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MODULE

Building Materials Technology (TMC)

Instructor

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Grade

Lecturer

Distribution of the overall hourly volume of the Teaching Unit:

Course: 1H30

Coefficients allocated to the Teaching Unit:

Coefficient : 2 S.H.V **:** 45H00 TMC1

Coefficient : 2 S.H.V **:** 45H00 TMC2

University Academic Year: 2024/2025

SUMMARY

MODULE DESCRIPTION

The module "Building Materials Technology (TMC)" aims to provide students with the fundamental knowledge and methodological tools required for a rational, sustainable, and efficient selection of materials used in the building sector. It seeks to develop a thorough understanding of the physical, mechanical, and environmental characteristics of construction materials, while integrating the principles of sustainable development and energy efficiency.

Through this course, students learn to identify, evaluate, and anticipate the potential effects of construction projects on the natural environment, as well as to design appropriate strategies to prevent, mitigate, or compensate for negative impacts. Particular attention is given to the valorization of local resources, the reduction of environmental footprints, and the rational management of raw materials.

The course content covers the scientific, technical, and regulatory foundations related to building materials. It addresses their composition, manufacturing processes, properties, and fields of application, while examining their durability, recyclability, and environmental impact. The course also includes a normative and comparative dimension, studying quality standards, ecological labels, and regulatory requirements with a focus on the Algerian context.

Finally, case studies and practical work enable students to apply the acquired knowledge through the analysis and selection of materials adapted to various architectural and climatic contexts, thereby fostering an integrated, innovative, and environmentally responsible approach to construction.

1. BUILDING MATERIALS

Summary

INTRODUCTION

The aim of this discipline is to develop the ability to make informed choices regarding construction materials, taking into account their specific characteristics while considering coherence, safety, durability, and associated costs (Zhang, 2016). Recognizing the diversity of available materials and their various applications within the construction industry is essential.

1. Definition

A material is a substance that humans utilize and/or create to manufacture objects, build structures, or develop machinery.Materials are categorized based on their origin (for example, derived from living organisms) and their specific attributes, whether mechanical (such as flexibility or rigidity), chemical (like permeability or impermeability to water), or physical (such as electrical or heat conductivity) (Cambridge University.2022).

2. Classification of materials

They are generally classified into different major families (Zhang, 2016):

- **Metallic materials** encompass metals such as iron, copper, bronze, and metallic alloys like stainless steel.
- **Organic materials** are derived from living organisms, including plants or animals, such as wood, cotton, or paper.
- **Mineral or inorganic materials** include rocks, ceramics, and glass.
- **Plastic materials typically** originate from fossil fuels found in the ground, such as petroleum, for example.
- **Composite materials** combine several materials from different families to achieve multiple properties, for instance, carbon fiber.

2.1. The main characteristics of the different families of materials

The main characteristics of the different families of materials are indicated in Table 1

Table 1. The main characteristics of the different families of materials
Source: https://www.acsce.edu.in/acsce/wp-content/uploads/2020/03/Aircraft-material-science.pdf,2025

<table>
<tr>
<td>MINERAL OR INORGANIC MATERIALS
- Rigidity
- Hardness
- Mechanical resistance
- Fragility to torsion
- Chemical resistance</td>
<td>METALLIC MATERIALS
- Mechanical resistance
- Resistance to torsion
- Electrical and thermal conductivity</td>
<td rowspan="2">COMPOSITE MATERIALS
The properties of composite materials depend on the materials included in its composition and the means of production
Example:
Reinforced concrete combines
the mechanical resistance
of concrete (mineral) with the torsion resistance capacity of steel (metallic).</td>
</tr>
<tr>
<td>PLASTIC MATERIALS
- Ease of shaping
- Elasticity</td>
<td>ORGANIC MATERIALS
- Easy to shape
- Biodegradable</td>
</tr>
</table>

2.2. Classification of Building Materials

In construction, it has become customary to distinguish between construction materials and protective materials based on their usage and primary characteristics (IOER-ISBE, 2021).

2.2.1. Construction Materials are those capable of withstanding substantial forces:

- Stones: Used for their durability and strength in various construction applications.
- Terracottas: Fired clay materials known for their resilience and often employed in construction.
- Concrete: A versatile composite material made of cement, aggregate, and water, renowned for its strength and adaptability in building structures.
- Metals: Including steel, iron, aluminum, and other alloys, valued for their robustness and versatility in construction purposes.

2.2.2. Protective materials refer to substances that possess the property of enveloping and safeguarding primary construction materials:

- Coatings: These encompass various substances applied to surfaces for protection, enhancement, or decorative purposes.
- Paintings: Refers to pigment-based liquids applied to surfaces for color, protection, or aesthetic purposes.
- Bitumens: Asphalt-based materials commonly used for waterproofing or sealing applications in construction.

3. Properties of building materials

The properties of construction materials determine the scope of their application. It is only by accurately assessing the quality of materials, specifically their most important properties, that we can construct buildings and structures that are robust, durable, economically feasible, and technologically advanced (Callister, W. D., & Rethwisch, D. G. 2020).

All properties of construction materials, based on their indicators, are categorized into physical, chemical, or mechanical properties (JBIET. 2020).

Physical properties include weight, density, permeability to liquids and gases, heat resistance, and resistance to the aggressive effects of the environment (RGMCET. 2020).

The latter property characterizes the material's resistance to change, succinctly determining the lifespan of construction elements. Chemical properties are assessed based on a material's resistance to acids, bases, and saline solutions, which can trigger exchange reactions leading to the deterioration or destruction of the material.

3.1. Physical properties

The ability of a material to resist compression, tension, impact, penetration of foreign bodies, as well as any other effect due to the application of a force, characterizes the mechanical properties.

These different properties are the subject of the respective sections of the course relating to each given material.

- **Apparent density:**

By density (kg/m) is meant the mass of the unit volume of the material (of the article) in its natural state (including pores and voids)

- **Apparent density:**

Yo = m / V or m, is the mass of the material, in kg; V; its volume, in m3,The density of the same material can be different depending on porosity and cavitation. Powdery materials (sand, gravel, cement, etc.) are characterized by their apparent density.The volume of these materials includes not only the pores of the separate grains, but also the voids between the grains. The density of a material largely reflects its properties

$$\gamma_{app} = \frac{M_t}{V_t}$$

technical, such as, for example, thermal resistance or conductivity. According to these data, the thickness of the protective structures of heated buildings, the dimensions of the construction elements are determined, they are also taken into account in the calculation of transport equipment and handling equipment, etc. The values of the density of construction materials vary widely. The density varies depending on the porosity and humidity of the construction material (Table 2) It increases with increasing humidity. To a certain extent, the density can serve as a criterion for the economic parameters of the material.

Table 2. Density of Common Construction Materials
Source:https://sheerforceeng.com/2021/12/26/density-of-construction-materials-and-construction-elements/,2025

Construction Material	Density (kN/m^3)	Density (kg/m^3)	Density (lb/ft^3)
Aluminium	26.7	2723	170.0
Asphalt	21.2	2162	135.0
Bitumen	10 to 14	1019 to 1427	64 to 89
Brass	83.5	8514	531.5
Cement Mortar	14.4	1468	91.7
Cement Mortar	20.1	2050	128.0
Chalk	21	2141	133.7
Clay Soil	19	1937	120.9

Density represents the degree of filling of a body's mass by solid material. It is calculated by comparing the density of the material to that of water at a specific temperature. Density is expressed without units.

$$D = \frac{Ms}{Me}$$

- **Porosity:**

Porosity is the ratio of the void volume to the total volume of a material.

$$P = \frac{V_{vide}}{V_{total}} \times 100(\%)$$

- **Compactness:**

Compactness is the ratio of the solid volume to the total volume of a material

$$c = \frac{V_{solide}}{V_{total}} \times 100(\%)$$

- **Porosity and compactness :**

Porosity and compactness are related by the following relationship: ***p + c = 1***

Void Index: is the ratio of the void volume to the total volume of the material.

$$\text{Void Index} = \frac{V_{\text{Void}}}{V_{\text{solid}}}$$

- **Humidity:**

Humidity is one of the important properties of construction materials. It refers to the actual water content of a material present in its pores. Generally denoted as ***W*** humidity is expressed as a percentage (%).

$$W = \frac{M_{hum} - M_{sec}}{M_{sec}} \times 100\ (\%)$$

- **Water Absorption Capacity:**

Water absorption capacity refers to a material's ability to absorb and retain water. It is defined by the quantity of water absorbed by a completely dry material when fully immersed. This characteristic can be expressed as a percentage of the mass (mass absorption capacity) or volume (volumetric absorption capacity) of the dry material. Water absorption is calculated as a percentage using the formula:

Water Absorption Capacity=(Initial mass or volume of the dry materialMass or volume of absorbed water)×100

$$Ab = \frac{M_{sat} - M_{sec}}{M_{sec}} \times 100$$

3.2. Chemical properties

- **Chemical stability**

is the ability of a material to resist the effects of acids, bases, saline solutions, and gases. Installations most often exposed to the action of corrosive liquids and gases include sanitary facilities, pipelines, and hydraulic systems (subjected to seawater containing high levels of dissolved salts).

Natural stones such as limestone, marble, and dolomite do not withstand the action of even the weakest acids; bitumen cannot resist concentrated alkaline solutions. Conversely, ceramic materials and elements made from plastics exhibit the highest stability against the effects of acids and bases.

- **Durability**

Durability is the ability of a material in service to withstand the combined effects of atmospheric and other factors. These factors may include fluctuations in temperature and humidity, exposure to various gases present in the air or saline solutions in water, the combined action of water and freezing, as well as exposure to solar radiation.

The loss of a material's mechanical properties can occur due to a disruption of its homogeneity (such as cracking), exchange reactions with ambient substances, and changes in the material's state (modification of the crystalline structure, recrystallization, transition from an amorphous to a crystalline state).

3.3. Mechanical properties

The mechanical properties of materials are characterized by their ability to withstand external forces (Callister & Rethwisch, 2020). Based on various indicators, a material's resistance to compression, bending, impact, torsion, etc., as well as its hardness, plasticity, elasticity, and wear due to friction, can be distinguished (Ashby & Jones, 2012). Mechanical strength refers to a material's ability to resist destruction under stress from an applied load (Budynas & Nisbett, 2020).

The materials comprising a structure can be subjected to different types of loads. Common loads experienced by construction structures include compression, tension, bending, and impact (Beer et al., 2015).

There are two methods to determine the strength of materials: the "Sample Destruction" method and the "Non-destructive Sample" method (Krause & Zhuang, 2018).

- **Method the "Sample Destruction“**

Method is the most commonly used, especially for determining compressive strength. Compressive strength is experimentally determined by testing specimens on mechanical or hydraulic presses. Specifically designed test specimens are employed for this purpose (Fig 1) .

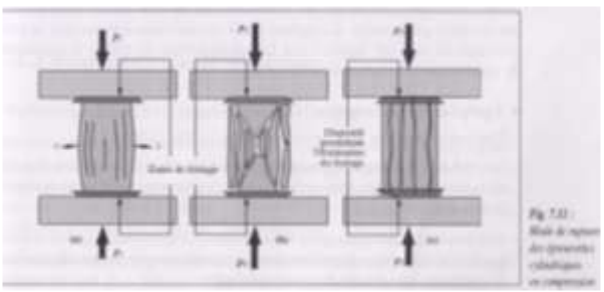


Fig 1. Testing specimens on mechanical (Source: R.Dupain, 2009)

The "Sample Destruction" method is an approach in which material samples undergo tests that may result in their destruction. Typically, these tests involve subjecting samples to loads until they reach their breaking point or their resistance limit. For instance, to assess the compressive strength of a material like concrete, specific test specimens are loaded until they crack or break, thereby measuring the material's ability to withstand compression forces. This method provides crucial data on the mechanical properties and strength of materials, but it often requires the destruction of the tested samples.

- "**Non-destructive Sample" method:**

The non-destructive sampling method is one of the approaches used to quickly assess the strength of structural materials (such as concrete in a structure) without physically removing hardened concrete through coring.

Typically, several methods are employed:

- Schmidt Hammer (also known as a rebound hammer or sclerometer) (Fig 2)
- Sonic sounding or sonic pulse (Fig 3)
- velocity testing

These techniques allow for the estimation or evaluation of material strength without the need for invasive sampling or removing portions of the structure. They provide valuable insights into the structural integrity of materials in situ.

Fig 3. Sonic sounding
(Source: R.Dupain,2009)

Fig 2. Sclerometre
(Source: R.Dupain,2009)

2. BINDERS

Summary

1. Definition

Binders are products generally used in the form of fine powders, which, after being transformed into a thicker paste with water, harden and form a hard and compact mass similar to natural rock (Taylor, 1997). Binders are used to make concrete mortars, paints, adhesives, sealants, etc (Neville, 2011).

2. The classification of binders

Binders can be classified into two major families based on their composition (Mehta & Monteiro, 2014):

2.1. Mineral binders: are generally obtained by high-temperature treatment of mineral materials and harden in the presence of water (Hewlett & Liska, 2019).

2.2. Organic binders: are synthesized by living organisms or by human science, starting from pre-existing mineral or organic matter (Ghosh, 2016). They are finely ground powders produced by the transformation of rocks. These powders mix with water to form a plastic paste that hardens over time due to chemical reactions (Scrivener et al., 2018). Some binders harden only in air, while others harden in humid or aquatic environments (Mindess et al., 2003).

3. The types of mineral binders

Calcined binders can be classified based on their hardening process (Hewlett & Liska, 2019):

3.1. Hydraulic binders: harden and retain their mechanical properties both in air and water:

- Cement
- Hydraulic lime

3.2. Aerial binders: harden and retain their mechanical properties only in open air:

- Lime
- Plaster
- Magnesian binders

They result from the firing of limestone rocks at a temperature of around 1000°C (Taylor, 1997). Natural limestone rocks often contain impurities, particularly clay. Depending on the purity of the limestone used, we can obtain: (Hydraulic binder, Aerial binder) (Mehta & Monteiro, 2014).

4. Hydraulic mineral binders

Hydraulic mineral binders are obtained by mixing limestone stones with a certain amount of clay or silica (Scrivener et al., 2018). They can be:

- Natural: meaning obtained from a deposit of lime containing clay.
- Manufactured: meaning derived from a mixture prepared in a factory.

5. Cement

Cement is a binder, a material that hardens and can bind to other materials (Neville, 2011). Depending on the cement's ability to be used in the presence of water, the cement used in construction is called hydraulic or non-hydraulic (Hewlett & Liska, 2019).

