressed as a ratio of compressive strengths with immersion in water and dry. The method of this test consists in making 12 small cylindrical asphalt molds: 2 intended to measure the density by hydrostatic weighing, 5 kept for 7 days in water at 18°C and 5 kept for 7 days in air.

After this time, the specimens are crushed in a hydraulic press.

Simple compressive strength = (crush load)/(specimen cross-section).

The strength of the specimen stored in water is: "r" The resistance of the specimen stored in air is: "R". The r/R ratio is the result of the test that gives the water resistance of the asphalt and which will be compared with the standard in force.

Figure 4.18: Principle of the Duriez test

4.6.2. Marshall test

The asphalt mixes are compacted in molds with the help of a mass to make cylindrical specimens. These specimens (temperature 60°C) are placed between the two semi-cylindrical jaws of a press which move closer to each other at a constant speed. During the test, the load and strain are recorded until failure. This test falls into the category of single-loading empirical tests which, due to the complexity of the stresses generated, do not allow the determination of an intrinsic property of the material. It leads to the direct determination of two quantities: creep (mm) and Marshall stability (kN), two measures related to the empirical characterization of rutting.

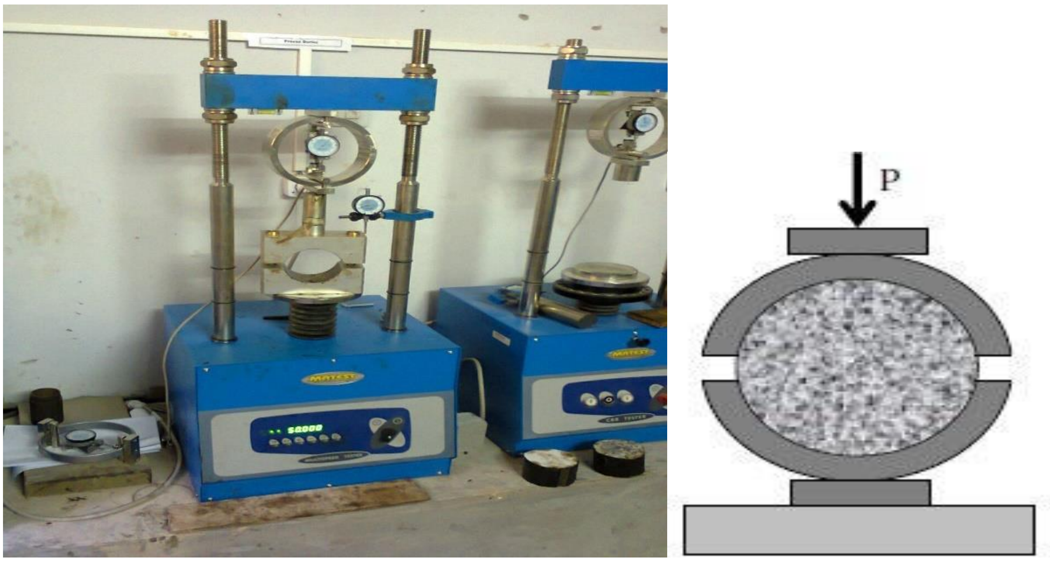


Figure 4.19: Principle of the Marshall Test

4.6.3. Gyratory Shear Press (GSP)

The GSP compaction test is a combination of gyratory shear and an axial resultant force applied by a mechanical head. The test is used to calculate the percentage of voids and compactness at n gyrations using the measured height of the tested specimen "hn". It should be noted that at 100% compactness, the minimum height of the specimen is 150 mm:

Percent voids = ((hn-150)/hn)*100; Compactness C = 100-% voids =(150*100)/hn.

The GSP test reflects the workability of the asphalt. This is because the steeper the slope of the line, the more manageable the material is.

This characteristic is derived from standards that require a certain percentage of voids at n gyrations. Maneuverability is an important factor as it reflects the ease of installation of the asphalt on the construction site.

If the values of the percentage of voids are correct and the coefficient of Maneuverability is favorable, continue the DURIEZ tests and the rutting plate, if not, modify the asphalt formula.

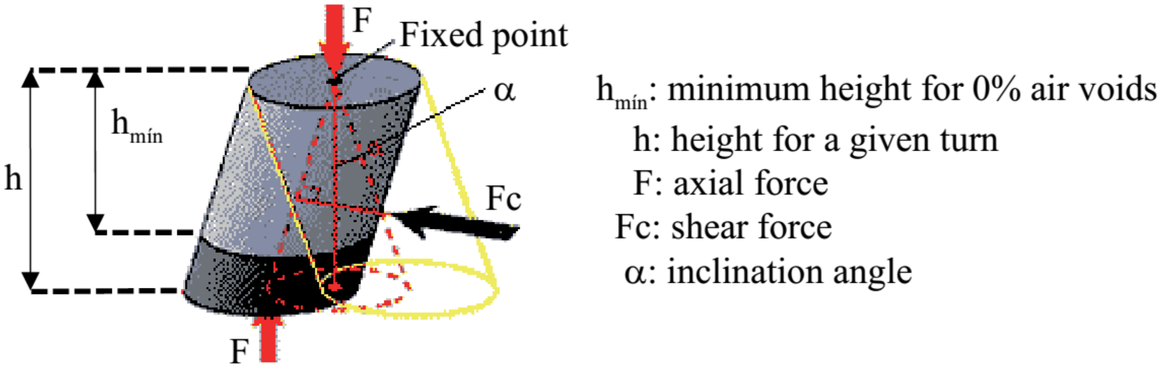


Figure 4.20: Gyratory Shear Press (GSP)

4.6.4. Diametrical compression test

Cylindrical test bodies are specimens made with a Shear gyratory or cores extracted from plates. Some of the specimens are stored without immersion at room temperature; the other part is kept submerged after extensive degassing for 70 h at 40 °C. Each group of specimens is crushed in diametrical compression at a temperature of 15°C. The ratio of the submersible to dry strength gives the water resistance of the mixture.

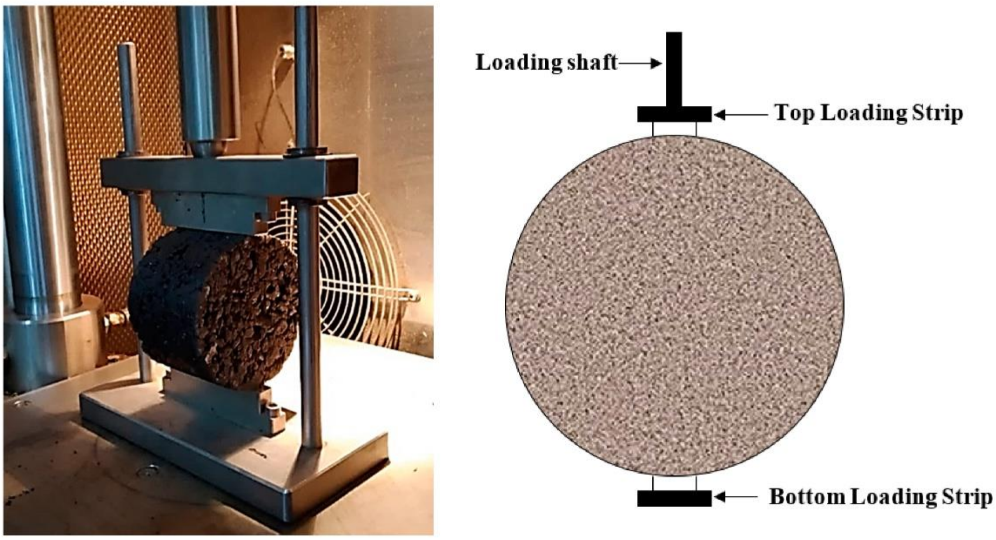


Figure 4.21: Principle of the Diametrical Compression Test

4.6.5. The rutting test

The test body is a 5 cm or 10 cm thick parallelepiped plate, depending on whether the asphalt processing thickness is less than or more than 5 cm. This plate is subjected to the traffic of a wheel equipped with a tire (frequency: 1 Hz, load: 5 kN, pressure: 6 bar), under severe temperature conditions (60 °C). The depth of the deformation produced in the wheel passage is noted as a function of the number of cycles. The specifications refer to a percentage of rut at a given number of cycles, which depends on the type of material, and its class.

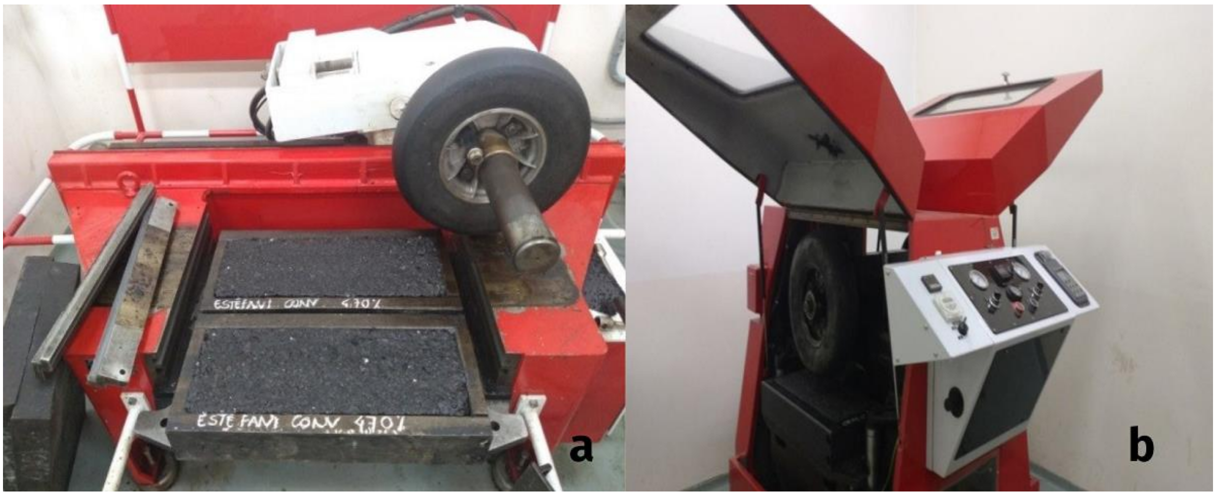


Figure 4.22: Principle of the rutting test

4.6.6. Direct tensile test

This is a constant temperature and constant strain rate tensile test. During the test, the parameters measured are stress and strain. The maximum stress, also known as the breaking stress, and the corresponding deformation, give direct access to the tensile strength of the material under test, for the test conditions (temperature, speed) considered.