The main component of cement is clinker, obtained from the calcination of an appropriate mixture of 80% limestone and 20% clay (Taylor, 1997) Fig 4.

Cement is referred to as a hydraulic binder because it has the property of hydrating and hardening in the presence of water (Scrivener et al., 2018).

Fig 4. The component of cement

Source: https://civiltoday.com/civil-engineering-materials/cement/10-cement-ingredients-with-functions,2025

5.1. Principle of Cement Manufacturing

The cement manufacturing process can be schematically reduced to the following steps:

- Extraction
- Homogenization
- Drying and Grinding
- Calcination
- **Additives:**Additives can be added during grinding or afterward, in mixers or even in concrete plants, which can lead to differentiation of products and ranges. (Fig 5.)

1).Extraction

Extraction involves obtaining the raw materials: limestone ($CaCO_3$) 75 to 80% and clay (SiO_2–Al_2O_3) 20 to 25%, from quarries.

The two quarries can be located on the same site or be distant from each other.

2).Homogenization

Creating a homogeneous mixture with well-defined chemical proportions is the homogenization phase.

This operation is carried out either in a pre-homogenization hall or in a vertical silo through blending.

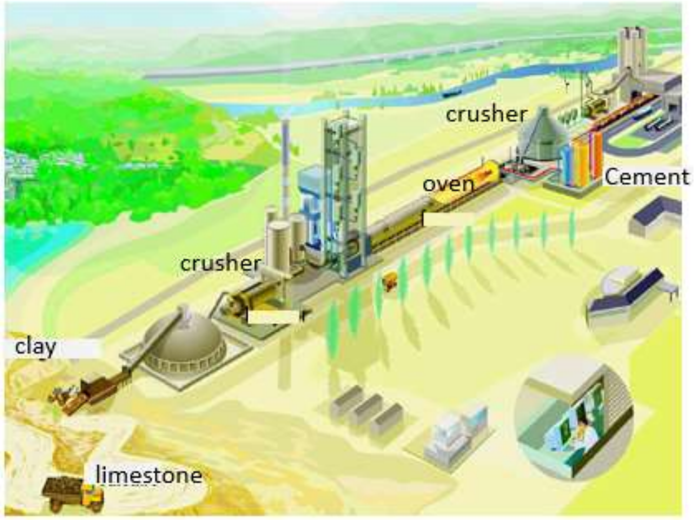


Fig 5. Cement kiln diagram rotary kiln

Source:https://www.cementequipment.org/cement-plant-operation-ccr-operator/kiln-control-operation/,2025

3).Drying and Grinding

The drying and grinding steps promote the following chemical reactions. The raw materials are ground very finely in ball mills or, more recently, in vertical roller mills, which are more energy efficient (Hewlett & Liska, 2019).

Depending on the type of preparation, there are three main categories of “routes”:

• **Wet Process**

• **Dry Process:** The raw meal is introduced into the kiln in powdered form after preheating in a heat exchange tower (Taylor, 1997).

• **Semi-Dry Process:** Before being introduced into the kiln, the raw meal is transformed into "granules" by humidification in granulators.

The raw material is mixed with water to achieve approximately 13% moisture, then these granules are preheated (350 °C) and decarbonated (900 °C) before entering the kiln. After that, the raw product is placed in a long kiln (60 to 200 m) that is rotary (1.5 to 3 revolutions per minute), tubular in shape (up to 6 m in diameter), and slightly inclined (2 to 3% slope) (Fig 6).

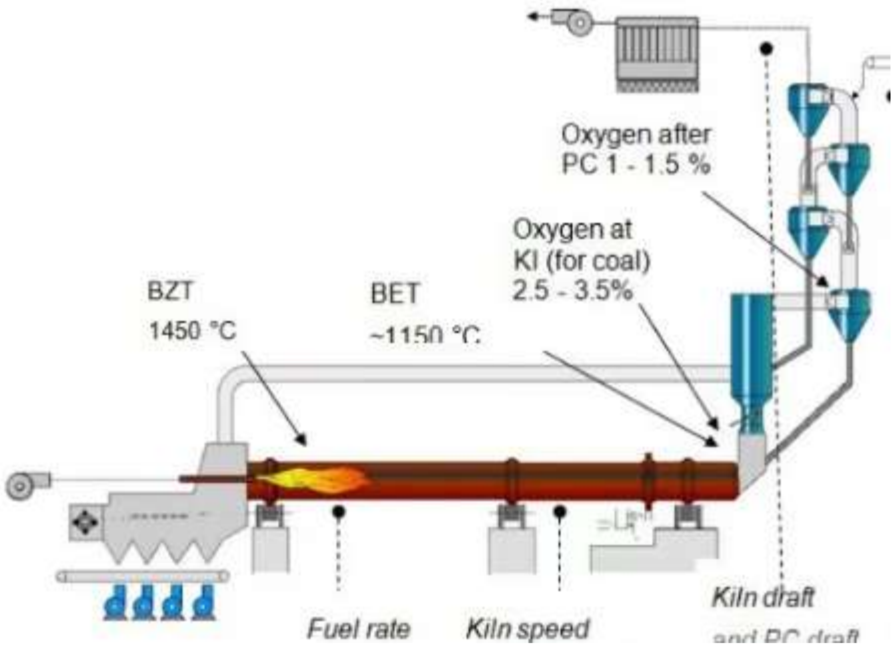


Fig 6. Cement kiln diagram rotary kiln

Source:https://www.cementequipment.org/cement-plant-operation-ccr-operator/kiln-control-operation/,2025

4).Calcination

As it slowly progresses through the kiln and encounters the flame, the raw material undergoes various transformation stages. The temperature required for clinkering is approximately 1450 °C. It takes the form of gray granules. The cement must be cooled and ground after exiting the kiln before being stored in silos.

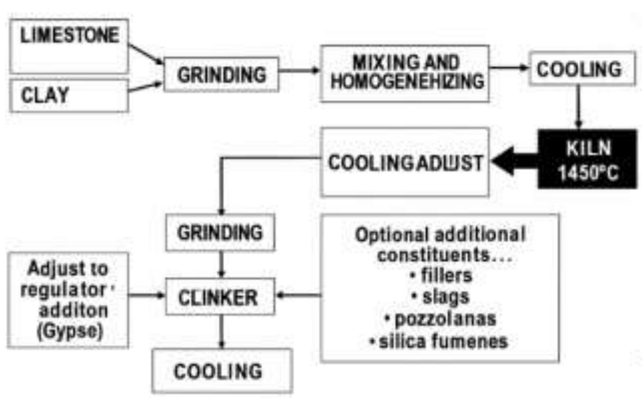
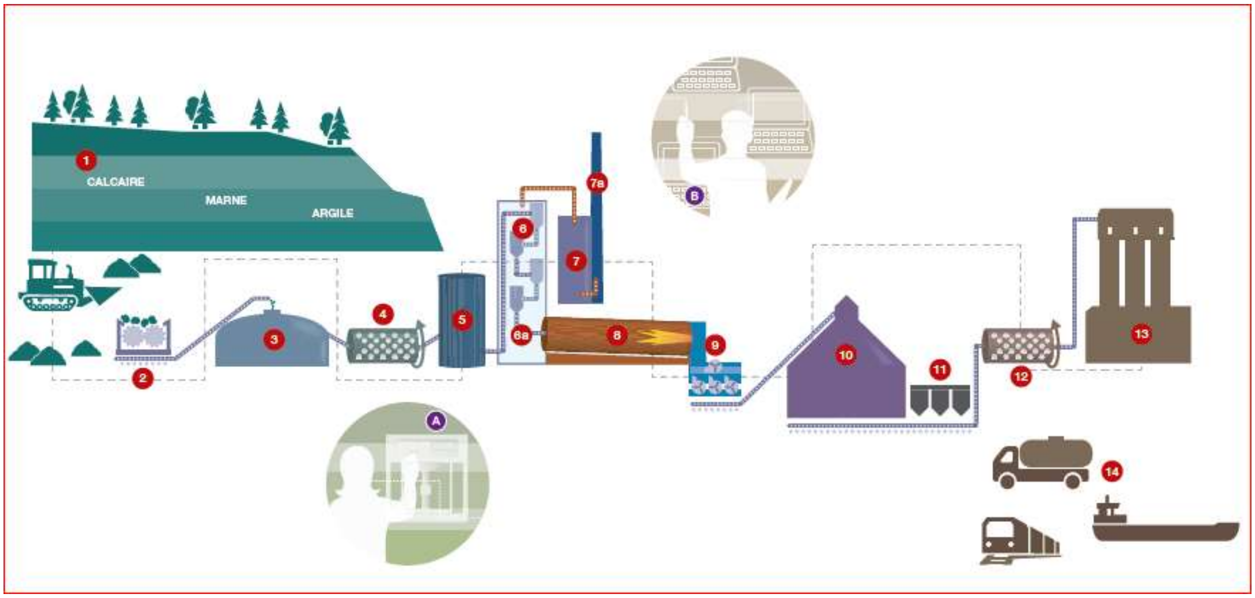


Fig 7*. Dry process cement manufacturing diagram

Source:https://wecivilengineers.wordpress.com/2018/08/24/dry-process-of-cement/,2025



1- Extraction of raw materials. 2- Primary and secondary crushers 3- Pre-homogenization hall

4- Crude dryer grinder 5- Raw homogenization silo. 6- Preheating tower + Precalciner.

7- Bag filter 8- Rotary oven.

11- Other constituents 12- Cement grinder. 9- 10 - Cooler + clinker storage silo.

Fig 7. Dry process cement manufacturing diagram
Source:https://wecivilengineers.wordpress.com/2018/08/24/dry-process-of-cement/,2025

5.2. Composition of Cement Clinker

The different constituents combine during burning to form cement clinker. The compounds formed during the combustion process possess the properties of setting and hardening in the presence of water. They are known as Bogue compounds, named after Bogue, who identified them (Taylor, 1997). These compounds are as follows:

- **Alite (Tricalcium Silicate or C3S)**
- **Belite (Dicalcium Silicate or C2S)**
- **Celite (Tricalcium Aluminate or C3A)**
- **Felite (Tetracalcium Alumino Ferrite or C4AF).**

1). Tricalcium Silicate: It is considered the best cementing material and is a well-burned cement. It accounts for about 25% to 65% (normally around 62%) of the cement. It makes the clinker easier to grind, increases resistance to freeze-thaw cycles, hydrates quickly generating high heat, and develops early hardness and strength (Hewlett & Liska, 2019).

2). Dicalcium Silicate: This constitutes about 20% to 40% (normally around 22%) of the cement. It hydrates and hardens slowly and takes a long time to increase its strength (after a year or more). It provides resistance to chemical attacks. An increase in C2S content makes the clinker harder to grind.

3). Tricalcium Aluminate: This accounts for about 5% to 11% (normally around 8%) of the cement. It reacts quickly with water and is responsible for the instant setting of finely ground clinker. The speed of action is regulated by adding 2% to 3% gypsum during the grinding of the cement. Tricalcium aluminate is responsible for the initial setting and high heat of hydration.

4). Tetracalcium Ferrite and Alumino: This constitutes about 8% to 14% (normally around 8%) of the cement. It is responsible for triggering flash set but generates less heat. It has the lowest cementing value.

5.3. Uses of Cement

- Cement mortar for masonry work, plastering, and jointing, etc.
- Concrete for laying floors, roofs, and constructing lintels, beams, frost walls, stairs, pillars, etc.
- Construction of major civil engineering works such as bridges, culverts, dams, tunnels, lighthouses, clocks, etc.
- Construction of water structures, wells, tennis courts, septic tanks, street lamps, telephone booths, etc.
- Manufacturing of precast pipes, garden seats, artistically designed benches, flower posts, etc.
- Preparation of foundations, waterproof floors, sidewalks, etc.

5.4. Different Types of Cement

There is a wide variety of cement types based on the components used and their proportions. Here are a few examples:

- Common cements
- Cements tailored for specific uses
- Special cements
- Hydraulic road binders

➢ Ordinary Portland Cement

Ordinary Portland cement is the most commonly used type of cement in the world. This cement is made by heating limestone (calcium carbonate) with small amounts of other materials (such as clay) to 1,450 °C in a kiln, according to a process called calcination, during which a molecule of carbon dioxide is released from calcium carbonate to form calcium oxide, or quicklime, which is then mixed with the other materials included in the mix. The resulting hard substance, called "clinker," is then ground with a small amount of gypsum to obtain a powder to make "ordinary Portland cement" (Mindess, Young, & Darwin, 2003).

This type of cement is used in construction when there is no exposure to sulfates present in the soil or groundwater.

- Rapid-Hardening Portland Cement:
- It is firmer than ordinary Portland cement.
- It contains more C3S and less C2S compared to ordinary Portland cement.
- Its strength at 3 days is the same as the strength at 7 days of ordinary Portland cement.

➢ **Low-Heat Portland Cement**

The heat generated in ordinary Portland cement after 3 days is 80 cal/g. In low-heat cement, it is approximately 50 cal/g of cement (Hewlett & Liska, 2019).

- It contains a lower percentage of C3A and relatively more C2S and less C3S.
- It reduces and delays the heat of hydration of this cement.

➢ **Sulfate-Resistant Portland Cement**

- This cement uses slag from the blast furnace.
- The cement clinkers are ground with approximately 60% to 65% of debris.

Its initial strength is lower, requiring a longer curing period. It proves to be economical because debris, which are waste materials, are used in its production(Mehta & Monteiro, 2014).

➢ **Pozzolanic Cement**

- The proportions of pozzolana can range from 10% to 25% by weight (e.g., burnt clay, shale, fly ash).
- This cement exhibits greater resistance to chemical agents and seawater due to the absence of lime.
- It releases less heat and has lower initial strength, but its final strength at 28 days is equal to that of ordinary Portland cement.
- It has less resistance to erosion and weathering.
- It provides a higher degree of water impermeability and is cost-effective.

5.5. Various Tests on Cement

Fundamentally, two types of tests are conducted to evaluate the quality of cement. These are either field tests or laboratory tests.

- **5.5.1. Field Test**

Four field tests can be performed to approximately verify the quality of cement. There are four types of field tests to assess the color, physical properties, and strength of the cement, as described below.

- **Color**

• The color of the cement should be uniform.
• It should have the typical color of cement, which is gray with a slight greenish tint.

- **Physical Properties**

• The cement should feel smooth to the touch between the fingers.
• If a hand is inserted into a bag or pile of cement, it should feel cool.

- **Presence of Clumps**

• The cement should be free of lumps.
• With a moisture content of around 5 to 8%, this increase in volume can range from 20 to 40%, depending on the sand's granulation.

- **Strength**

• A thick paste of cement with water is made on a piece of thick glass and kept underwater for 24 hours. It should set without cracking.

5.5.2. Laboratory Tests

Six laboratory tests are conducted primarily to evaluate the quality of cement. These are: fineness, compressive strength, consistency, setting time, soundness, and tensile strength.

- **Fineness**

• This test is performed to check the proper grinding of cement.
• The fineness of the cement particles can be determined either by a sieve test or by a permeability apparatus test.
• In the sieve test, a sample of 100 g of cement is continuously passed through a standard BIS No. 9 sieve for 15 minutes. The residue is then weighed, and this weight should not exceed 10% of the original weight.
• In the permeability apparatus test, the specific surface area of the cement particles is calculated. This test is superior to the sieve test. The specific surface area serves as a measure of the frequency of medium-sized particles.

- **Compressive Strength**

• This test is performed to determine the compressive strength of cement.
• A mortar of cement and sand is prepared in a 1:3 ratio.
• Water is added to the mortar in a water-cement ratio of 0.4.

- The mortar is placed in molds. The samples are in the form of cubes, and the molds are made of metal. For cubes measuring 70.6 mm and 76 mm, the required amounts of cement are 185 g and 235 g, respectively.
- The mortar is then compacted in a vibrating machine for 2 minutes, and the molds are placed in a humid chamber for 24 hours.

➢ **Compressive Strength**

- The samples are removed from the molds and immersed in clean water for curing.
- The cubes are then tested in a compression testing machine after 3 days and 7 days. This is how the compressive strength is determined.

➢ **Consistency**

The purpose of this test is to determine the percentage of water needed to prepare cement paste for other tests.

- Take 300 g of cement and add 30 percent by weight, or 90 g of water.
- Mix the water and cement thoroughly.
- Fill the mold of the Vicat apparatus, and the mixing time should be between 3.75 and 4.25 minutes.
- The Vicat apparatus consists of a needle attached to a movable rod, which has an indicator fixed to it.
- There are three attachments: square needle, plunger, and annular collar needle.
- The plunger is attached to the movable rod. The plunger is gently lowered onto the paste in the mold.
- The settlement of the plunger is noted. If the penetration is between 5 mm and 7 mm from the bottom of the mold, the amount of water added is correct. If not, the process is repeated with different percentages of water until the desired penetration is achieved

➢ **Setting Time**

- This test is used to detect the deterioration of cement due to storage. The test is performed to determine the initial and final setting times.
- The cement mixed with water is poured into the Vicat mold.
- A square needle is attached to the movable rod of the Vicat apparatus.
- The needle is quickly released and can penetrate the cement paste. Initially, the needle penetrates completely. The procedure is repeated at regular intervals until the needle does not penetrate completely (up to 5 mm from the bottom).
- Initial setting time = ≤30 minutes for ordinary Portland cement and 60 minutes for low-temperature cement.
- The cement paste is prepared as described above and poured into the Vicat mold.
- An annular collar needle is attached to the movable rod of the Vicat apparatus.
- The needle is gently released. The moment at which the needle makes an impression on the test block and the collar fails to do so is noted.

• The final setting time is the difference between the moment water was added to the cement and the time recorded in the previous step, and it should be ≤10 hours.

- **Soundness**

• The purpose of this test is to detect the presence of uncombined lime in the cement.
• A cement paste is prepared.
• The mold is placed and filled with cement paste.
• It is covered on top with another glass plate. A small weight is placed on top, and the entire setup is immersed in water for 24 hours.
• The distance between the indicator points is noted. The mold is placed back in the water, and heat is applied so that the boiling point of the water is reached in about 30 minutes. Boiling of the water is continued for one hour.
• The mold is removed from the water and allowed to cool.
• The distance between the indicator points is measured again.
• The difference between the two readings indicates the expansion of the cement and should not exceed 10 mm.

- **Tensile Strength**

• This test was previously used to provide an indirect indication of the compressive strength of cement.
• A sand and cement mortar is prepared.
• Water is added to the mortar.
• The mortar is placed in briquette molds. The mold is filled with mortar, and then a small mound of mortar is formed on top. It is tamped with a standard spatula until water appears on the surface. The same procedure is repeated for the other side of the briquette.
• The briquettes are kept in a humid place for 24 hours and carefully demolded.
• The briquettes are tested in a testing machine after 3 and 7 days, and an average is established.

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3. THE LIMES

Summary

3.4. Slaking
4. Main Properties
4.1. Physical
4.2. Chemical Properties
5. Use in Construction
5.1. Plasters
5.2. Laying and Joint Mortars

1. The limes

They result from the firing of limestone rocks at around 1000°C. Natural limestone rocks often contain lower levels of purity compared to the limestone used. Limestone products, such as quicklime and slaked lime, are referred to as lime. Limestone is a natural stone rich in calcium and/or magnesium carbonates. Limestone is extracted from quarries and mines around the world(Boynton, 1980).

Limestone : is used to produce lime. Calcium carbonate, also known as pure limestone, is composed of $CaCO_3$. However, impurities such as $MgCO_3$, Al_2O_3, and SiO_2 may be present.

Limes are generally classified as either non-hydraulic or hydraulic. Non-hydraulic limes cannot harden without the presence of air, such as underwater**.**

2. Air binders (Fat lime)

Fat lime has been one of the earliest binders used (along with plaster and bitumen) for millennia. Ancient civilizations constructed durable structures using lime-based mortars. Lime, obtained by firing limestone rocks ($CaCO_3$) or dolomitic rocks (a combination of $CaCO_3$ and $MgCO_3$) followed by slaking with water, hardens slowly in the air, which is why it is commonly referred to as air lime (Fig 8).

Fig 8. Fat lime
Source : https://www.buildersmart.in/blogs/lime-material/,2025

3. Production of Air Lime

It is carried out according to the following steps (Fig 9):

3.1. Extraction
3.2. Crushing, screening, and grading
3.3.Firing or calcination
3.4.Slaking

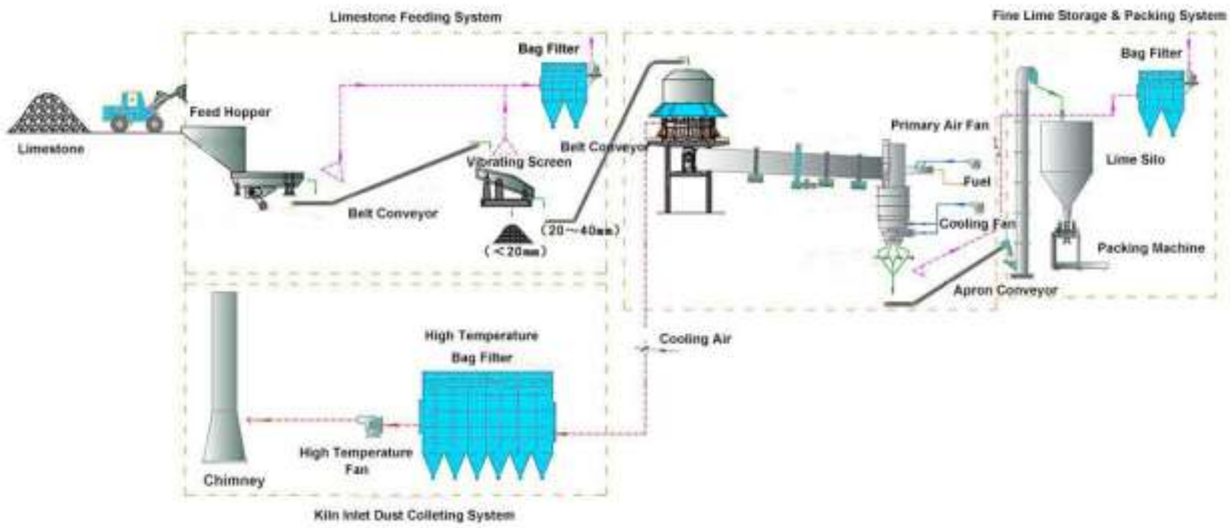


Fig 9. Production of Air Lime

Source : https://cement-plants.com/epc-project/lime-production-line/,2025

3.1.Extraction

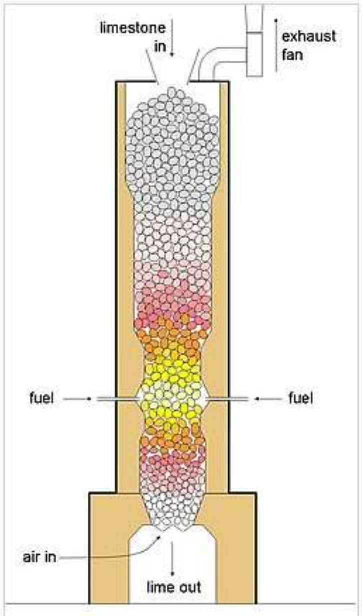
Quarries produce limestone. Traditionally, extraction was done using manual tools such as picks and shovels. Currently, rock extraction is facilitated by the use of explosives (blasting). The produced blocks consist of rock and are transported using mechanical shovels before being loaded into trucks. They are then transported to preparation workshops where their processing (crushing, screening, and grading) begins(Oates, 1998).

3.2.Crushing, Screening, and Grading

The first step involves crushing the blocks before screening them to obtain a stone size suitable for the type of kiln used. Vertical kilns require a size range of 20 to 140 mm, while rotary kilns need a size range of 5 to 40 mm.

3.3. Firing or Calcination

In the industry, two types of kilns are used for firing limestone (Fig 10). The vertical or shaft kiln, modeled after primitive kilns, typically takes the form of a steel cylinder (average diameter: 2 m and height: 8 m), lined internally with a refractory material that is resistant to abrasion and corrosion. It is equipped with fans for draft. A discharging grate is located at the bottom. The annular shaft kiln has become the most energy-efficient kiln in recent years due to advancements in technology (Boynton, 1980).



An oven for calcination of limestone

Fig 10. firing limestone

Source : https://en.wikipedia.org/wiki/Calcination,2025

The material is fired between 1000°C and 1300°C to produce lime, depending on the type of lime being produced. One side of the kiln introduces the limestone. Before undergoing calcination, the limestone passes through a preheating zone. After calcination, the lime is cooled before extraction. The stone slowly descends after passing through the preheating zone. This crucial step prevents the blocks from bursting by evaporating the free water contained in the stone. The stone then undergoes calcination in another section, which is a decarbonization process that results in the loss of CO_2 at 900°C.

The decarbonization of dolomites occurs at a temperature of 400°C or lower to produce magnesia (MgO). The fumes vent the water vapor produced and contribute to the proper decarbonization of the limestone. The quicklime generated then descends to a third cooling zone before being extracted. The introduction of fresh air at the bottom of the kiln creates a counter-current airflow that moves through the kiln and assists in various stages of lime production, such as cooling, combustion.

3.4. Slaking

"Swelling" is the process that converts quicklime into slaked lime, causing an increase in volume. This is the result of molecular structure changes and the formation of lime hydrate needles.

At the time of use, the lime must be fully hydrated, otherwise, structural swelling may occur in the works.
$CaO+H_2O \rightarrow Ca(OH)_2$This is an exothermic reaction, releasing 155 Kcal/kg of CaO.

Slaking is achieved by adding water and can be done using various methods:

The **spontaneous slaking method** involves exposing quicklime to the slow and continuous action of the air. The slaking water is provided by the humidity in the atmosphere.

The **manual watering method** consists of adding just the right amount of water necessary for slaking (10 to 15%). In the case of lime blocks, the reaction is exothermic (releasing heat) and produces splashing.

The **traditional immersion method** involves soaking the lime blocks in water, draining them, and then storing them to allow for the slaking process. This is an exothermic process (15,500 cal/mol.g; T = 150°C). The lime must be added carefully, as the reaction can cause splashing and bubbling.

- The first three methods produce powdered lime. The quicklime granules are crushed and passed through a hydrator. The water introduced (7 to 10%) not only hydrates the quicklime but also helps dissipate the heat released during the reaction (T = 150°C).

- Sieving is used to remove unreacted particles, such as "grappiers" (impurities, overcooked or undercooked materials, etc.). The slaked powdered lime is then mixed and packaged in 25 or 50 kg bags, or in bulk.

4. Main Properties

4.1. Physical

- The residue on an 800 mm sieve is zero, and the residue on an 80 mm sieve must be less than 10%.
- The overall fineness should be between 8,000 and 20,000 cm^2/g.
- The absolute density is between 2200 and 2500 kg/m^3, while the bulk density is between 500 and 700 kg/m^3.
- Quicklime is highly reactive to water and slakes by hydrating with significant heat release. This property is used to dry and treat soils that are heavily waterlogged(Taylor, 1997)..
- The refractory temperature resistance of air lime is between 1800°C and 2000°C.
- Air lime begins to set slowly, with hard setting taking place in 600 minutes (10 hours).

Air limes are used in construction for the production of mortars and limewash. (Boynton, 1980).

4.2. Chemical Properties

- The content of free lime and magnesia (CaO and MgO) should exceed 80%.
- The carbon monoxide (CO) content must not exceed 5%.

5. Use in Construction

5.1.Plasters

They primarily serve two purposes: protection and aesthetics. The high elasticity of lime mortars helps prevent shrinkage cracks and crazing. Once hardened, lime mortars are impermeable to water yet breathable, allowing air to pass through to ensure the wall "breathes."

5.2. Laying and Joint Mortars

The compressive strength of a laying mortar is more significant than its bonding strength. Lime mortars, which are capable of producing...

Lime mortars, which achieve this adhesion thanks to their plasticity, are ideal for the task. They are also low in water permeability and resistant to cracking. They do not cause efflorescence. Lime mortars are excellent for joints in soft stone masonry, aerated concrete, or bricks. They are also frequently used in construction projects (Oates, 1998).

4. PLASTER

Summary

Introduction

Plaster is one of the oldest building materials used by humans, known since ancient times (Murray, 2003; Taylor, 2011). While it is still used to create coatings in its traditional form as a powder mixed with water, it is increasingly being used in the form of factory-prefabricated elements (tiles, slabs, panels) to meet modern construction needs (Bensted & Barnes, 2002).