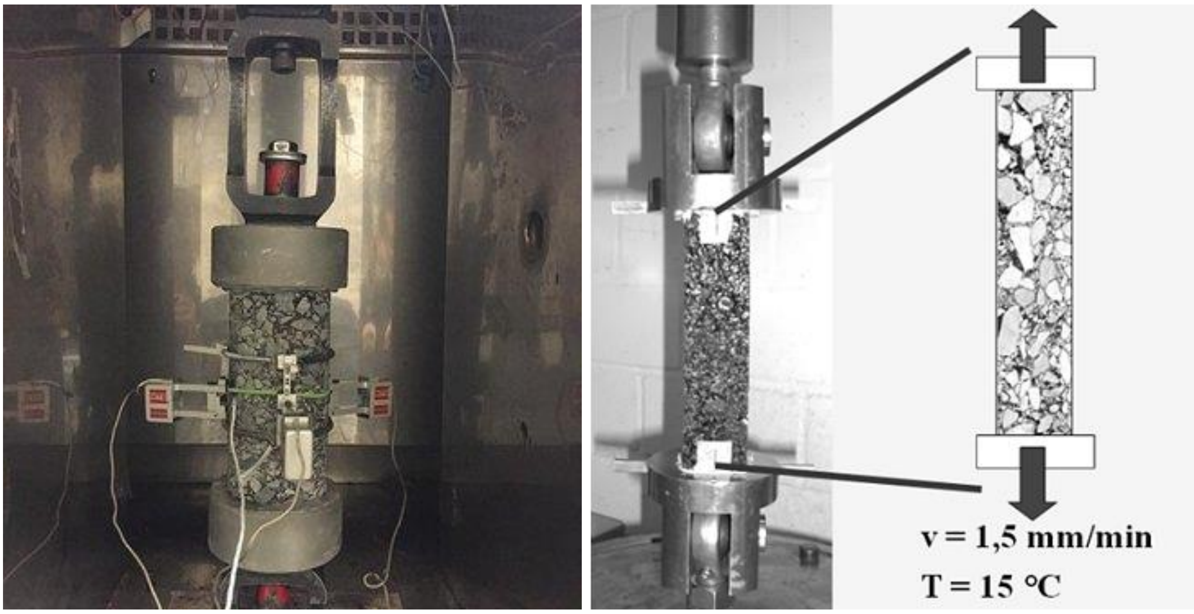


Figure 4.23: Principle of the Direct Tensile Test

4.6.7. Uniaxial Static Creep Test

The test consists of axially loading, with a constant load, of the cylindrical asphalt specimens in order to determine the resulting deformation in the direction of the load. The relative deformation "ε" equal to the ratio "ΔH/H" can be represented as a function of time.

Figure 4.24: Principle of Uniaxial Cyclic Compression Test Under Confinement

4.6.8. Dynamic Creep Test

This test consists of determining the deformation resistance of a cyclic specimen of bituminous mixtures. The specimen is prepared in the laboratory or extracted from the pavement.

A cylindrical specimen, maintained at a high conditioning temperature, is placed between two parallel and flat loading pistons. The specimen is subjected to a confinement stress "σ_c " to which a cyclic axial stress "$\sigma_a(t)$" is overlaid.

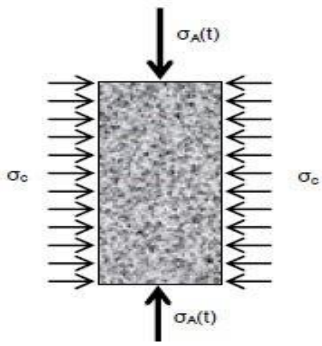


Figure 4.25: Representation of the stresses exerted on the specimen in the case of a dynamic creep test

4.6.9. Modulus Testing

The stiffness of the mixture is determined either by a complex modulus test (sinusoidal stress on a trapezoidal specimen) or by a direct tensile test (on a cylindrical or parallelepiped specimen). The load is applied in a range of small deformations, controlling the time or frequency, the temperature and the loading law.

The modulus (stress-to-strain ratio) is calculated for each elemental test (temperature, frequency).

Thanks to the time-temperature equivalence, the master curve of the module is plotted at a given temperature. This representation makes it possible to know the behavior of the mixture over a wide spectrum of charging times or frequencies. The specification is for the module at 15 °C and a frequency of 10 Hz or a charging time of 0.02 s.

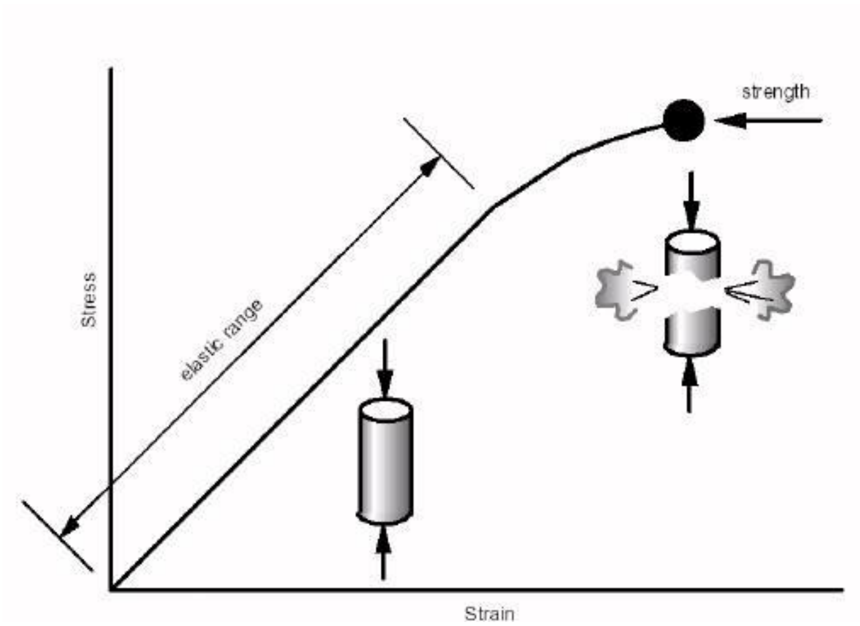


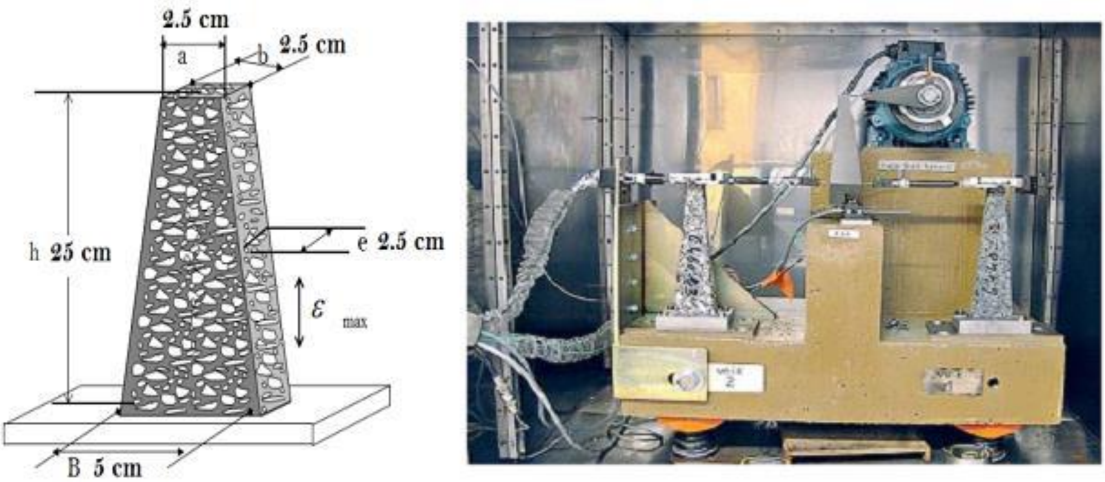
Figure 4.26: Stress-strain diagram

4.6.10. Fatigue tests

This test makes it possible to study the behavior of asphalt mixes with regard to cracking; It is performed on trapezoidal specimens. The specimen is clamped at the base, stressed at the head in sinusoidal bending by imposed displacement of constant amplitude chosen in order to characterize the fracture at one million cycles.

The test is carried out at 10°C and at a frequency of 25 Hz.

The repetitiveness of the alternating bending cycles leads to damage to the specimen (cracks are localized). The test is conducted until the force measured at the head is halved, this is the criterion for failure. The results obtained are plotted on a diagram (deformation - number of cycles at break).