Plaster is produced by dehydrating gypsum, a natural rock or a byproduct of certain industries, which is a hydrated calcium sulfate with the formula $CaSO_4 \cdot 2H_2O$ (Kurdowski, 2014).

Calcium sulfate is primarily found in nature in the following two forms:

• Hydrated with two water molecules per molecule of calcium sulfate ($CaSO_4 \cdot 2H_2O$): this is gypsum (Singh & Middendorf, 2007).

• Anhydrous ($CaSO_4$): this is anhydrite (Lea, 1998).

The plaster is made from gypsum, also known as "calcium sulfate dihydrate." Heating gypsum in a kiln dehydrates it and transforms it into plaster or calcium sulfate hemihydrate (Miller, 2016). Gypsum is primarily composed of calcium sulfate with two water molecules ($CaSO_4 \cdot 2H_2O$), which accounts for approximately 79% of calcium sulfate associated with 21% water (Bensted & Barnes, 2002). However, gypsum rarely achieves this theoretical composition because it often contains various impurities such as limestone, clay, sand, silica, magnesia, etc. (Singh & Middendorf, 2007). Additionally, its water content can vary (Taylor, 2011).

1. Gypsum

There are two main categories of gypsum:

- Natural gypsum
- Synthetic gypsum

2. Natural gypsum

Gypsum is a water-soluble sedimentary rock from the evaporite family (Smith et al., 2009).

- Lamellar gypsum, spearhead gypsum, and lenticular gypsum are the main varieties found in nature in macro-crystallized form.
- Alabaster gypsum, fibrous gypsum, saccharoidal gypsum, and aeolian gypsum are available in micro-crystallized form.

3. Synthetic Gypsum

Industrial chemical reactions primarily produce synthetic gypsum. Its production is limited due to technical, economic, and impurity-related reasons. Expensive chemical treatments are necessary to eliminate these impurities during this type of process (Wolter & von Eynatten, 2015).

4. Plaster manufacturing

The following steps are followed to produce plaster from natural gypsum (Fig 11) (Metha & Monteiro, 2014):

:

Fig 11. Gypsum panel manufacturing process
Source: https://gypsum.org/making-gypsum-board/,2025

4.1. Extraction

Plaster comes from gypsum. It can be extracted through open-pit mining (Fig 12) or underground quarrying.

Fig 12. Through open-pit mining
Source: https://en.wikipedia.org/wiki/Open-pit_mining,2025

4.2. Crushing and Screening

Before being introduced into the kilns, the gypsum is crushed and screened with recycling. Before being calcined, the gypsum may be dried in rotary cylinders if necessary.
The purpose of crushing is to convert the gypsum extracted from the quarry into finer products.

4.3. The calcination

The calcination process allows for the production of various components of plaster through a more or less extensive dehydration of gypsum (Harrison, 2012).:
There are numerous types of calcination equipment that are typically classified according to:

Heating Method: Dry or wet atmosphere.
Type of Kiln: Fixed, rotary (Fig 13), or other types.
Thus, the calcination process occurs through two pathways:

Fig 13. Gypsum Calcination Kiln
Source: https://gypsumtechnology.com/rotary-kiln.html,2025

1).Dry Process

This process is carried out to obtain as much plaster as possible. By using temperatures ranging from 110 to 180°C in discontinuous indirect-heating kilns, semi-hydrate is produced. It is composed of 94% crystallized $CaSO_4$ and 6% H_2O.

The semi-hydrate is flaky with scaly cracks and forms thick but weak mixtures with water. It requires a significant amount of mixing water (70%, compared to 35% for the alpha variety, at equal fineness), and its setting time is longer than that of alpha plaster.

•Soluble anhydrite ($CaSO_4$ III), which is unstable due to its high affinity for water, can be obtained at temperatures of 180°C ($170 < T < 250$°C). When added to traditional plaster, it activates the setting process.

•Overcooked or insoluble anhydrite ($CaSO_4$ II) is produced by calcining in continuous direct-heating kilns at temperatures ranging from 400 to 600°C. It can still combine with water (hydraulic plaster), but this process takes time. For the production of plasters for coatings, it is added to the semi-hydrate in a proportion of approximately thirty percent.

•An inert product that cannot set is produced at temperatures ranging from 600 to 900°C. Soluble anhydrite ($CaSO_4$ II) is produced with a very slow setting time (ranging from several hours to 15 days or more) if the calcination temperature exceeds 1100°C.

•When the calcination temperature reaches 1350°C, the anhydrite melts and dissociates.

2).Wet Process

Calcination is performed in an aqueous medium at temperatures above 100°C, either in a pressure autoclave (2 to 12 atmospheres) or in a concentrated saline solution. This process yields α-semi-hydrate, which is compact, crystalline, and slightly soluble in water, resulting in fluid products.

It is used in dental plaster and has high mechanical strength (Schneider et al., 2010).

4.4. Grinding

After calcination, the stones are ground according to two principles:

1).Standard Grinding

The plaster is reduced to particles of 200 µm using a system of rotating hammers inside a screen (ensuring a maximum particle size).

As in standard grinding, the plaster is crushed by rotating hammers and then drawn through a rotating "squirrel cage." Depending on its weight (and thus its size), the plaster grain, subjected to two opposing forces (centrifugal and suction), either passes through or is retained by the squirrel cage.

2).Mixing and Additives

Additives such as white cement, air lime, synthetic resin, setting modifiers, etc., are incorporated into the Beta and Alpha plaster mixes in highly variable proportions based on the intended use of the final product. It is also possible to add lightweight aggregates, which impart specific fluidity, expansion, and kinetics to the material. This creates a range of products tailored for each specific application (Gou, J.et al ,2025).

4.5. Control and Validation

The moisture content and purity of the gypsum are regularly checked upstream (after extraction). Samples are then taken throughout the manufacturing process and monitored in the laboratory.

4.6. Packaging

Plaster is sold in bulk or in paper bags of 25 or 40 kg.

5. Main Properties of Plaster

- **Coarse Plaster:**

Sieve residue of 800 µm: varies between 5 and 20%

Mixing water: 75 to 100%

Setting time: 8 to 25 minutes

Consumption: 8 kg/m² (5 m² per 40 kg bag)

- **Mortar composition:**

1:3 by weight (fine sand 0/2)

- The nature of the plaster, ambient temperature, the amount of mixing water, additives, and other factors influence the setting time.
- Plaster has a short setting time and rapid hardening.
- Plaster hydrates with an expansion of 0.3 to 1.5% depending on the type of plaster, followed by slight shrinkage due to water evaporation (one-tenth of the initial expansion).
- Plaster is particularly well-suited for molding because it expands and penetrates deeply into all the crevices of the mold.
- Plaster is a porous substance. It is permeable to air and water vapor. However, wet plaster encourages mold growth, which accelerates its degradation. For this reason, it is not recommended to use plaster alone for exterior coatings.
- Plaster is non-combustible. During a fire, plaster (gypsum) releases 18 to 20% of its bound water. The unexposed side remains below the temperature limit of 140°C, as specified by regulations. For example, a metal door without a coating does not resist fire, whereas a door covered with a 2 cm plaster coating resists fire for 30 minutes.
- Plaster has a low thermal conductivity coefficient of 0.4 to 0.6 kcal/m.h.°C, making it an excellent thermal and acoustic insulator. (Table 3.)

Table 3. Thermal characteristics of plaster (Source:https://www.google.com/search?q=Thermal+characteristics+of+plaster&sca_esv,2025)

Material or Application	Dry Density ρ (kg/m³)	Thermal Conductivity λ (W·m⁻¹·K⁻¹)	Specific Heat Capacity c (J·kg⁻¹·K⁻¹)	μ (dry)	μ (humid)
Plaster	600	0.18	1000	10	4
Plaster	900	0.3	1000	10	4
Plaster	1200	0.43	1000	10	4
Plaster	1500	0.56	1000	10	4
Plasterboard	900	0.25	1000	10	4
Insulating plaster coating	600	0.18	1000	10	6
Plaster coating	900	0.3	1000	10	6
Plaster coating	1300	0.57	1000	10	6
Plaster and sand mixture	1600	0.8	1000	10	6

6. Use in Construction

6.1. Plaster Coatings

A commonly used mortar for both exterior and interior coatings is made by combining plaster with sand and fat lime (10 to 15%).

Coarse plaster is used for the first application layer on walls, ceilings, and floors. The final finishing layer is made with fine plaster.

6.2. Building Materials

- Plaster can be reinforced with fibers. "Staff" is used in decoration and is made of plaster reinforced with hemp fibers.
- Plaster is also used to manufacture tiles and panels, which are often used for partitioning. The panels are plaster "sandwiches" placed between two sheets of cardboard.

5. AGGREGATES

Summary

Introduction

1. Definition
2. Variety of aggregates
3. Natural aggregates
   3.1 Various rocks
   3.2 Categories of natural aggregates
4. Production - aggregates processing (Fig 14).

Fig 14. Quarried-aggregate-production
Source : https://www.gmat.co.uk/quarried-aggregate-production/,2025

Introduction

Aggregates are the primary component in the majority of construction works. It is therefore important to understand all of their properties (and influences), both from the perspective of their production and their usage (implementation), in order to control costs while meeting quality criteria (Neville, 2011).

The nature and deposits determine the intrinsic properties (strength, porosity, etc.) of aggregates. However, the geometric characteristics (granularity, shape, etc.) and cleanliness depend on the production process. To manufacture products with the required quality, aggregate producers often use increasingly complex facilities that rely on well-mastered technologies (crushing, gravity separation, washing, etc.) (Mindess et al., 2003).

1. Definition

Aggregates are small-sized stony materials produced by erosion or mechanical crushing of rocks. They are inert materials used in the composition of concrete and mortars. They form the skeleton of concrete and represent about 80% of the total weight of the concrete.

They consist of coarse and fine sands, as well as gravel. However, aggregates must meet certain quality requirements to be used in concrete.
Since aggregates are heavy materials, transportation costs are relatively high compared to their own value. Therefore, production sites are naturally located close to consumption areas(Mehta & Monteiro, 2014).

Aggregates are composed of a combination of mineral grains that, depending on their size, are classified into one of six categories (Fillers, Sablons, Sands, Gravels, Pebbles, Ballast)(Fig 15). Their nature, shape, and characteristics vary according to the deposits and production techniques.

NAME		sieve mesh size in (mm)
broken stones and pebbles	Big	50 - 80
	Medium	31.5 - 50
	Small	20 – 31.5
gravel	Big	12.5 - 20
	Medium	8 – 12.5
	Small	5 - 8
sand	Big	1.25 - 5
	Medium	0.31 -1.25
	Small	0.08 -0.31
fines, flours and fillers		< 0.08

Fig 15. Categories of aggregates
Source : https://www.baichy.com/Knowledge/used-terms-in-sand-and-gravel-industry.html,2025

2. Variety of aggregates

The geological diversity of the subsoil allows for obtaining a wide variety of aggregates from very different rocks. The main types of rocks include:

- Glacial alluvium
- Fluvial alluvial sands and gravels

- Layers of sands or sablons
- Recent volcanic rocks
- Marine alluvium
- Consolidated sedimentary rocks
- Metamorphic rocks

An aggregate, depending on its nature and origin, can be natural: of mineral origin, coming from loose rocks (fluvial or marine alluvium) or from massive rocks (igneous, limestone, metamorphic rocks), having undergone no transformation other than mechanical processes (such as crushing, grinding, screening, washing) (Illston & Domone, 2010).

Artificial: of mineral origin resulting from an industrial process including, for example, thermal transformations: industrial by-products, refractory aggregates.

Recycled: obtained by treatment of an inorganic material previously used in construction, such as concrete from the demolition of buildings or road structures (Vegas et al., 2015).

3. Natural Aggregates

3.1. Various Rocks

Natural aggregates come from various rocks:

- **Magmatic or eruptive rocks:** they come from the cooling of previously melted magma. Among the eruptive rocks, we distinguish:volcanic rocks that are born by solidification of lava flows: basalts, andesites, rhyolites; plutonic rocks: granites, diorites, syenites, gabbros, etc.

- **Sedimentary rocks:** They form at the Earth's surface through the accumulation of sediments. They result from the erosion of igneous rocks or the deposition of marine sediments. They are often found in the form of loose rocks such as siliceous alluvium, silico-calcarenite, or limestone. Sedimentary rocks are categorized as follows:

- **Siliceous:** sandstone, quartzite, flint, chert, glacial sediments…
- **Carbonate:** limestone, dolomite…

- **Metamorphic rocks:** They are formed as a result of tectonic phenomena. They originate from the transformation of igneous or sedimentary rocks under the influence of temperature, pressure, or the addition of chemical substances: quartzites, gneiss, schists, mica schists, marbles… They are particularly exposed in ancient mountain ranges.

3.2.Categories of natural aggregates

Natural aggregates are classified into two categories:

- **Alluvial aggregates** or loose rock aggregates, referred to as rolled aggregates, which have a rounded shape acquired through erosion. These aggregates are washed to remove clay particles (which are detrimental to the strength of concrete) and screened to obtain different granular classes. They are extracted from rivers or near shallow marine beds. The extraction is carried out based on the deposit, the height of the river, or the water table, whether dry or submerged.
- Aggregates from solid rocks are obtained through blasting and crushing, which gives them angular shapes. A pre-screening phase is essential for achieving clean aggregates. Different stages of crushing lead to the desired gradation classes.

Crushed aggregates exhibit characteristics that depend on a variety of parameters, including:

- **Origin of the rock**
- **Uniformity of the deposit**
- **Degree of crushing**

4. Production - aggregates processing

The production of aggregates requires two main types of operations:

- **Extraction and processing:** Extraction takes place in quarries that use different techniques depending on whether it involves solid rocks or loose alluvial aggregates, either in dry conditions or in a hydraulic environment.
- **Processing**: This is carried out in processing facilities typically located on the quarry site. Sometimes, the facilities may be situated at a different location from the extraction site (Fig 16). In any case, the same five main production steps are involved:

  1).Stripping of Non-Extractable Levels

  2).Extraction of Materials

  3).Transfer to Processing Locations

  4).Processing of Aggregates

  5).Site Rehabilitation

1).Stripping (Overburden Removal): Stripping refers to the process of removing the materials located above the levels to be extracted, including:

- **Topsoil**
- **Weathered or partially altered rocks**
- **Sterile layers**

Overburden materials, such as topsoil and sterile materials, must be stored separately to allow for reuse during the rehabilitation of the quarry, without hindering the various phases of extraction. Considering the quantity of overburden is important in the study of a deposit. If the amount of overburden is deemed excessive, it may lead to a decision to forgo the opening of an extraction operation.