(a) (b)

Figure 4.27: Point Bending Fatigue Test on Trapezoidal Specimens

Chapter 5: Polymers

5.1. Definition

The generic term polymer or plastic refers to a wide range of materials artificially extracted from organic substances that have the property of being able to be formed by heating.

Common characteristics of plastics:

- ✓ They are called plastics because, at a certain stage, they are plastic
- ✓ 30 to 40% of production via Civil Engineering
- ✓ There are both natural and synthetic polymers.

Examples of polymers:

- ✓ Rubber
- ✓ Plastics
- ✓ bitumen,
- ✓ wood
- ✓ leather
- ✓ straw

States polymeric materials:

- ✓ Solid
- ✓ Expanded
- ✓ Textile
- ✓ Fibers
- ✓ Binding
- ✓ Felts

5.2. Advantages of polymers

- ✓ Bass density
- ✓ By varying the bonds of the carbon atoms, an infinite variety of plastic materials can be created.
- ✓ Usually inert

- ✓ Ease of Formatting & Molding
- ✓ Good thermal insulator

5.3. Disadvantages of polymers

- ✓ Deterioration by UV
- ✓ Temperature sensitive
- ✓ Soft (bottom module elasticity)
- ✓ Susceptible to fire
- ✓ Limited raw material

5.4. Polymer properties

5.4.1. Glass Transition Temperature

For most polymers, there is a temperature called the glass transition temperature, Tg, which marks a boundary between two ground states:

- ✓ **Rubbery state:** soft, viscous liquid (high temperatures)
- ✓ **Vitreous condition:** hard and brittle (low temperatures)

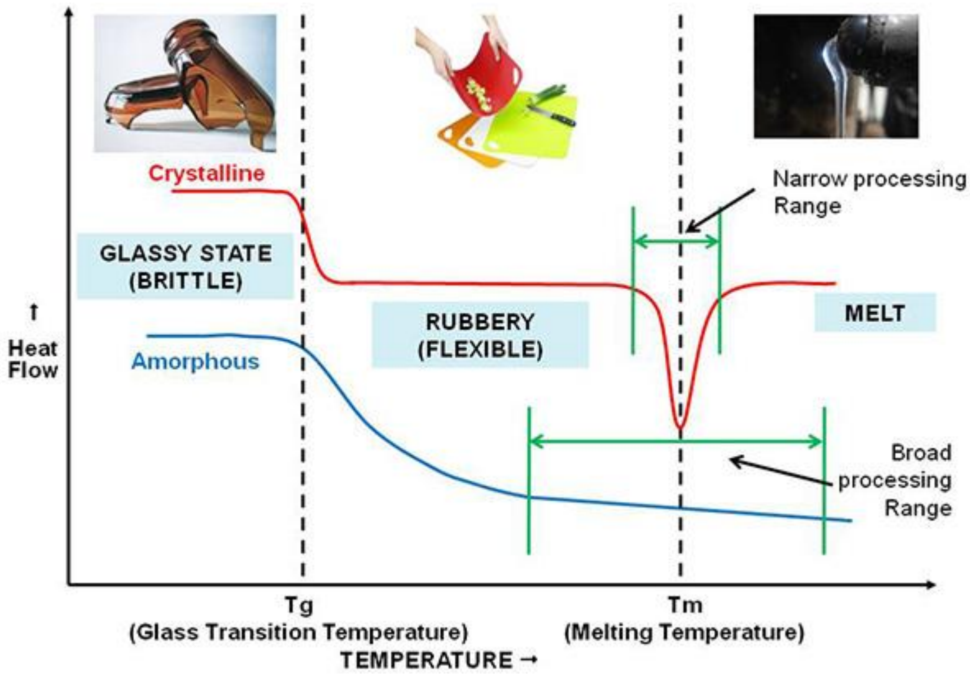


Figure 5.1: Variation of specific volume as a function of temperature for amorphous and crystalline polymers

5.4.2. Mechanical aspects

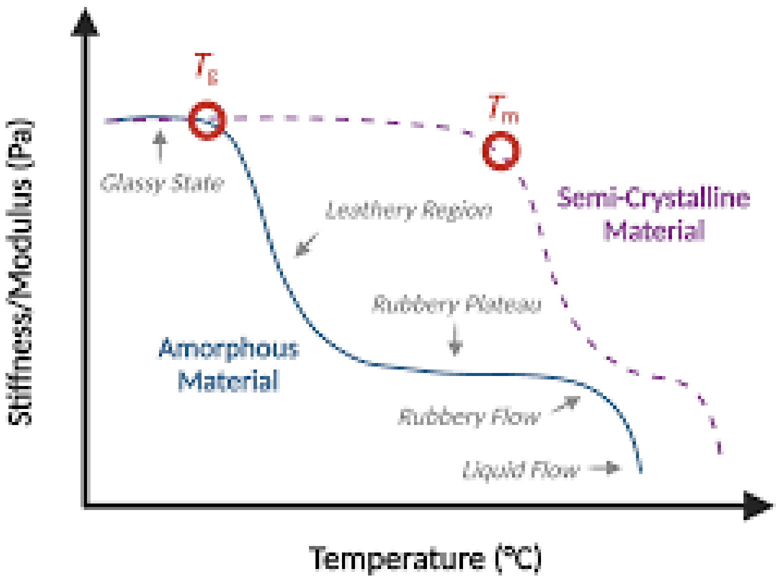


Figure 5.2: Elastic modulus variation as a function of temperature for polymers.

5.4.3. Parameters Influencing the Tg Value

The most important parameters:

- ✓ Chain flexibility
- ✓ The size and polarity of the side groups
- ✓ Molecular weight

5.5. Application of polymers in construction by type

Structureless applications:

Components in the building envelope, waterproofing, Adhesives, Repair, Interior Finishing

5.5.1. Thermoplastics

5.5.1.1. Polyethylene (PE)

Figure 5.3: Polyethylene (PE) products

Polymerization of ethylene by compression from 1000 to 2000 MPa and at a temperature of 150-300°C, used for the manufacture of barrier sheets, domestic containers, sewage pipe (HD) embrittled by UV=>black carbon.

Monomer: C_2H_4 or $CH_2=CH_2$

opening of the double binding:

Polymer: $-CH_2-CH_2-CH_2-CH_2-CH_2-$

5.5.1.2. Polytetrafluoroethylene (PTFE: Teflon)

$$-CF_2-CF_2-CF_2-CF_2-CF_2-$$

High chain attraction and crystallization => high stability, low mechanical friction, low flammability and high melting point helical structure => crystal stability, T = 350°C, as ribbon in joint pipes, mixed with fiberglass, in roofs

Figure 5.4: Polytetrafluoroethylene products

5.5.1.3. Polyvinyl chloride (PVC)

-CH2-CHCl-CH2-CHCl-CH2-CHCl-

Hard, flammable, resistant to acid and base attack; softens at 80°C. At high T (200°C), PVC takes on a fluidity that is too low for injection; plasticizers are added; Depending on their quantity, rigid, semi-rigid, flexible or elastic products can be obtained.

Uses: drinking water and wastewater piping, ventilation ducts, joinery profiles, blinds and wall and floor coverings.

Figure 5.5: PVC applications

5.5.1.4. Polypropylene (PP)

-CH2-CHCH3-CH2-CHCH3-CH2-CHCH3-

Hard and insoluble in any organic solvent. Its mechanical and chemical resistance above 100°C allows it to be used for sanitary appliances and water pipes. Added to concrete in the form of a fiber, it improves mechanical properties.

Figure 5.6: Polypropylene products

5.5.1.5. Polystyrene (PS)

Easily suitable for molding and extrusion, household objects and electrical items. It is also used for paintings. By heating polystyrene granules containing a blowing agent, an expanded material is obtained, which is used for thermal insulation.

Figure 5.7: Polystyrene sheet

5.5.1.6. Acrylic resin

It is obtained by the polymerization of acrylic acid esters and metacrylic acid. On the one hand, polyacrylic resins are obtained for the manufacture of insulation and glue and on the other hand, polymetacrylic resins, marketed under the name plexiglass. This product has good chemical and mechanical resistance; it is transparent and easy to work with; It often replaces glass, as it is lighter and unbreakable. Also used in paints, as a binder in polymer concrete, crack repair. Flammable!

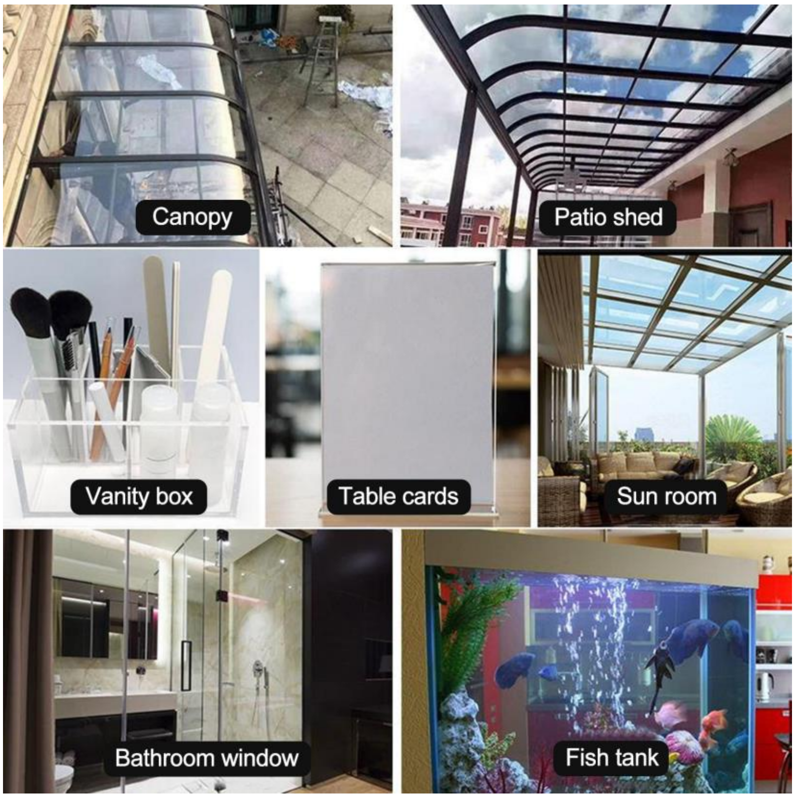


Figure 5.8: Acrylic resin applications

5.5.2. Thermosetting

5.5.2.1. Resins

- ✓ ***Phenol (PF)*** industrial production: Bakelite. Manufacture of laminates such as Formica. Water-resistant adhesives (industrial use because it is very acidic)
- ✓ ***Melamine (MF)***; flammable, solvent-resistant, can be colored and glazed; manufacture of laminates.
- ✓ ***Epoxy (EP):*** very good resistance to chemical agents and wear; are used for jointless flooring. High-quality adhesives (araldite), very good adhesion to steel and wood. Resin concrete. Composite. High cost but very good performance.
- ✓ ***Polyester (UP)*** for paints or in textile form for the manufacture of panels, often reinforced with glass fibers. Cold water cistern, prefabricated swimming pool, ...

Figure 5.9: Prefabricated swimming pool

5.5.3. Elastomers

High deformation capacity (>100%), low E Used as a sealant and deformable support

5.5.3.1. Natural rubber, NR

Supports for bridges, reduction of vibration in Buildings

Figure 5.10: Natural rubber applications

5.5.3.2. Silicone rubber

For waterproofing, good adhesion, good elastic properties, good durability, hydrophobic

Figure 5.11: Silicone rubber products

5.5.4. Additives

Despite the wide variety of polymers, to meet the requirements of use, several additives can be used in the composition of a polymer, resulting in significant variations in their properties:

1. **Plasticizers:** molecules with low molecular weight, reduce the bond strength between chains, improve the flexibility of a rigid polymer.

2. **Lubricants**: facilitate friction qualities. E.g.: Teflon powder and talcum powder
3. **Stabilizers**: slow down the degradation of polymers during processing or use by improving resistance to the effects of heat, radiation and oxidation
4. **Flame retardants**: during combustion polymers release toxic gases, flame retardants make it more difficult to initiate or spread combustion
5. **Fillers**: Adding 5-60% filler helps to strengthen mechanical properties such as hardness, strength and abrasion resistance, decrease the price. Ex. carbon black or carbonate de calcium
6. **Reinforcements**: for structural applications

5.6. Application of polymers in construction by domain

a) Concrete with polymers

- ✓ Polymer-impregnated concrete
- ✓ Polymer concrete
- ✓ Cement and polymer concrete
- ✓ PVC, PMMA, polyester, etc.

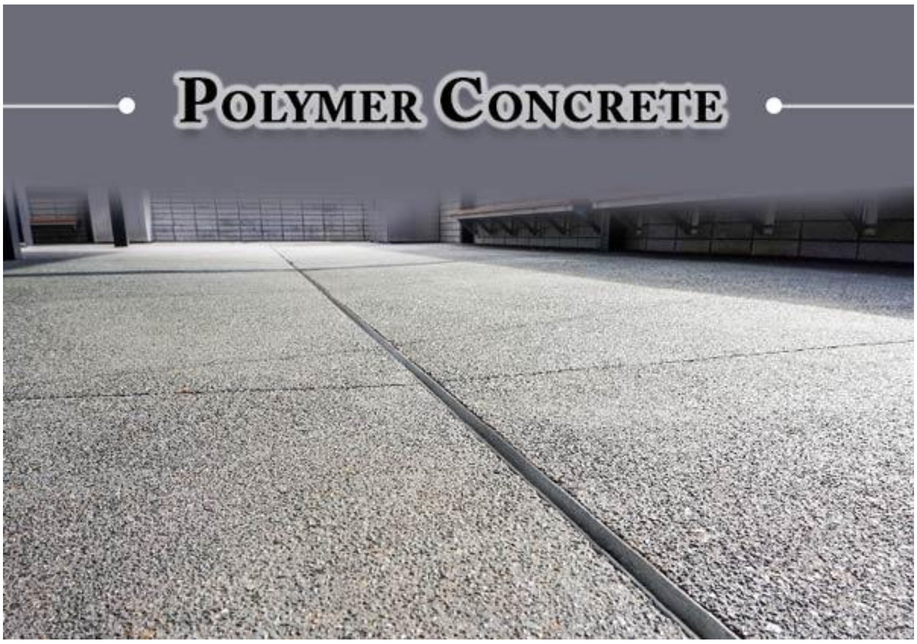


Figure 5.12: Polymer concrete

b) Floor coverings

- ✓ PVC, resistance to wear and chemical agents
- ✓ resins

c) Deformable supports

- ✓ PTFE elastomeric supports, rubbers

d) Pipes, sheaths(jackets)

- ✓ PVC, PP, PB, manufactured by extrusion

e) Adhesives and sealants

- ✓ Seals, good adhesion to the substrate, high deformability, low modulus of elasticity, good resistance to aging.
- ✓ Joints: PU, silicones, polyacrilics
- ✓ Glues & Adhesives, wet the bonded surfaces, be chemically compatible with the surfaces be resistant in the environment (e.g. resin epoxy, polyurethanes, polyester, etc.)

Figure 5.13: Polymeric adhesives and sealants

f) Foams

- ✓ rigid and semi-rigid foams as the core of sandwich panels (aluminum + PS or fiber plaster + PS) for lightweight partition wall.

- ✓ Thermal insulation: volume of still air in bubbles with λ = 0.024 W/mK, λ from 0.030 to 0.050 W/mK, Expansion of a gas into a polymer in a fluid or viscous state: the addition of a foaming agent or gas produced during a reaction (e.g. polymerization of polyurethane by water produces $C0_2$)
- ✓ polystyrene
- ✓ Polyurethanes
- ✓ Phenolic
- ✓ Rigid PVC

g) Fibers

- ✓ Reinforcement (polyethylene, polyamides), Kevlar

h) Geotextiles

- ✓ Mattresses made of plastic material, often reinforced with a fabric. Geotextiles are used to prevent water from entering the ground (waste storage) or a structure (insulating roofs or bridges). Another application is for the stabilization of the terrain.

5.7. Polymeric matrix composites

Composites are endowed with physical and mechanical properties that each of the constituents does not possess separately.

- ✓ High rigidity in one direction
- ✓ Very high strength
- ✓ High strength-to-weight ratio

Mainly two categories:

- ✓ Fiber-based composite materials
- ✓ Laminated materials

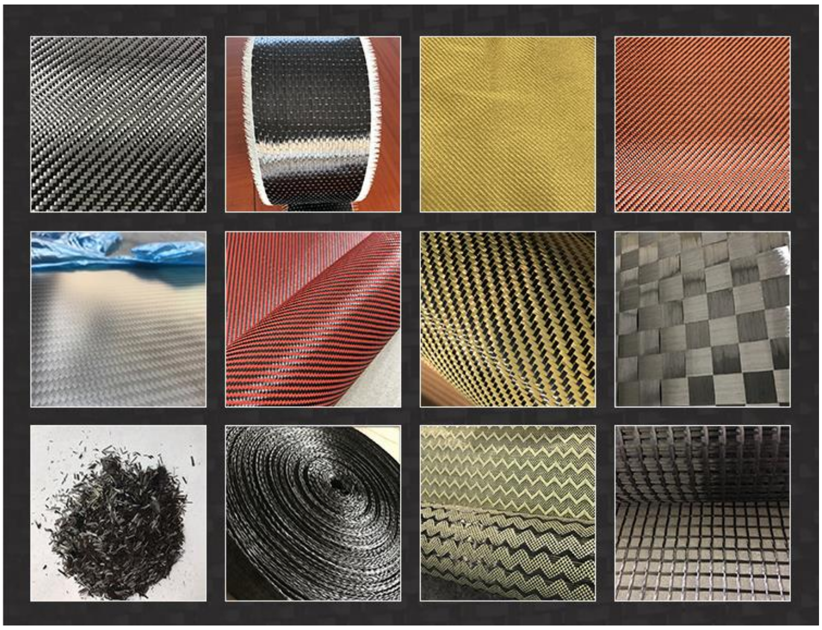


Figure 5.14: Polymeric matrix composites

5.7.1. Fiber-based composites

Consisting of a continuous matrix reinforced by Fibers.

5.7.1.1. Matrix

- ✓ thermoset matrices; epoxy resin, unsaturated polyester
- ✓ thermoplastic matrices; Thermal resistance if semi-crystalline, allow thermoforming from

5.7.1.2. Fibers

- ✓ Carbon Fibers
- ✓ Glass Fibers
- ✓ Kevlar Fibers

Unidirectional fibrous composites mechanical properties similar to steels with a density of 1 to 2 compared to 7.8 (stress parallel to the fibers).

5.7.2. Laminates

5.7.2.1. Laminated Plates & Shells

In a bending stressed plate, the layers are the most loaded. Minimum three layers (2 skins, 1 core).