Fig 16. Production - aggregates processing

https://www.gmat.co.uk/quarried-aggregate-production/,2025

2).Extraction of Materials

- **Extraction in Loose Terrain**
  On Land (Dry Environment): When the alluvial aggregate deposit is located above the water level (groundwater, river water, etc.), the materials are directly extracted using traditional public works equipment, such as shovels or loaders (bulldozers equipped with a wide tilting bucket).

Extraction can take place through top-down excavation or bottom-up excavation, with lateral progression of the face of the cut.

- **In Submerged Sites (Hydraulic Environment):**Extraction can be performed using floating equipment, such as bucket dredgers, grab dredgers, or suction dredgers. In the case of shallow submerged sites, operations may occur from the shore using cable-operated shovels equipped with draglines, hydraulic shovels, or bucket excavators. Dredging brings the material to the surface, which is then loaded onto boats, trucks, or conveyor belts at the shore (Fig 17).

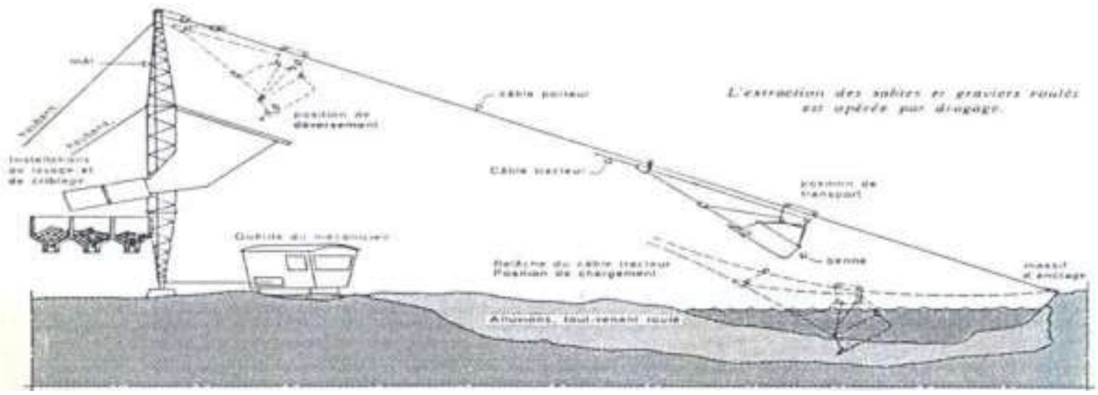


Fig 17. Extraction in Submerged Sites (Hydraulic Environment)
Source: https://www.agg-net.com/resources/articles/marine-aggregates/underwater-extraction-of-sand-and-gravel,2025

- **Extraction of Solid Rocks:**In this type of compact deposit, the extraction of solid rocks requires the use of explosives. Blasting operations result in the fragmentation of a large quantity of materials. The rock fragments (usually several decimeters in size) are then loaded and transported to the processing center (Fig 18).

Fig 18. Extraction of Solid Rocks
Source:https://globalroadtechnology.com/explosives-used-in-rock-blasting-a-grt-review/ ,2025

3).Transfer to Processing Facilities

The handling of materials between the extraction site and the processing center (as close as possible) occurs either continuously or intermittently:

- **Continuous Handling**: This is done using belt conveyors. The position of the conveyor units is adjusted based on the progression of the extraction process. This allows for efficient and uninterrupted transport of materials to the processing facilities.

In the case of extraction in a hydraulic environment, a system of pipelines or floating conveyor belts may sometimes be used between the dredger and the shore.

- **Intermittent Handling**: For terrestrial extractions, materials are transported by trucks and dumpers, while boats or barges are utilized for submerged operations that are quite far from the shores(Fig 19)..

Fig 19. Processing center
Source: https://www.gmat.co.uk/quarried-aggregate-production/,2025

4).Processing of Aggregates

- **Crushing**

Crushing phases are carried out in crushers, which progressively reduce the size of the materials. There are various types of crushers, (Fig 20) including:

- **Jaw crushers**
- **Impact crushers**
- **Centrifugal crushers**
- **Gyratory crushers**

The production of aggregates from solid rock always requires several crushing operations. For alluvial aggregates, crushing is only applied to the larger elements (such as pebbles or large gravel) or in specific cases.

Fig 20. Centrifugal crushers
Source: https://www.dscrusher.com/special-reports/sand-maker/,2025

- **Screening**

Screening or sieving operations allow for the selection of grains, with the screen only allowing elements smaller than a certain size to pass through its mesh. Through a series of screenings, grains can be sorted, and aggregates of all possible sizes can be obtained (Fig 21).

This process can yield either aggregates of a precise size (granulometry), for example, 3 mm sand, or within a defined range, for example, 10 mm < aggregates < 20 mm.

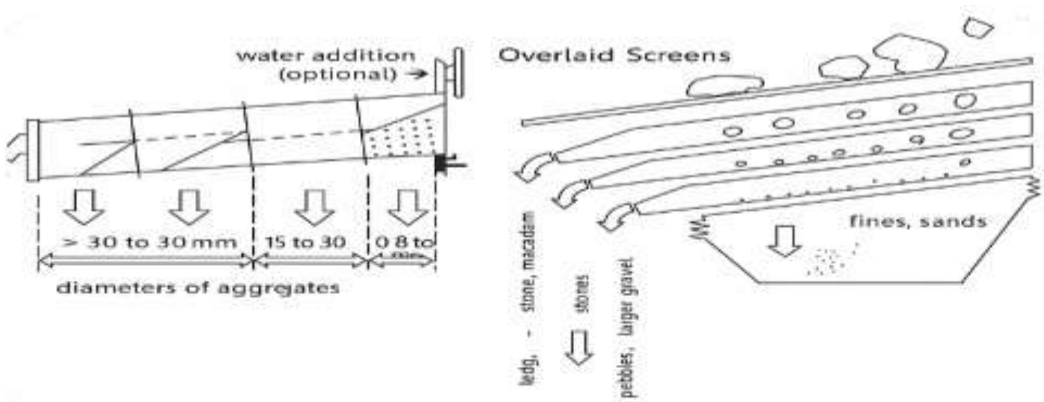


Fig 21. Screening of aggregates
Source : https://www.hellopro.fr/fa/concasseur-de-pierre-37734.html,2025

- **Washing**

- **Deburring, washing, or dust removal** ensures clean aggregates (Fig 22). Cleanliness of aggregates is an industrial necessity. The presence of sludge, clay, or dust mixed with or coating the grains prevents them from bonding with binders (cement, lime, slag, or bitumen), making them unsuitable for use. In all cases, the washing water is subsequently decanted in special basins, allowing it to be reused or returned clean to the river or lake.

Screening and washing operations are often performed simultaneously, with a water jet ramp placed above the screen.

Fig 22. Cleanliness of aggregates
Source : https://www.cdegroup.com/applications/sand-aggregates/silica-sands,2025

➢ **Storage and Delivery**

At the end of the processing, quality products are obtained that meet specific criteria:

- **Type of aggregates**: limestone, silica, volcanic, etc., depending on the quarry;
- **Shape of grains**: angular, rounded;
- **Precise granulometry** or granulometric range (cut-off)

....

5-1-AGGREGATES

Summary

1. Designation of Aggregates:

Aggregates are often designated based on their smallest and largest dimensions as follows:
Aggregate d/D
Aggregate: sand or gravel
d: minimum grain size
D: maximum grain size with a tolerance of 15% of elements (Neville, 2011).

Examples of commonly used aggregates: sand 0/3, gravel 3/8, gravel 8/15, gravel 15/25.

2. Aggregate Characteristics

The choice of aggregates is an important factor in concrete composition, as they make up two-thirds of the concrete's volume. To obtain the desired aggregate, it is essential to know some of its characteristics (Mehta & Monteiro, 2014).

2.1. Physical Characteristics

2.1.1.Granulometry
Definition: Granulometry (Fig 23) determines the range of grain sizes contained within an aggregate.

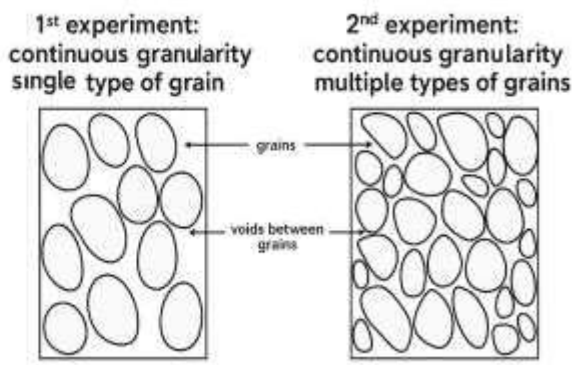


Fig 23. Granulometry
(Source: R.Dupain,2009)

The cement must fill the gaps between the grains to achieve a concrete of maximum compactness. However, cement is the most expensive component in the concrete mix. Therefore, it is desirable to minimize the gaps between grains. To do this, an optimal ratio of gravel, sand, and cement is sought. Determining the grain size of sand or gravel requires a laboratory test known as granulometric analysis (Kosmatka, Kerkhoff, & Panarese, 2002).

2.1.2.Granulometric Analysis

- **Definitions and Representations**
  Granulometric analysis is the process used to determine:
- **Granulometry**: The measurement of grain sizes.

- **Granularity**: The dimensional distribution of grains within an aggregate.

Granulometric analysis involves separating the material into various size fractions using sieves. The masses of the different retained fractions are then related to the initial dry mass of the material. The resulting percentages are presented in a graph (granulometric analysis curve)(Mindess, Young, & Darwin, 2003).

- Sieves are defined by the standard [EN 933-2]. The square mesh openings allow for granular classification. The successive mesh sizes follow geometric progressions:

$\sqrt[10]{10} \approx 1.25$ For the old French series

$10^{1/20} \approx 1.12$ For the new European series

The module of a sieve is calculated as ten times the decimal logarithm of the opening size in microns, plus one. For example, the module of a 5 mm sieve is calculated as: 10·log(5000)+1=3810 \cdot \log(5000) + 1 = 3810·log(5000)+1=38.

The term **granular class** refers to the range of sizes containing the smallest and largest grains within the same aggregate d/D.

- **Sieving** is the operation of separating a material into different fractions using a series of sieves with known characteristics.
- The term **sieve underflow** (or **passing**) (Fig 24). refers to the portion of material that passes through the sieve, while the **retained fraction** refers to the material that remains on the sieve.

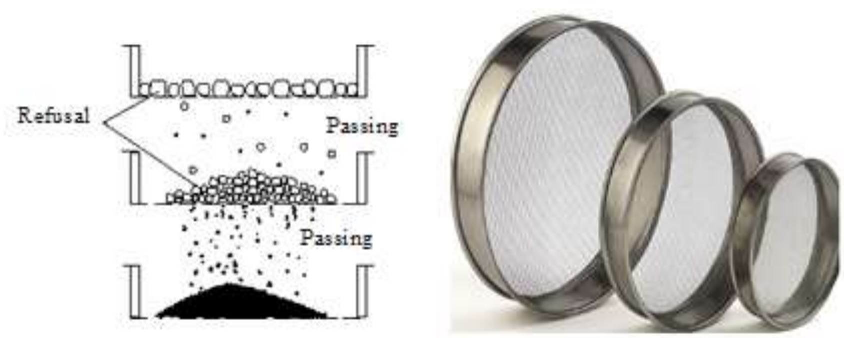
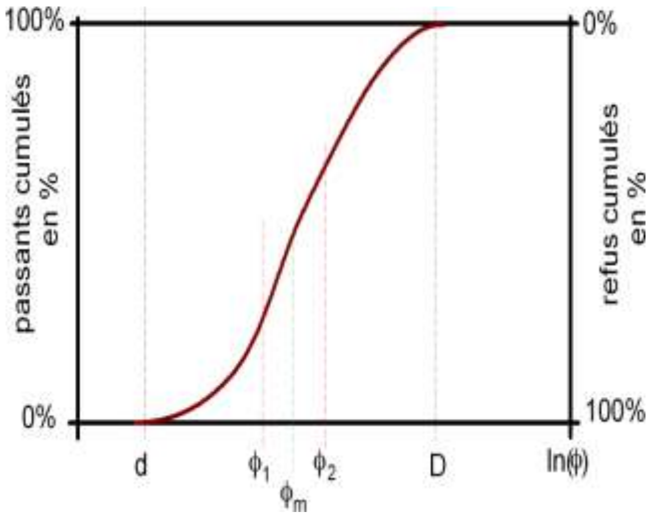


Fig 24. The sieve underflow
(Source: R.Dupain,2009)

The term **cutoff** refers to the di/Di fraction of an aggregate within a granular class d/D. This term is primarily used by quarry operators and in road engineering. It characterizes screening operations but is also often used as an alternative to the term d/D designation (Taylor, 1997).

- **Representations**

  For a given cutoff, the **mean diameter** can be defined as the average size of particles within that specific fraction. (Fig 25)



$$- \phi_m = \frac{\phi_1 + \phi_2}{2}$$

ou

$$- \phi_m = \sqrt[3]{\frac{(\phi_1 + \phi_2^2)(\phi_1 + \phi_2)}{4}}$$ formule de Mellor

Fig 25. The average size of particles within that specific fraction.

(Source: R.Dupain,2009)

- **Sample Preparation and Sieving According to the Operating Procedure**
- **Check the Condition of Sieves**

Verify that the sieves are in good condition and clean. (Fig 26)

Pour the Sample

Next, pour the clean, dry sample of material **Ms1** into the sieving column.

Weighing the Retained Fractions

For each sieve, weigh the cumulative retained material to the nearest gram by pouring its contents into a container placed on the balance.

The maximum allowable retained material on each sieve must be less than:

- 100 g si $d < 1$ mm,
- 200 g si $1 \leq d \leq 4$ mm,
- 700 g si $d > 4$ mm.

Fig 26. Check the Condition of Sieves

(Source: R.Dupain,2009)

- **Plot**

Calculate for each sieve the cumulative percentages of material rejections in relation to the mass Ms:

$$R_{ci\%} = \frac{M_{rci}}{M_s}.100$$

- Plot the particle size curve.

➢ **Fineness modulus**

The fineness modulus is a coefficient used to characterize the importance of fine elements in an aggregate.The fineness modulus is equal to 1/100 of the sum of the cumulative rejects expressed inpercentages on the sieves of the following series: 0.16 - 0.315 - 0.63 - 1.25 - 2.5 - 5 mm.