Skins: Rigid material with flexural strength (composite or not).

Core: Light material, low stiffness, low strength. Difference in stiffness, shear stress at the interface, risk of delamination.

Ex.: Al-wood balsa wood panels in aeronautics, skiing, glulam wood.

5.7.2.2. structures sandwiches

Rigidity, high mechanical strength and light weight E.g.: roof, floor, wall, aircraft tail

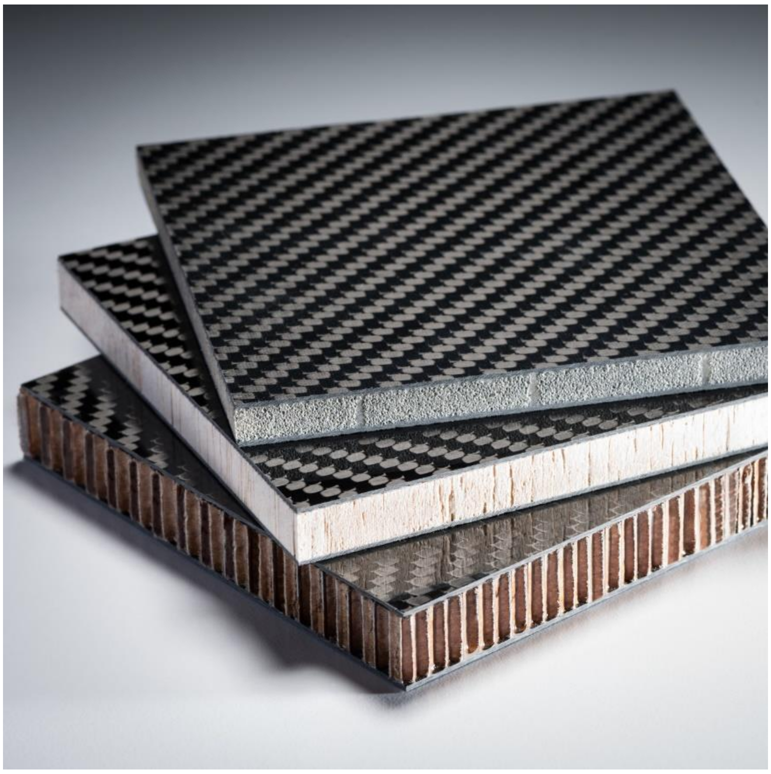


Figure 5.15: Sandwich composites

5.7.3. Polymeric composite application in civil engineering

Fiber-reinforced polymer composites have a great potential to be integrated into civil engineering

- ✓ Long life service
- ✓ Light
- ✓ Easy to build
- ✓ Good strength-to-weight ratio
- ✓ Operate under aggressive conditions to other materials
- ✓ High fatigue and corrosion resistance

5.7.3.1. Areas of application

a) Bridge repair, structural reinforcement

Figure 5.16: Carbon Fiber Reinforced Polymer (CRP) stripes for the reinforcement of a bridge.

b) Structural Uses

- ✓ Guyed bridges (cables and slabs)

Figure 5.17: Composite cable-stayed bridge

It can be used as a bridge platform instead of reinforced concrete, usually fiberglass + polyester resin, very easy and quick to set up.

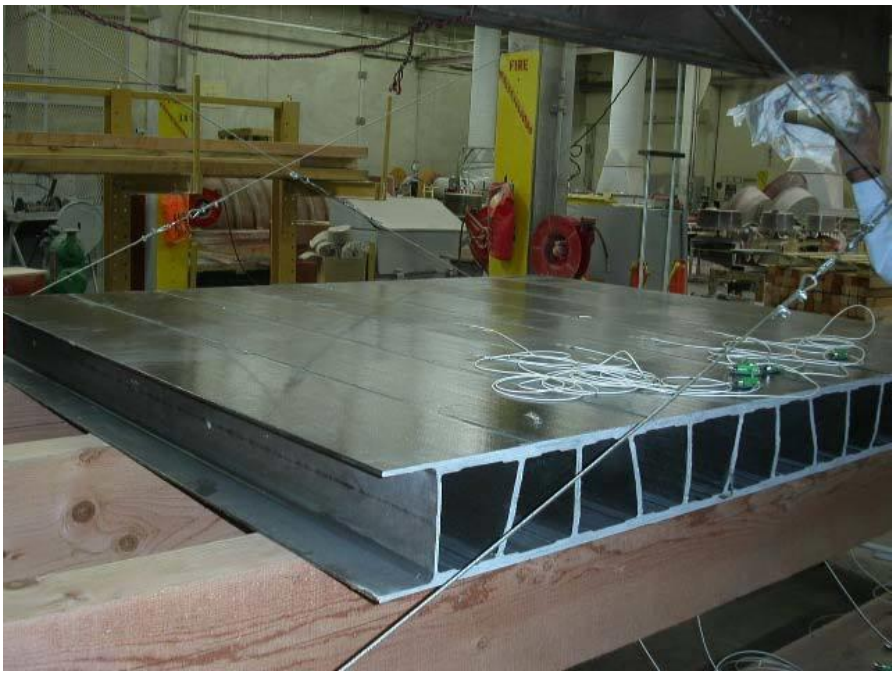


Figure 5.18: Fiber-reinforced composite panels

Figure 5.19: The deck slab is made of fiber-reinforced composite panels.

However, these new technologies also come with risks. Due to their low mass, bridges made of fiber-reinforced composites are prone to vibrations.

In construction, translucent roof elements, radar dome, silos and tanks (good chemical resistance), pipes.

5.8. Degradation

Factors that influence the durability of polymers

- ✓ Chemical environment (oxygen in the atmosphere, acid smoke and rain, humidity)
- ✓ Heat and Thermal Shock
- ✓ Ultraviolet radiation
- ✓ High Energy Radiation
- ✓ polycarbonic structures are unstable at high temperature.
- ✓ The resistance of polymers to degradation depends on composition and superstructure.

Antioxidants, UV stabilizers can be used to increase polymer's longevity.

Chapter 6: Compressed earth products

6.1. Introduction

Building with raw earth has many advantages, thanks to the inherent qualities of the material: recyclability, energy performance, fire resistance, durability...but obviously, it is necessary to respect the essential rules of the art of building with raw earth in order to guarantee the works.

Furthermore, the diversity of earth architecture processes and the simplicity of its implementation are two strong points which provide it with technological autonomy and a reduction in both the financial and environmental impact of construction thanks to the energy savings. These architectures are anchored in the contemporary vision of progress.

6.2. Diversity of earth construction

From Latin America to China, the earth material and earth architecture are represented under different construction and manufacturing techniques.

Among the best-known techniques, we cite: rammed earth, adobe, (or thob) compressed earth blocks (BTC), stabilized earth blocks (BTS), straw earth and cob. They are currently the subject of technological development both in terms of control and improvement of performance and in the production process.

Researchers have schematically listed the twelve main techniques in a “wheel” of earth construction techniques (Figure 6.1), but they still specify that there are around a hundred in reality.

In addition to being a simplification, this circular table also does not distinguish between traditional techniques and new techniques.

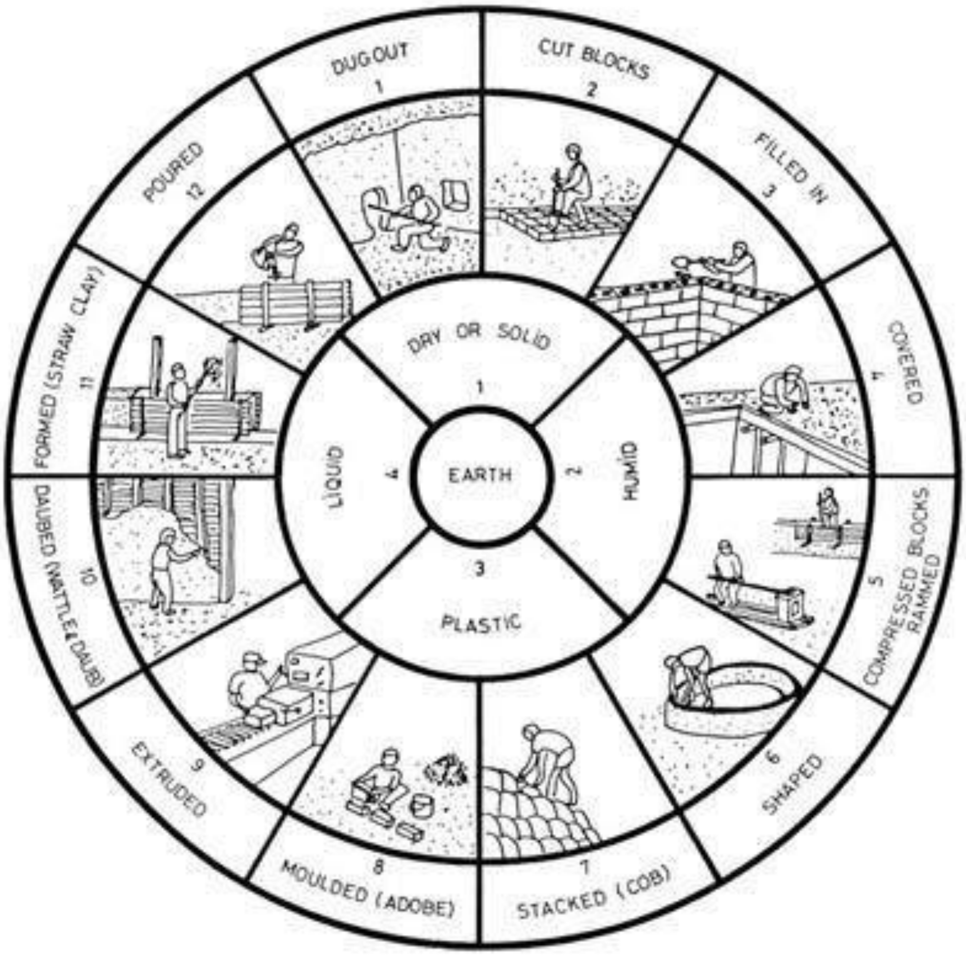


Figure 6.1: Wheel of different construction techniques

The following is a summary of the main techniques.

6.2.1. Adobe

6.2.1.1. Definition

The first prefabricated building elements used by man were molded mud bricks called "adobes", a technology used for millennia throughout the world. Adobe is a building material made from a mixture of sand, clay, a quantity of chopped mulch or other fiber. Quite clayey in nature (up to 30% fine fraction), but very sandy, added with water until a semi-firm paste is obtained (15 to 30% water).

Each element of the mixture plays its role. The sand reduces the probability of microcracks in the block of earth, the clay agglutinates the particles and the chopped straw, for its part, gives a certain grade of flexibility. This mixture is then placed by hand in a wooden mold to make small masonry elements, the size required to be unmolded and dried directly on the ground (figure 1.2). The adobe brick can vary in size from 15 x 25 x 10 cm or 30 x 60 x 10 cm. Adobe construction is widespread around the world, from China to countries in the Middle East, Africa, Latin America, France and the United States of America.

Table 6.1: Characteristics of mud bricks (adobe)

Characteristics	Adobe
Density (kg/m^3)	1200-1700
Compressive Strength MPa	$2*10^{-3} – 5*10^{-5}$
Conductivity λ (W/m°.C)	046 – 0.81
Absorption (%)	5
Sound insulation (dB)	-
Shrinkage on Drying (mm/m)	1

Figure 6.2: Adobe blocks

6.2.1.2. Production

The production of adobe blocks must take into account successive stages from the extraction of the earth to the final storage of the material ready to be used in construction

6.2.1.3. Adobe production methods

There are two main methods of production of adobes, one manual and the other mechanized, reflecting a traditional mode of production and a modernized mode of production.

6.2.1.3.1. Manual production method

a) ***Simple Molds***

It corresponds to traditional molding either by manual shaping or using a mold. Shaped by hand (Figure 6.3), the earth is generally used in the state of a semi-firm plastic paste. The earth can be used to two different water states, either in the form of a semi-soft dough and using a method called "water blow" (mold previously cleaned and wet to facilitate unmolding), or in the form of a semi-firm dough and using a method called "sand blast" (the mold, previously cleaned and wet, is powdered with sand to facilitate unmolding). In these two manual molding techniques, average production yields are 400 to 600 blocks per day for 2 workers.

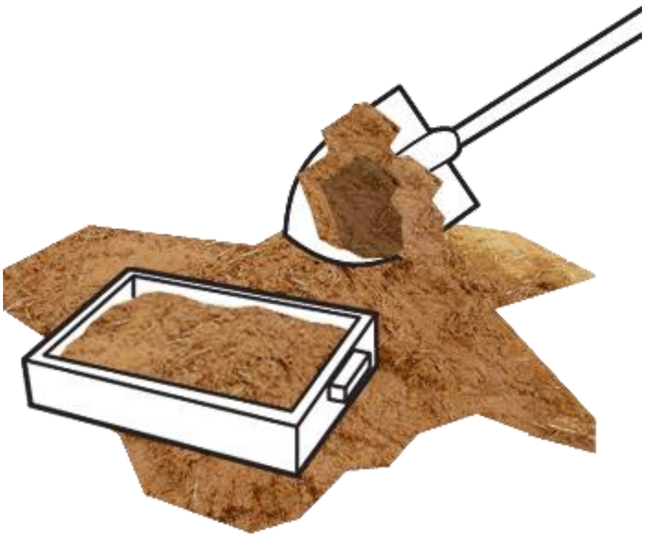


Figure 6.3: Simple mold

b) ***Multiple molds***

It combines the use of large molds with multiple compartments, generally ladder-shaped or square shaped subdivided into small compartments, and the delivery of the earth, in a fairly liquid state, by wheelbarrows, dumpers or bucket bulldozers. Sometimes the earth is poured directly from the mixer which is then mobile and towed by or on a truck.

The molds must be easily handled by 2 workers (not too heavy) and must be clean and wet before pouring the soil into them. Given the more liquid water state of the earth, adobes produced in this way present a risk of shrinkage and therefore greater cracking. It is therefore appropriate to compensate for this risk by using soil whose texture is rich in coarse sand and small gravel. The organization of mechanized production is around two main positions which are mixing and molding and mobilizes 5 to 6 workers depending on the size of the units. The average production for this type of organization is around 8,000 at 10,000 blocks per day.

Figure 6.4: Multiple molds

6.2.1.4. The advantages of Adobe

Adobe has several advantages over industrial materials:

- ✓ It has the ability to regulate the humidity of the air.
- ✓ To store heat.
- ✓ Reduce energy consumption.
- ✓ To produce virtually no pollution.

- ✓ Inexpensive construction.
- ✓ Does not result in the production of gas.

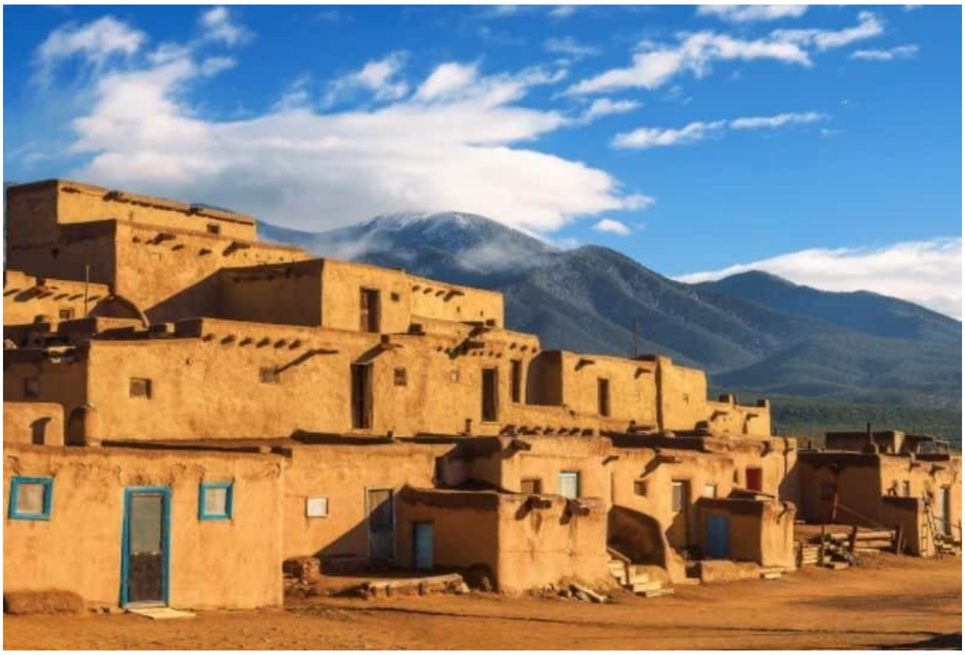


Figure 6.5: Traditional adobe houses.

6.2.2. Rammed earth

6.2.2.1. Definition

Rammed earth, a centuries-old technique for using raw earth, offers exceptional qualities of habitability and adaptation but requires attention and regular monitoring. Well-constructed and protected, the rammed earth building has survived the centuries and adapts naturally to the diverse needs of men. Traditionally, rammed earth buildings wear "good boots" and a "good hat". That is to say that the base is treated in such a way as to avoid capillary rise (most often made of pebbles, stone or masonry terracotta bricks) and the roof overhang is sufficient to avoid water runoff. on the facade. Rammed earth, for its part, is in fact the compaction of a volume of earth inside a formwork manually using a pestle or using specialized machinery. (Figure I.3) shows an example of formwork that can be used for the manufacture of rammed earth walls.

Figure 6.6: Rammed earth construction

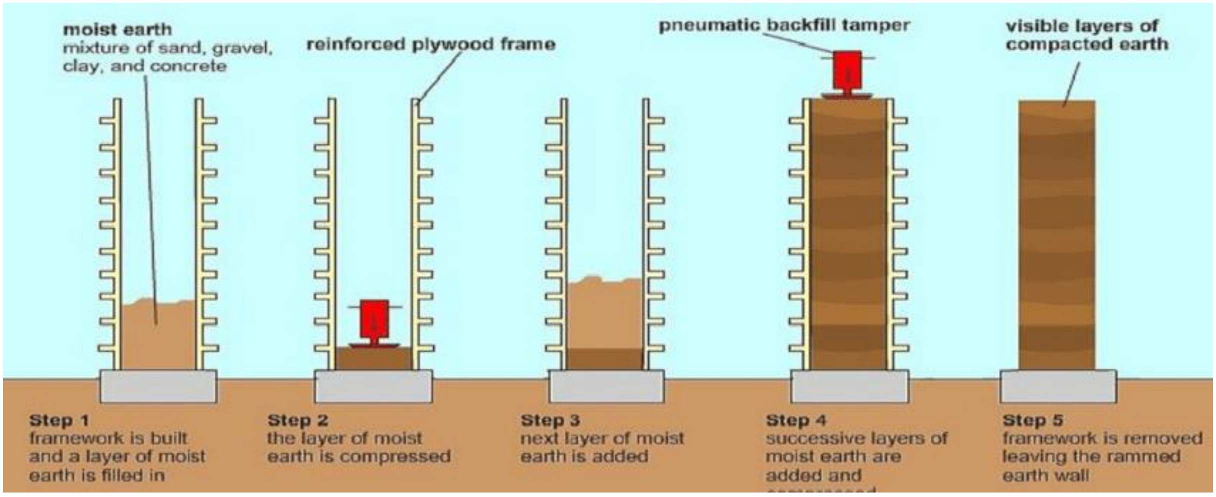


Figure 6.7: Rammed earth building technique

6.2.2.2. The advantages of rammed earth

Clay has many qualities in the field of buildings:

- ✓ Humidity regulator: ability to allow water vapor to pass through.
- ✓ Lifespan: heritage of hundred-year-old buildings with a strong presence
- ✓ Phase shifting: it slows down heat transfer (and allows for undeniable summer comfort)
- ✓ It is an element of high inertia, i.e. it has a good capacity to store heat and release it by radiation.