- Discussion of the granulometric curves:
- Curve No. 1 reflects a continuous dimensional distribution, on the other hand curve No. 2 showsan absence of grains from 3.15 to 25 mm: we say that thegranularity is discontinuous. -Contrary to curve No. 1 where a large number of granulardimensions are represented (spread granularity), curve No. 3 indicates that the majority of grains are between 4 and 16 mm (tight granularity). See (Figure27)

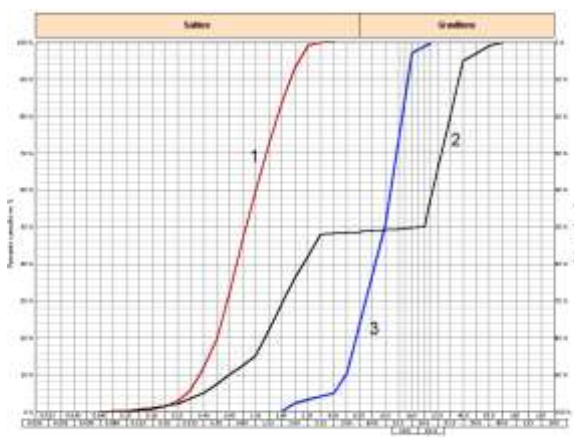


Fig 27. Fineness modulus

(Source: R.Dupain, 2009)

➢ **Shape of Gravel (Flattening Coefficient)**

The shape of gravel is determined by the flattening test (A). The flattening coefficient characterizes the shape of the aggregate based on its largest dimension and thickness. The higher the value of A, the more the gravel contains flat elements. Poor shape affects workability and promotes segregation.

The shape of an aggregate is defined by three geometric dimensions:

Length (L): The maximum distance between two parallel planes tangent to the ends of the aggregate.

Thickness (E): The minimum distance between two parallel planes tangent to the aggregate.

Size (G): The dimension of the smallest square mesh sieve that allows the aggregate to pass through.

- **Shape of the gravel (Flattening coefficient)**

- The flattening coefficient A of a set of aggregates is the weight percentage of the elements that satisfy the relationship:Shape of the gravel (Flattening coefficient)The flattening coefficient A of a set of aggregates is the weight percentage of the elements that satisfy the relationship (Fig 28):

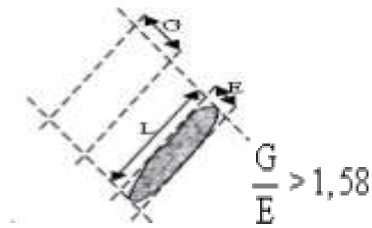


Fig 28. Fineness modulus
(Source: R.Dupain,2009)

- The shape of the aggregates influences:

The ease of implementation and compaction of the concrete. The compactness of the mixture, therefore the volume of voids to be filled by the cement paste.

- The surface condition of the grains influences:

The compactness of the mixture. The adhesion of the aggregate to the cement paste. The shape is all the better when it is close to a sphere or a cube.

- **Densities**

There are 2 types of density:

1. Absolute density: The absolute density of the aggregate (excluding voids between grains) is significantly higher: from 2500 to 2600 kg/m3.

$$\gamma_s = \frac{M_s}{V_s}$$

2. Apparent density: It depends on the packing of the grains. It is between 1400 kg/m3 and 1600 kg/m3 for rolled silico-calcareous aggregates.

$$\gamma_{app} = \frac{M_t}{V_t}$$

2.1.3. Water content, void ratio, porosity and compactness

In soils as well as in aggregates, we find the 3 phases of the material. These 3 phases are modeled as follows: With:

V: total volume of the materialVa: volume of air contained in the material

Vw: volume of water contained in the material;

Vv: volume of voids contained in the material(Vv= Va+ Vw);

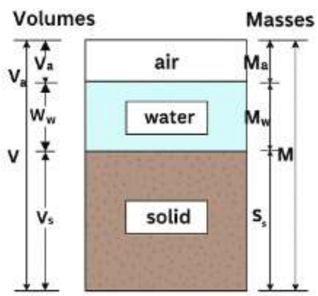
Vs: volume of solid grains contained in the material;

Ma: mass of air contained in the material; it is generally negligible;

Mw: mass of water contained in the material;

Ms: mass of solid grains contained in the material;

M: total mass of the material (dry or wet) (Fig 29).



Water content	$W \frac{W_w}{M_s} \times 100$
Void index	$e = \frac{V_v}{V}$
Porosity	$n = \frac{V_v}{V} \times 100$
Compacity	$C = \frac{V_s}{V} \times 100$

Fig 29. porosity and compactness
(Source: R.Dupain,2009)

2.2. Physicochemical characteristics

Impurities can disrupt the hydration of the cement or cause aggregate-paste adhesion defects, which can affect the strength of the concrete.Cleanliness reflects the absence of undesirable fine elements in the aggregates. It essentially refers to the content of clayey fines, the value of which must be limited.

- **In the case of gravel**, it is given by the percentage passing through a 0.5 mm sieve (sieving carried out under water).
- **In the case of sand**, cleanliness (SE) is provided by the test called "sand equivalent" which measures the clay fraction of the material.

2.2.1.Physicochemical characteristics

The test consists of separating the sand from the clayey or fine materials (Fig 30).

Which flocculate to the upper part of the test tube where the washing has been carried out (the higher the ES value, the cleaner the sand).It can also be evaluated by the "methylene blue (VB) test", the lower the VB value, the cleaner the sand.

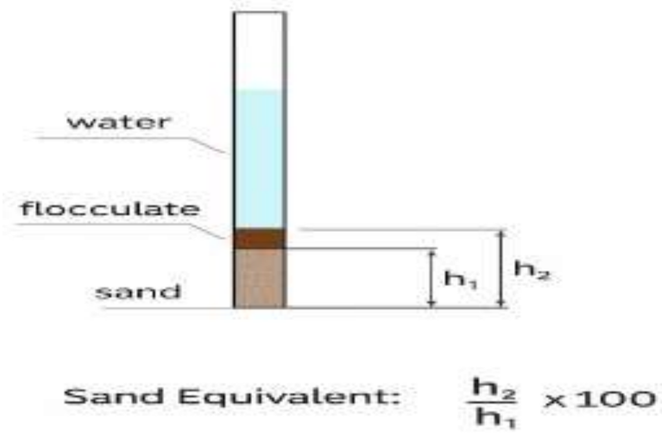


Fig 30. The test of separating the sand from the clayey. (Source: R.Dupain, 2009)

It is important to emphasize the importance of the cleanliness of the aggregates on the quality of the concrete. The presence of clay particles is in fact unfavorable, both to the implementation of the concrete and to its final performance, by lowering the adhesion of the cement paste on the aggregates.

2.2.2.Chemical Characteristics

- **Chloride Ion Content**

Chlorides modify the kinetics of cement hydration and cause corrosion of the reinforcement. Therefore, the chloride content from all components of the concrete is limited.

- **Alkali Reactivity**

Under unfavorable conditions (aggregates containing a significant fraction of reactive soluble silica in an alkaline-rich environment) and in the presence of moisture, alkali-silica reaction phenomena can cause swelling of the concrete.

- **Sulfur and Sulfate Content**

Aggregates may contain small amounts of sulfates and sulfides, provided that the total sulfur content S does not exceed 0.4% by mass. The sulfate content (SO_3) must be less than 0.2%. It is determined if S is greater than 0.08%. The sulfides present in the collection can oxidize and transform into sulfates, which may cause swelling phenomena. Therefore, it is important to limit the sulfur content to guard against this issue. Sulfates can damage foundations and affect the performance of additives, so it is crucial to limit their content in concrete.

2.3. Wear resistance of gravel

The wear resistance of aggregates is determined by the "Micro-Deval test" in the presence of water. This test consists of reproducing friction wear phenomena in a rotating cylinder. This resistance is characterized by the Micro-Deval MDE coefficient which represents the proportion of fine elements produced during the test. The lower the MDE coefficient, the higher the wear resistance of the gravel.

2.3.1. Mechanical Characteristics

- **Polishing Resistance of Gravel**

  This characteristic pertains to the aggregates used for constructing wearing surfaces. The higher the accelerated polishing coefficient (CPA), the greater the resistance to polishing.

- **Resistance of Gravel to Freeze-Thaw Cycles**

  The vulnerability of the aggregate in concrete to freeze-thaw action depends on its nature, use, climatic conditions, and the concrete formulation (for example, the use of entrained air).

2.3.2. Aesthetic Characteristics

Aggregates contribute to the color of concrete surfaces. Their appearance is enhanced based on the surface treatment applied. Depending on availability and the desired aesthetic, rolled, crushed, or semi-crushed aggregates can be used interchangeably.

Sands and gravels are available in a wide variety of natural shades. The color of concrete that has undergone surface treatment (washed concrete, exposed aggregate concrete, bush-hammered concrete, polished concrete) is linked to the color of the aggregates and coarse sand grains.

6-SAND

Summary

Introduction

Aggregates are composed of a combination of mineral grains, classified into one of six categories based on their size: Fillers, Fine Sands, Sands, Gravels, Pebbles, and Ballast. Their nature, shape, and characteristics vary depending on the deposits and production techniques used.
Sand is a granular solid material composed of small particles resulting from the breakdown of mineral (primarily rock) or organic materials (such as shells, coral skeletons, etc.) with dimensions ranging between 0.063 mm (silt) and 2 mm (gravel).

1. According to the Definition of Granular Materials in Geology

Sand's composition can reveal up to 180 different minerals, including quartz, micas, feldspars, and even limestone debris. Sand has numerous applications as a granular material, the most important of which is in concrete production. It is a non-renewable resource.

2. Grain Size or Granulometry

The size or diameter of grains or particles (granulometry) refers to the diameter of individual sediment grains or lithified particles in clastic rocks. This term can also apply to other granular materials. A single grain may consist of multiple crystals. Granular material can range from very fine colloidal particles to larger ones, including clay, silt, sand, gravel, pebbles, or boulders.

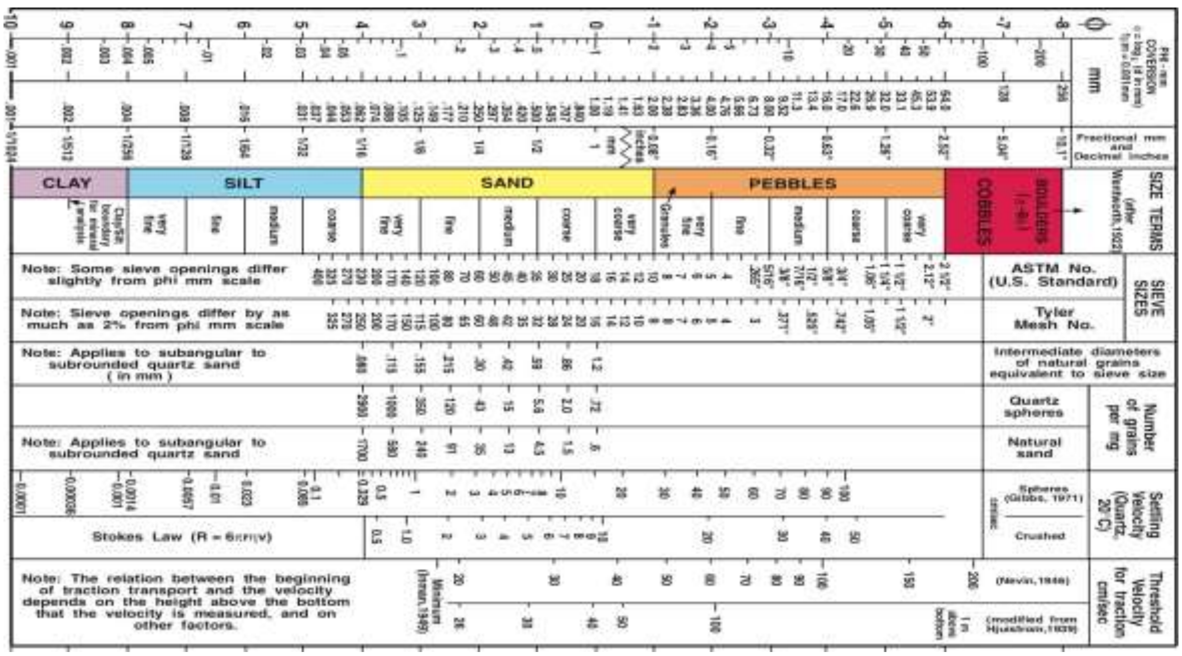
3. The Krumbein Phi (ϕ) scale

The **Krumbein Phi (ϕ) scale** is a logarithmic scale used to measure and categorize the sizes of sediment particles. It was introduced by William Christian Krumbein in 1934 to simplify the comparison of grain sizes in sedimentology. The scale uses a mathematical transformation to convert particle diameter measurements into a more manageable set of values, which is particularly useful when dealing with a wide range of grain sizes.

4. Grain Size Classification Scale

The grain size of sand (Table 4) is classified using a granulometric scale, which helps categorize sands based on the size of the particles.

Table 4. The grain size of sand. (Source: https://en.wikipedia.org/wiki/Grain_size ,2025)



Typically, sand is defined as grains ranging from 0.0625 mm to 2 mm in diameter, but the specific classification may vary slightly depending on the source. The general scale for particle sizes is as follows:

Clay: Smaller than 0.002 mm
Silt: Between 0.002 mm and 0.0625 mm
Sand: Between 0.0625 mm and 2 mm
Granule: Between 2 mm and 4 mm
Pebble: Between 4 mm and 64 mm
Cobble: Between 64 mm and 256 mm
Boulder: Larger than 256 mm

This classification helps in understanding the texture, behavior, and applications of different sands in various fields such as construction, geology, and materials science.

5. Physicochemical Characteristics

An individual particle is called a sand grain. Sands are identified based on their grain size (granulometry). Sand is characterized by its ability to flow (Fig 31). The rounder the grains, the more easily the sand flows. Artificial sand, produced by cutting or mechanically grinding rocks, is primarily composed of grains with pronounced roughness.

It is also possible to distinguish sand that has been transported by wind from sand transported by water. The former is more rounded and spherical in shape, while the latter tends to be more ovoid.

Fig 31. The sand

Source: https://opentextbc.ca/physicalgeologyh5p/chapter/weathering-and-erosion-produce-sediments/,2025

Sand is often the product of the decomposition of rocks due to erosion. The most common components of sand are quartz, the least alterable constituent of granite, as well as micas and feldspars.