- ✓ Good sound insulation and sound quality.
- ✓ Easy to take over, but requiring know-how.

6.2.3. Wattle and daub

The Wattle and daub technique uses a wooden frame filled with earth, or most often a mixture of earth and straw. The material in its plastic state is thus forced to fill the empty spaces. The surface can be left as is or coated to obtain a more regular finish. Daubed walls are not load-bearing and their thickness is generally between 15 and 20 cm.

Figure 6.8: Wattle and daub wall

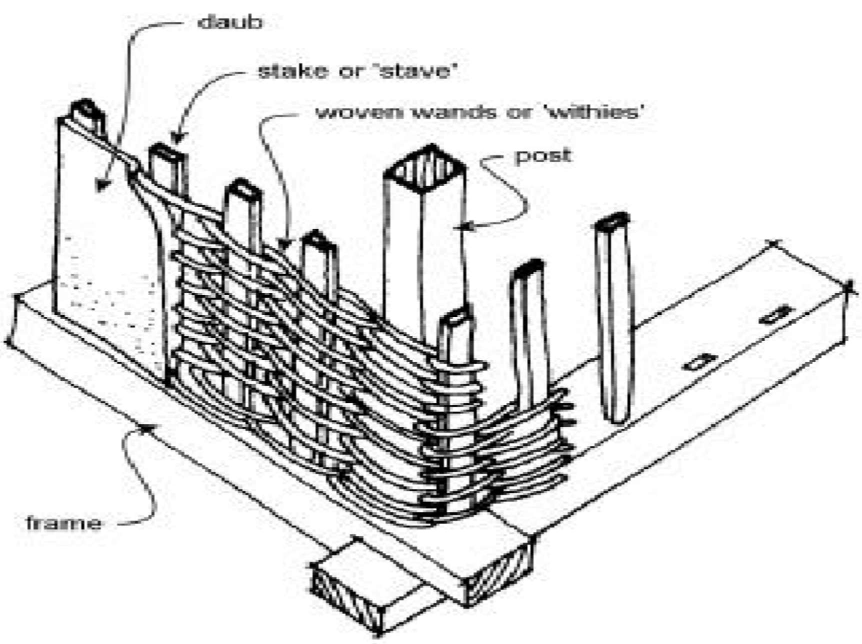


Figure 6.9: Wattle and daub technique.

6.2.4. Stacked (COB)

The cob is mounted in self-supporting earth piles without the aid of mortar or formwork. For this type of construction, the earth is slightly moistened and is often mixed with plant fibers. The mixed material is either piled by hand in mounds or thrown vigorously against the wall. The rough surface is then coated to obtain a smooth wall. Given the significant quantities of water introduced to the material during construction, significant drying shrinkage phenomena are likely to occur. Careful selection of soil and implementation is necessary. Low compaction energy leads to low densities, even though shrinkage ultimately increases.

Figure 6.10: COB building technique.

6.2.5. Shaped earth

The shaped earth technique is implemented with earth in a plastic state, without mold or formwork. This way of doing things makes it possible to obtain a wide range of often very rich architectural forms while reducing labor and construction costs. The tools used are simple and the walls made with this technique allow good adhesion of the coatings. On the other hand, controlling drying and shrinkage cracking is complex and the mechanical performance of the material is rather problematic.

Figure 6.11: Shaped earth building.

6.2.6. Poured earth (earth concrete)

The poured earth technique can be compared to the poured lean concrete technique. It uses the earth in the state of liquid mud whose granularity is preferably sandy or gravelly.

The advantages of this technique are multiple: easy preparation of the material, ease of implementation and wide range of applications, but it also has a big disadvantage: shrinkage during drying is significant. However, stabilization can solve this problem. We can also compartmentalize the constructions in order to reduce shrinkage or simply fill the cracks after drying when they do not pose structural problems. Poured earth makes it possible to make bricks, paving stones and walls, reinforced or not.

Figure 6.12: Poured earth wall.

6.2.7. Compressed earth blocks

Figure 6.13: compressed earth blocks building

This modern version of the block of molded raw earth, or adobe, uses earth with characteristics quite similar to those of rammed earth but which can be more clayey (up to 25%) and stripped of their larger elements (diameter > 20 mm). The sandy fraction (large sands) must be dominant and the gravelly fraction (small gravels) may be less. The material thus composed, of a fairly uniform particle size, is compacted to a low humidity state using presses of very diverse types and performance registers. The production of compressed earth blocks can be compared to that of terracotta blocks produced by compaction, with the exception of the firing phase.

There are several types of molds for these presses producing different types of bricks (Figures 6.14). Depending on the work that will be carried out (load-bearing masonry, filling masonry, reinforced masonry, special work, installation by juxtaposition, installation by interlocking, etc.), the most suitable brick will be chosen.

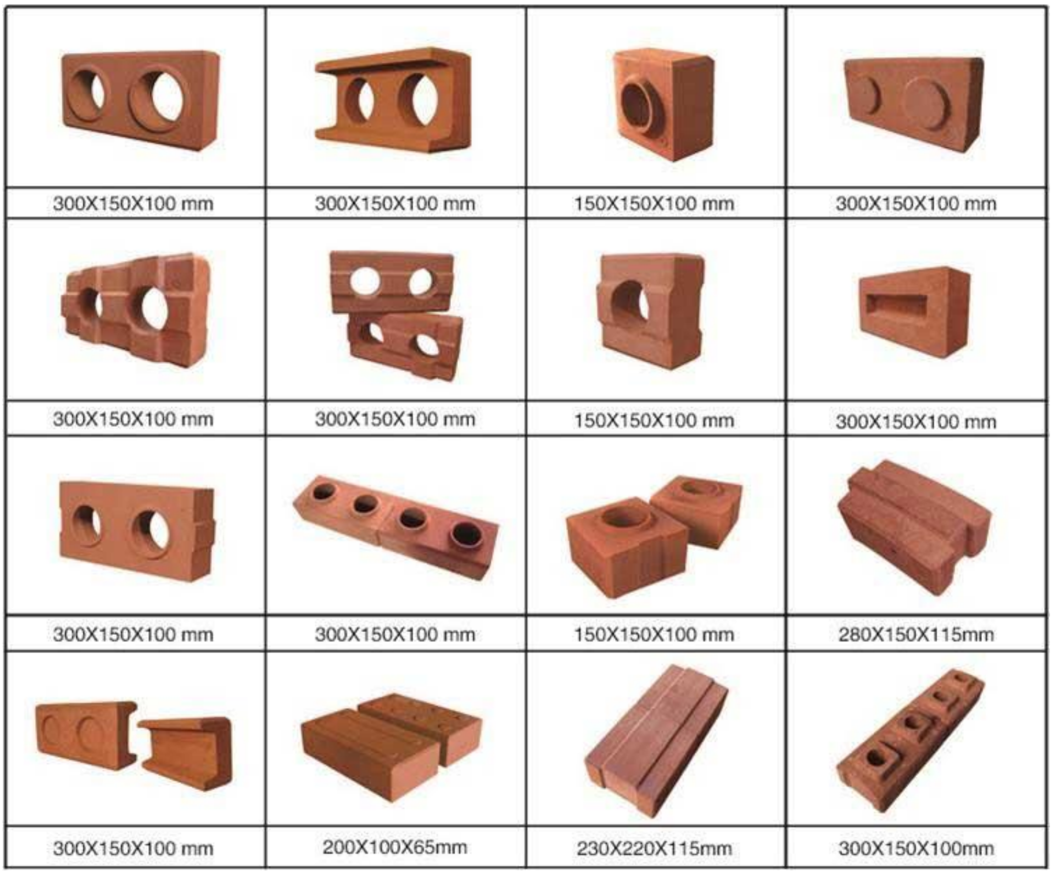


Figure 6.14: Different shapes compressed earth blocks

6.2.8. Straw clay

The earth-straw technique is a technique carried out on a wooden frame. The mixture used includes more straw than in the cob. To prepare it, we sift the earth to 1.5 cm, then throw it into the concrete mixer with water. It is important to always stir so that the clay remains in suspension. We take out the mud and put it in a trailer in which we add the straw (impregnated with water). The mixture is then left to soak overnight before using it. Formwork must be made between the framing posts and the earth-straw must be packed into it. Then the formworks are removed immediately. The interval between the bridges can be greater than in cob and, as no wooden rods are installed, much less wood is used. The average width of a wall is 28 cm for a weight of 200 - 300 kg/m^3.

Figure 6.15: Straw clay building process

6.2.9. Cut blocks

Depending on the region, this technique (Figure 6.16) is known by different names: “t’épate” in Mexico, “caliche” in the U.S.A. “mer gel” in Holland, “Marl” in England and “tuff” in the countries Mediterranean. The size of the cutting blocks is carried out in the quarry. The extraction of these blocks is similar to that of traditional stone, that is to say it is carried out using picks, chisels, wedges and saws. These quarries have soil that is sufficiently coherent and of such hardness that we can directly cut blocks that can be used for construction.

The soil from these quarries is generally rich in carbonate elements. The cut blocks are implemented like classic blocks.

Figure 6.16: Cut blocks extraction

6.2.10. Extruded earth

The earth is extruded by a powerful machine close to or derived from the equipment used for the manufacture of products intended to be cooked.

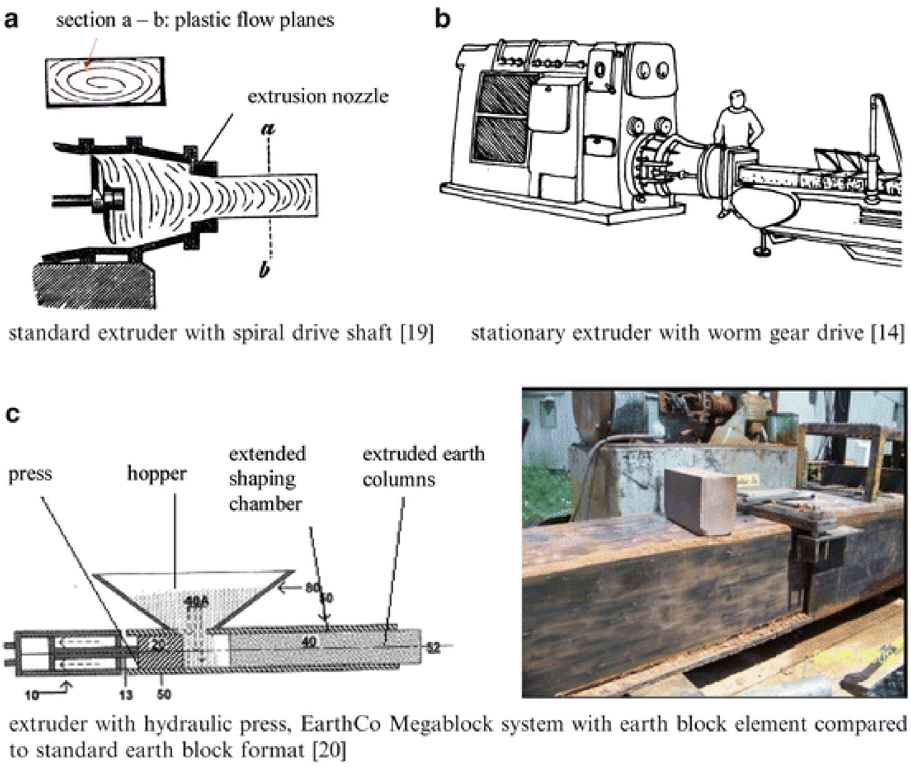


Figure 6.17: Extruded earth technique

Figure 6.18: Extruded earth block

6.3. Advantages of earth material

Raw earth offers many advantages. In fact, it is an ecological and 100% recyclable material. It also has good thermal and acoustic inertia (good noise absorption coefficient). It offers good permeability to water vapor which allows it to be a natural temperature regulator.

Much research dealing with earth material is being conducted because earth constitutes a material which meets the concerns of sustainable construction to the extent that it meets several targeted criteria. Among its criteria we can list the following points:

6.3.1. Economic advantages

- ✓ Reduction in foreign currency flight through a reduction in imported materials (cement, steel and wood).
- ✓ Labor-intensive manual production which favors the local economy.
- ✓ Local material.
- ✓ earth material is less expensive than conventional materials, particularly in developing countries where manual use is not expensive.
- ✓ Construction materials (concrete, terracotta bricks, concrete blocks) consume a lot of energy, which are among the highest of all sectors of human activity. Earth reduces energy costs associated with construction whose manufacturing, simple implementation (press, molds, light formwork) and transport of earth materials require little energy (oil, gas, etc.).

- ✓ The earth material reduces energy consumption linked to air conditioning and heating,

6.3.2. Environmental advantages

- ✓ Natural material.
- ✓ Earth can be fully recyclable which produces no industrial or chemical waste.
- ✓ Earth constructions also function very well in hygrothermal ways which contribute to the regulation of thermal comfort environments, thermal phase shift (effusivity and diffusivity) and also give buildings the possibility of "breathing" by absorbing or releasing humidity by depending on the surrounding water conditions, The reduction of gas emissions (an entirely positive pollution balance).

6.3.3. Socio-economic advantages

- ✓ The creation of jobs throughout the production chain
- ✓ The land allows us to extend the heritage of architectural traditions using local materials.
- ✓ Earth constructions can guarantee access to the dignity of decent housing for populations who most often live in precarious and miserable conditions.
- ✓ Whatever the earth construction techniques, treatment is kept to a minimum.

Bibliography

[1] NATTERER, Julius. Construction en bois : matériau, technologie et dimensionnement. PPUR presses polytechniques, 2004.

[2] COURARD, Luc. Matériaux de construction. 2012.

[3] ELLOUMI, Imen. Caractérisation des propriétés diélectriques du bois et des composites bois-polymère. 2016. Thèse de doctorat. Université du Québec en Abitibi-Témiscamingue.

[4] BENOIT, Yves et PARADIS, Thierry. Construction de maisons à ossature bois. Editions Eyrolles, 2009.

[5] URI: http://dspace.univ-djelfa.dz:8080/xmlui/handle/123456789/1194

[6] http://elearning.univ-biskra.dz/moodle2019/mod/resource/view.php?id=18802

[7] VALENTIN, Jean-Louis. La charpente, mode d'emploi. Editions Eyrolles, 2014.

[8] https://fr.scribd.com/document/722749297/020macgs1-chapitre9-leboisetderives

[9] Gottfried W. Ehrenstein, Fabienne Montagne : Matériaux polymères Structure, propriétés et applications ; HERMES Science Publications, Paris, 2000, ISBN 2-7462-0149-6.

[10] Haddadi S, Influence de la poudrette de caoutchouc sur le comportement au fluage des Enrobés bitumineux. Thèse de Doctorat d'état, FGC/USTHB FGC/USTHB 2007.

[11] Jacque B et Fernand P : Matériaux bitumineux spéciaux. Rapport général Bulletin de Liaison des Laboratoires de Ponts et Chaussées. N° V144. Juil-Décembre 1986.

[12] Junod. A, ing. Dipl. EPF Prof A.-G. Dumont Formulation et optimisation des formules d'enrobés Mandat de recherche ASTRA 2000/421-2 Décembre 2004.

[13] Lesueur Didier, la rhéologie des bitumes : Principe et modification. Vol 2 1-30 (2002).

[14] Oyekunle. L.O, Certain Relationships between Chemical Composition and Properties of Petroleum Asphalts from Different Origin, Vol. 61 (2006), No. 3, pp. 433-441

[15] Toby Singleton, effects of rubber – bitumen interaction on the performance of impact absorbing asphalt. 2000 Society of Chemical Industry. All rights reserved LPS 107/2000, ISSN 1353-114X.

[16] Soudani K, Caractéristiques mécaniques et rhéologiques des enrobés bitumineux modifiés par des polymère- Impact sur l'environnement,2009.

[17] Nicolas Ward, Caractérisation de nouveau bitume caoutchouc. Université de Sherbrooke 2003.

[18] Yann .L, Contribution à l'étude du comportement en fatigue des enrobés bitumineux Étude de l'allongement des éprouvettes comme manifestation de l'endommagement diffus, Expérimentation modélisation. Thèse de doctorat LNPC 2001.

[19] http://dspace.univ-djelfa.dz/xmlui/handle/123456789/1194

[20] https://fr.slideshare.net/maitrungtrung/polymerescomposites

[21] SALMI, Safia. La construction en pisé entre performances énergétiques et perception des usagers: cas du village kabyle Ait Itchir. 2014. Thèse de doctorat.

[22] DOAT, Patrice, HAYS, Alain, HOUBEN, Hugo, et al. Construire en terre. Éditions Alternative et parallèles, 1979.

[23] GUILLAUD, Hubert. Architecture de terre. 2007. Thèse de doctorat. Université Pierre Mendès France.

[24] EAG, CRA Terre. Bloc de terre comprimée volume I. Manuel de production.

[25] DJOUHRI, Mohamed. Confection d'une brique à base de sable de dunes. 2007. Thèse de doctorat.

[26] GIVONI, Baruch et IZARD, Jean-Louis. L'homme, l'architecture et le climat. Paris : Editions du moniteur, 1978.

[27] RECHT, Thomas. Study of eco-design of plus energy houses. 2016. Thèse de doctorat. Université Paris sciences et lettres.

[28] Paulus, Jehanne, et al. Construction en terre crue : dispositions qualitatives, constructives et architecturales–Application à un cas pratique : Ouagadougou. 2015.

[29] TAALLAH, Bachir. Etude du comportement physico-mécanique du bloc de terre comprimée avec fibres. 2014. Thèse de doctorat. Université Mohamed Khider Biskra.