It can have several colors, depending on the nature of the sandy particles (minerals) derived from the parent rock:

Black (e.g., sand from volcanic rock)
White (e.g., White Sands, dunes of pure gypsum; shell sand enriched with certain shell debris; sands rich in worn quartz and white micas)
Garnet (e.g., beaches made up of garnets, minerals that are rich and abundant in the parent rock)
Pink (e.g., beaches along the pink granite coast).
Depending on the type and quantity of pigments that cover the sand particles (iron oxide, etc.), it takes on a yellowish, rusty color.Sand can also take other forms: sandstone, sand stone.Grains of sand are light enough to be transported by wind and water.

Physical properties

Sand naturally forms stable slopes up to about 30°, beyond this angle, it flowsin successive avalanches to find this stable slope.

6. Uses

The size, nature, and more or less rounded shape of sand grains make it a high-quality material sought after for construction.

In **masonry**, sand is used as an aggregate mixed with a binder such as lime or cement.

In **electronics**, sand, specifically the silicon contained in silica, is used to make microprocessors.

In **ferrous** or light alloy foundries, molds can be made of sand bound by resins or clays for casting parts.

6.1. Mobility of Sands

In both water and air, fine sands and their dust are easily transported, sometimes over thousands of kilometers.

They alter the chemistry of meteoric waters, and geoscience research has recently shown that they sometimes play a major role in the nutrient balance of large ecosystems (Fig 32).


Fig 32. The sand

Source: https://constrofacilitator.com/types-of-sand-used-in-construction/,2025

The problem is that desert sand is not suitable for construction: shaped by the wind, its grains are too fine and too smooth. However, to make concrete, industries need aggregates with angular shapes and different sizes so they can interlock and bond easily.

6.1.2. Different aggregates depending on the use of concrete

The type of sand used is closely related to the intended use of the concrete. Aggregates from hard rock quarries, which are crushed, provide grains of different shapes and sizes, ideal for earthworks, making asphalt, blocks, or cinder blocks. Alluvial aggregates (called “rounded”) are mainly used for ready-mix concrete.

Each type of sand has unique physical and chemical characteristics based on the nature of the rock, as well as the shape and granularity of the grains. Lightweight aggregates from volcanic rocks, such as pozzolana, for example, produce concrete with low density and good thermal insulation.

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7. MIXING WATER FOR CONCRETE

Summary

1. Definition of mixing water for concrete

Mixing water for concrete refers to the water used in the process of preparing and mixing concrete components, typically consisting of cement, aggregates (such as sand and gravel), and water. This water is a crucial ingredient in the concrete mix, playing a key role in the hydration process of cement and influencing the workability, strength, and durability of the final concrete product(Neville, 2011).

The quality of mixing water is essential for producing concrete with desired properties. It should meet specific standards and criteria to ensure the proper chemical reactions between cement and water, as well as to prevent adverse effects on the concrete's performance (Mehta & Monteiro, 2014). The characteristics of suitable mixing water include cleanliness, absence of harmful impurities, appropriate chemical composition, and proper temperature.

Using mixing water that meets established standards helps ensure the development of a strong and durable concrete structure. The choice of mixing water is a critical factor in concrete mix design, and careful consideration of its physical and chemical characteristics is necessary to achieve the desired properties in the finished concrete (Kosmatka, Kerkhoff, & Panarese, 2002).

2. Role and function of mixing water

The water used in concrete, often referred to as mixing water, plays a critical role in the overall performance and durability of the concrete. Here are some key requirements for water to be suitable for use in concrete:

2.1. Potability

Mixing water should be potable and safe for human consumption. It should meet the standards set by local health authorities to ensure that it does not introduce harmful contaminants or pathogens into the concrete.

2.2. Cleanliness

The water used in concrete should be free from impurities such as oils, organic

matter, debris, and excessive amounts of silt or clay(Mindess, Young, & Darwin, 2003). Clean water helps maintain the integrity of the concrete and ensures proper bonding between cement particles.

2.3. Chemical Composition

The chemical composition of the water, particularly its ion content, should be within acceptable limits. Excessive amounts of certain ions, such as sulfates and chlorides, can lead to corrosion of reinforcing steel and affect the durability of the concrete.

- **PH Level:**

The pH of the mixing water should be in the range specified by concrete mix design. Highly acidic or alkaline water can influence the setting time and strength development of the concrete (Taylor, 1997).

- **Sulfate Content:**

High sulfate content in water can lead to sulfate attack on concrete, causing expansion and cracking. The sulfate content in mixing water should be within acceptable limits to prevent this issue.

- **Chloride Content:**

Excessive chloride content can contribute to the corrosion of reinforcing steel in concrete. The chloride content of the mixing water should be controlled to ensure the long-term durability of the concrete.

- **Temperature:**

The temperature of the mixing water can affect the setting time and curing of

concrete. Extremely hot or cold water may impact the workability and strength development of the concrete.

- **Consistency:**

The water-cement ratio in the concrete mix should be controlled to achieve the desired consistency and workability. Proper water-cement ratio is crucial for achieving the desired strength and durability of the concrete.

- **Compatibility with Admixtures:**

If admixtures are used in the concrete mix, the mixing water should be compatible with these admixtures. Incompatible water can reduce the effectiveness of admixtures and potentially lead to undesirable effects.

- **Testing and Quality Control:**

Regular testing of the water, especially in large construction projects, is important to ensure that it meets the required standards. Quality control measures should be in place to monitor and adjust the properties of the mixing water as needed.

Adhering to these requirements helps ensure that the water used in concrete mixing contributes to the production of high-quality and durable concrete structures. It's important to follow local building codes and standards for concrete mix design and water quality.

3. Different types of mixing water

The term "mixing water" can refer to water used in different contexts, and the type of mixing water can vary depending on the application. Here are a few types of mixing water in various contexts:

- **Potable Water:**

This is drinking water that meets certain quality standards set by regulatory authorities. It is safe for human consumption and can be used in various applications, including cooking, mixing beverages, and other domestic purposes.

- **Deionized Water:**

Deionized water has had ions removed, making it highly pure. It is often used in laboratories, manufacturing processes, and electronics to prevent the introduction of impurities into sensitive systems or reactions.

- **Distilled Water:**

Distilled water is produced by boiling water and then condensing the steam back into liquid form. This process removes impurities and minerals, resulting in relatively pure water. Distilled water is commonly used in laboratories, medical applications, and some industrial processes.

- **Tap Water:**

Tap water refers to water supplied to households and businesses through a municipal water system. Its quality can vary depending on the location, and it is commonly used for various domestic purposes, including mixing in cooking and cleaning.

- **Seawater:**

Seawater is water from the ocean and contains a significant concentration of salts and other minerals. While not suitable for many industrial processes, it is sometimes used in specific applications, such as cooling systems in coastal power plants.

- **Groundwater:**

Groundwater is water that comes from underground aquifers. It can vary in quality depending on the geological characteristics of the region. Groundwater is often used as a source of water for agriculture and some industrial processes.

- **Recycled Water:**

Recycled water, also known as reclaimed water, is wastewater that has been treated and purified for reuse. It is used in non-potable applications like irrigation, industrial processes, and some environmental restoration projects.

- **Process Water:**

Process water is water used in various industrial processes. It may undergo specific treatments to meet the requirements of the particular manufacturing or production process (Neville, 2011).

These are just a few examples, and the type of mixing water chosen for a specific application depends on factors such as purity requirements, regulations, cost, and the nature of the process or activity. Water treatment processes may also be applied to modify the characteristics of the water to meet specific needs.

4. Action of impurities in the mixing water on concrete

The presence of impurities in mixing water used for concrete can have several adverse effects on the properties and performance of the concrete. The impurities in mixing water can come from various sources, including natural sources, groundwater, surface water, or even the water used in the concrete mixing process (Kosmatka et al., 2002).Here are some potential actions of impurities in mixing water on concrete(Mehta & Monteiro, 2014) :

- **Reduced Strength**

Certain impurities, such as excessive amounts of dissolved salts or chlorides, can adversely affect the strength of concrete. Chlorides, for example, can lead to the corrosion of reinforcing steel within the concrete, compromising its structural integrity.

- **Delayed Setting Time**

Some impurities may cause delays in the setting time of concrete. This can be problematic, especially in construction projects where a specific timeline for curing and setting is crucial.

- **Increased Permeability**

Impurities in water can contribute to increased permeability of concrete. This can result in a higher likelihood of water and aggressive substances penetrating the concrete, leading to deterioration over time.

- **Alkali-Aggregate Reaction (AAR)**

Impurities in the mixing water may contribute to alkali-aggregate reactions, a chemical reaction between alkalies in the cement and reactive minerals in aggregates. This can result in the formation of a gel, causing expansion and cracking in the concrete.

- **Reduced Workability**

Certain impurities, such as excessive amounts of organic matter or certain minerals, can affect the workability of concrete, making it more challenging to place and finish during construction.

To mitigate the impact of impurities in mixing water, it is essential to use water that meets the recommended quality standards for concrete mixing. Water testing and treatment may be necessary in some cases to ensure that the water used in the concrete mix is free from harmful impurities. Adhering to proper construction practices and specifications can also help minimize the potential negative effects of impurities on concrete performance.

5. Consequences of excess and insufficient mixing water

The amount of mixing water used in concrete plays a critical role in determining the properties and performance of the final product. Both excess and insufficient mixing water can lead to various consequences that affect the quality and durability of concrete (Mindess et al., 2003). Here are the consequences of excess and insufficient mixing water (Taylor, 1997):

5.1. Consequences of Excess Mixing Water

- **Reduced Strength**

Excessive water can weaken the concrete by diluting the cement paste.
This leads to lower compressive strength, making the concrete more susceptible to cracking and structural failure.

- **Increased Permeability**

  Excess water can increase the porosity of concrete, making it more permeable. This heightened permeability allows water and aggressive substances to penetrate the concrete more easily, leading to durability issues.

- **Workability Issues**

  While excess water can improve short-term workability, it can also lead to segregation and bleeding, negatively impacting the finishing and overall quality of the concrete surface.

- **Cracking**

  Shrinkage cracking is more likely to occur in concrete with excess water. As the concrete dries and cures, excessive water can result in higher levels of shrinkage, leading to cracking.

- **Delayed Setting Time**

  Excess water can extend the setting time of concrete, causing delays in construction schedules and potentially affecting the quality of the finished product.

- **Efflorescence:**

  Increased water content can contribute to efflorescence, the formation of white, powdery deposits on the concrete surface due to the leaching of soluble salts.

5.2. Consequences of Insufficient Mixing Water

- **Poor Workability**

  Insufficient water can lead to a lack of workability, making it challenging to mix, place, and finish the concrete. This can result in a mix that is difficult to handle and properly compact.

- **Incomplete Hydration:**

  Inadequate water can hinder the complete hydration of cement particles, leading to insufficient strength development and a less durable concrete structure.

- **Honeycombing:**

  Insufficient water may prevent proper consolidation and compaction of the concrete mix, resulting in voids or gaps within the structure known as honeycombing. This compromises the structural integrity and aesthetics of the concrete.

- **Reduced Durability**

  Inadequate water can lead to a less dense and more porous concrete, reducing its resistance to freeze-thaw cycles, chemical attacks, and other environmental factors.Balancing the water-cement ratio is crucial to achieving the desired properties in concrete. Proper mix design and control of water content during the construction process are essential to avoid the negative consequences associated with both excess and insufficient mixing water.

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8. MORTARS

1. Definition of mortar

Mortar is a mixture of cement, sand, and water that is used to bond or bind masonry units, such as bricks or stones, together. It plays a crucial role in the construction of various structures, providing strength and durability to the overall building (Neville & Brooks, 2010). The basic ingredients of mortar include:**(Cement,Sand and Water)** (Mehta & Monteiro, 2014).

The proportions of these ingredients can vary depending on the specific application and the desired properties of the mortar. Different types of mortar may be used for different purposes, such as bricklaying, stonemasonry, or plastering. Proper mixing and application of mortar are essential for the structural integrity and longevity of a building.

2. Composition and manufacturing of mortars

The composition and manufacturing of mortars depend on the specific type of mortar needed for a particular application. However, I can provide a general overview of the composition and manufacturing process of traditional cement mortar used in construction:

2.1. Composition of Cement Mortar

Cement: Portland cement is commonly used in mortar. It is a fine powder that, when mixed with water, forms a paste that hardens over time. The chemical reaction between cement and water, known as hydration, is a key factor in the setting and hardening of the mortar.

Sand: Sand is the aggregate component in mortar. The type and gradation of sand can influence the strength and workability of the mortar. Coarse sand is often used for strength, while finer sand may improve workability.

Water: Water is essential for the hydration of the cement and the overall workability of the mortar. The right water-to-cement ratio is crucial to achieving the desired strength and consistency.

2.2.Manufacturing Process

The manufacturing process of mortar typically involves the following steps:

Mixing: The dry ingredients, including cement and sand, are measured and mixed thoroughly to achieve a uniform blend. The proportions of cement to sand can vary based on the desired characteristics of the mortar.

Adding Water: Water is gradually added to the dry mix while continuing to mix. The goal is to achieve a workable consistency without making the mortar too wet, as an excessive amount of water can weaken the mortar.

Mixing Continues: The mixing process continues until a homogeneous and uniform mortar paste is obtained. The mortar should be free of lumps and have a smooth texture.

Application: Once the mortar is mixed, it is ready for application. It is typically used for bonding masonry units, such as bricks or stones, together. The mortar is applied between the units, and the structure is allowed to cure and harden over time (Mamlouk & Zaniewski, 2016)..

It's important to note that there are different types of mortars, including masonry mortar, pointing mortar, and plaster mortar, each with its own specific requirements and variations in composition. Specialty mortars may also include additives or admixtures to enhance certain properties, such as durability or flexibility.

The specific manufacturing process can vary based on the type of mortar and its intended use.

3. Implementation and applications of mortars

The implementation and applications of mortars are diverse and depend on the specific type of mortar being used. Here are some common implementations and applications of mortars:

3.1. Construction and Masonry:

- **Bricklaying and Blocklaying:** Mortar is widely used to bond bricks or concrete blocks together in the construction of walls, buildings, and other structures.
- **Stonemasonry:** In the construction of stone structures, mortar is applied to bond individual stones, providing stability and strength to the overall structure.
- **Pointing**
  Mortar Pointing: Mortar is used for pointing, which involves filling in gaps or joints between bricks or stones to improve the appearance and weather resistance of a structure.

- **Plastering**
  Interior and Exterior Plaster: Mortar is employed for plastering interior and exterior surfaces, providing a smooth and even finish to walls and ceilings.
- **Tile Setting**
  Tile Adhesive Mortar: Mortar is used in tile setting to bond tiles to surfaces, such as floors or walls, providing a secure and durable attachment.
- **Repair and Restoration:**
  Structural Repairs: Mortar is often used for repairing and restoring damaged masonry structures, including filling cracks, replacing deteriorated mortar joints, or restoring historical buildings.
- **Fireproofing**
  Fire Mortar: Specialized fire-resistant mortars are used to create fireproof barriers in industrial settings or areas where fire resistance is critical (Lea, 2004).
- **Waterproofing**
- **Waterproofing Mortar:** Some mortars are designed to be waterproof, making them suitable for applications in areas prone to water exposure, such as basements or bathrooms.

3.2. Specialized Applications

- **Refractory Mortar:** Used in high-temperature environments, such as in the construction of fireplaces or industrial furnaces.
- **Soundproofing Mortar:** Designed to absorb or dampen sound vibrations, used in soundproofing applications.

The specific implementation and application of mortars can vary based on factors such as the type of mortar, the construction requirements, environmental conditions, and the intended use of the structure. It's crucial to choose the right type of mortar for a particular application to ensure the desired performance and durability. Additionally, advances in construction materials may lead to the development of new mortar formulations tailored to specific needs.

3.3. Quality of a good mortar

The quality of mortar is essential for ensuring the structural integrity, durability, and overall performance of a construction project. Several factors contribute to the quality of a good mortar:

- **Proper Mix Proportions**

The correct proportion of cement, sand, and water is crucial. Deviations from the recommended mix ratios can affect the strength, workability, and durability of the mortar.

- **Consistent Mixing**

The mixing process should be thorough and consistent to ensure uniform distribution of ingredients. This helps in achieving a homogenous mortar with a smooth and workable consistency.

- **Appropriate Water Content**

The water-to-cement ratio is critical. Too much water can weaken the mortar, while too little can result in poor workability. The goal is to achieve a balance that allows for proper hydration of the cement without compromising the mortar's strength (Mindess, Young, & Darwin, 2003).

- **Use of Quality Materials:** The quality of the raw materials, including the cement and sand, directly influences the mortar's performance. High-quality cement and clean, well-graded sand contribute to a stronger and more durable mortar.
- **Adherence to Specifications:** Following the recommended specifications and guidelines for the type of mortar and application is essential. Different construction projects may require specific mortar formulations to meet structural and performance standards.
- **Appropriate Curing:** Proper curing involves maintaining the right conditions, such as temperature and moisture, during the initial setting and hardening of the mortar. Adequate curing helps prevent cracking and ensures optimal strength development.
- **Consistent Workability:** The mortar should have consistent workability to facilitate easy application and proper bonding of masonry units. This is especially important in construction applications where mortar needs to be applied in various conditions.
- **Admixtures (if necessary):** In some cases, admixtures may be used to enhance specific properties of the mortar, such as workability, water retention, or resistance to certain environmental conditions. The addition of admixtures should be done in accordance with industry standards.
- **Compatibility with Substrates:** The mortar should be compatible with the substrates it is bonding. Different substrates may require different types of mortar to ensure proper adhesion and long-term stability.

- **Resistance to Environmental Factors:** A good mortar should exhibit resistance to environmental factors such as freeze-thaw cycles, chemical exposure, and moisture. This ensures the long-term durability of the structure.

Regular testing and quality control measures during the manufacturing and construction processes help ensure that the mortar meets the required standards. Following best practices and industry guidelines is crucial for achieving a high-quality mortar that contributes to the success and longevity of a construction project.

4. The different mortars

4.1. Cement mortars

Cement mortars are widely recognized for their exceptional resistance, rapid setting, and quick hardening properties, making them a staple in the construction industry. The fundamental volumetric dosage ratio of cement to sand in cement mortars is commonly established at 1:3, a formulation that balances the cohesive strength required for structural integrity(Neville & Brooks, 2010).

This ratio may, however, be subject to variations based on the specific demands of diverse construction projects. Moreover, the meticulous control of the water-to-cement ratio plays a pivotal role in achieving optimal performance. Typically hovering around 0.35, this ratio ensures the mortar's workability without compromising its overall strength. One noteworthy attribute of cement mortars is their capacity to become practically waterproof when a sufficient dosage of cement is employed.

This waterproofing quality enhances the durability of structures by preventing the infiltration of water, which is particularly advantageous in diverse environmental conditions. These characteristics collectively contribute to the versatility and reliability of cement mortars in various construction applications.

4.2. Lime mortars

Lime mortars, in contrast to their cement counterparts, exhibit distinctive characteristics that set them apart in the realm of construction materials (Fig 33).

 

Fig 33. Lime mortars
Source: https://en.wikipedia.org/wiki/Lime_mortar,2025

Notably, lime mortars are recognized for their unique texture, often described as "greasy and creamy." This distinct quality imparts a certain flexibility to lime mortars, making them more accommodating to movements and settlement within a structure. Unlike the rapid setting of cement mortars, lime mortars undergo a comparatively slower hardening process.

This delayed hardening time can be advantageous in situations where a more gradual and controlled setting is desired, allowing for greater workability and ease of application. Additionally, the slower setting time of lime mortars contributes to their compatibility with historic or older structures, as it minimizes the risk of damage during restoration or conservation efforts. It's worth noting that the performance of lime mortars is often evaluated based on their breathability, which allows moisture to pass through, making them suitable for certain heritage conservation applications (Ashurst & Dimes, 2012).

4.3. Bastard mortars

Bastard mortars represent a distinctive category within the spectrum of mortar types, characterized by their binder composition, which is a combination of both cement and lime. In the formulation of these mortars, it is common practice to incorporate equal proportions of lime and cement. However, the flexibility inherent in bastard mortars allows for adjustments in the ratio, with the specific quantity of one binder being varied relative to the other.

This variability is determined by the intended application and the desired qualities of the mortar, allowing for a tailored approach to meet the unique requirements of different construction projects. The hybrid nature of bastard mortars capitalizes on the advantageous properties of both cement and lime, offering a balance between the rapid setting and high strength associated with cement, and the flexibility and slow-setting characteristics characteristic of lime mortars. As a result, bastard mortars find application in diverse contexts, providing a versatile solution for construction projects that demand a nuanced blend of properties.

Fig 33. MALTA BASTARDA - Traditional "bastard type" mortar
Source: https://www.fornacigrigolin.it/en/costruzione-tradizionale/malte-del-piave/malta-bastarda.htm,2025

4.4. Mortars manufactured on-site

Mortars manufactured on-site represent a pragmatic approach to construction, where the materials are sourced and prepared directly at the construction site (Fig 34). The primary constituents of these mortars include cement and sand sourced from the immediate construction environment. Commonly used cements, such as CPA or CPJ cement, are supplemented with specialized variants like fused aluminous cement to meet specific project requirements.

Fig 34. Mortars manufactured on-site
Source: https://www.ultratechcement.com/for-homebuilders/home-building-explained-single/descriptive-articles/different-types-of-mortar, 2025

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Additionally, the inclusion of hydraulic lime and, on occasion, masonry binders adds a layer of flexibility to the mortar composition, catering to diverse construction needs.

The sand used in on-site manufactured mortars is typically of silico-lime nature, with some instances incorporating crushed sand. The mixing process is carried out manually with a shovel or, for larger projects, using a small concrete mixer. Although the sands employed may vary from one delivery to another, it is imperative that they are consistently clean and possess a suitable particle size to ensure the desired mortar properties (Taylor, 1997).

The dosing of sand in on-site mortars is generally performed by weight, a method preferred for its accuracy. In smaller construction sites, volume-based dosing might be employed, necessitating careful consideration of the phenomenon of sand abundance. This variability in the composition and preparation of on-site manufactured mortars acknowledges the practical constraints of construction environments while highlighting the importance of maintaining essential standards for cleanliness and particle size.

4.5. Premixed dry industrial mortars

Premixed dry industrial mortars stand out as a modern and efficient solution in the construction industry, offering a host of advantages that contribute to streamlined and high-quality construction processes (Fig 35). These mortars are meticulously manufactured from dry, carefully selected components, packaged in factory-controlled conditions, and consistently maintain a regular and uniform composition. The simplicity of use is a defining characteristic – users need only add the required amount of water, mix the mortar, and apply it as needed(Mamlouk & Zaniewski, 2016)..

Fig 35.Light Gray Dry Ready PreMix Sand Cement Mortar, Packaging Size: 40 Kg
Source: https://www.indiamart.com/proddetail/dry-ready-premix-sand-cement-mortar, 2025

The composition of these premixed mortars is versatile, incorporating various binders, sands, and sometimes additives or colorings to meet specific construction requirements. The key advantages of using premixed dry industrial mortars are evident in the pre-dosing of components, ensuring a constant composition that guarantees regularity and high-quality performance. This feature not only enhances the reliability of the construction material but also contributes to time savings during the construction process. The efficiency of these premixed mortars significantly reduces the preparation time, resulting in cleaner and more organized construction sites.

Manufacturers of industrial mortars offer a comprehensive range of products, catering to diverse construction needs. This includes mortars designed for coatings with varied color and appearance, waterproofing mortars to protect structures from water ingress,thermal insulation mortars for enhancing energy efficiency.

Pointing mortars for joint applications, leveling mortars to create smooth surfaces, sealing mortars for enhanced durability, screed mortars for floor applications, adhesive mortars for tiles on either plaster or cement bases, and repair mortars for addressing structural or cosmetic issues. This extensive product range ensures that construction professionals have access to a variety of solutions that align with the specific requirements of their projects.

4.6. Fresh mortars delayed, stabilized, ready to use

The construction industry has witnessed the emergence of a novel generation of mortars in recent years—fresh, delayed, and stabilized mortars, conveniently provided by ready-mixed concrete plants. This innovation in mortar technology has significantly enhanced the efficiency of construction processes (Mehta & Monteiro, 2014) (Fig 36). A distinctive feature of these mortars is their delayed setting, allowing for delivery and storage in substantial quantities.

Fig 36. Mortar Delay Set: For Hot Weather Mortar Work
Source : https://fritzpak.com/store/mortar-set-retarder/?srsltid=AfmBOopGr4MCeReeOZyc1qiYFGPGTm1cJ85v5q3GX_u5bn1hkUaqJycG, 2025

This characteristic extends the window of usability, providing construction professionals with a generous timeframe of up to 36 hours to utilize the mortar without the need for constant small-batch preparations.

The convenience of these mortars is further underscored by their user-friendly nature and homogeneity. Their ease of handling streamlines construction procedures, making them particularly advantageous for masonry and pointing applications.

Despite their delayed setting, these mortars exhibit sufficient strength to meet the demands of the intended work, ensuring that they provide robust performance in structural and finishing aspects of construction projects.

This evolution in mortar technology not only addresses the logistical challenges of on-site mortar preparation but also contributes to enhanced project management, allowing construction teams to focus on other critical aspects of the build. The ability to store and utilize these fresh, delayed, and stabilized mortars efficiently represents a notable advancement in construction materials, marking a significant step forward in optimizing construction processes.

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9. CONCRETE

Summary

Introduction

Concrete refers to an artificial material resulting from the hardening of a mixture of binder, water, and aggregates (such as sand and crushed stone or gravel) selected in a rational manner. Before hardening, this combination of materials is referred to as concrete mix (Neville, 2011).

In concrete, the grains of sand and crushed stone form the basic structure. When the concrete mix is combined with water, the resulting cement paste coats these grains, filling the spaces between them, acting as a lubricant for the aggregates, and imparting plasticity to the concrete. Upon hardening, this cement paste binds the aggregate grains, thus forming concrete, an artificial stone (Mindess, Young, & Darwin, 2003).

Achieving high-quality concrete mixes and concretes requires a thorough understanding of technological processes, appropriate selection of components based on their qualities and optimal proportions, as well as mastery of preparation, implementation, compaction, and curing techniques. This knowledge is essential for ensuring the construction of durable, resilient, and cost-effective concrete structures (Mehta & Monteiro, 2014). Concrete is one of the most important materials in all construction fields due to its ability to vary properties widely by using suitable components and specialized treatment methods. Its plasticity enables the creation of diverse construction elements without requiring significant labor, while its predominantly local aggregate composition makes it an economically advantageous material (Taylor, 1997).

1. Definition

Concrete is a mixture of : pure paste (cement + water + air); aggregates (sand, gravel, and occasionally crushed stones); possible additional products (admixtures) (Kosmatka, Kerkhoff, & Panarese, 2002).

2. Concrete Components

2.1. Cement

Cement is the quintessential hydraulic binder. It is typically composed of limestone and clay. It is one of the main components of concrete, binding its constituents together and imparting certain essential characteristics such as strength. The composition of cement can vary depending on different types of needs, which categorizes it into several categories :

CEM I (Portland cement) is suitable for the design of reinforced or prestressed concrete as it offers a high level of strength.

CEM II A or B (composite Portland cement) are known for their ease of handling. They are therefore used in common works such as traditional screeds or simple coatings.

CEM III A, B, or C (blast furnace cement) are suitable for harsh environments and are known for their durability.

CEM IV A or B (pozzolanic cement) are also suitable for aggressive environments, ideal for hydraulic structures. Not available in France.

CEM V A or B (composite cement) have the same physical properties as CEM III but different constituents.

2.2. Mixing Water

Mixing water is an essential element in concrete design. It allows for the hydration of cement, unlocking its binding capabilities, and also makes the application of concrete easier. The water used must be clean! (Avoid using seawater) and be careful not to add it excessively, as this could compromise the performance of your concrete. Indeed, excessive water could decrease its strength and durability.

2.3. Aggregates

Aggregates, whether natural or artificial, are mineral grains of varying dimensions. As the main components of concrete, they impart certain technical and aesthetic characteristics to it, notably its strength. Therefore, the choice of aggregate type should not be taken lightly as it will have an influence on durability.

2.4. Admixtures

Admixtures are chemical products added during the mixing of concrete and are dosed in small quantities during preparation (less than 5% of the mass of concrete). These products offer the possibility to improve certain characteristics of concrete such as its setting time or waterproofing. Widely used today, there are different types of admixtures that will allow you to obtain the desired concrete. (Fig 37)

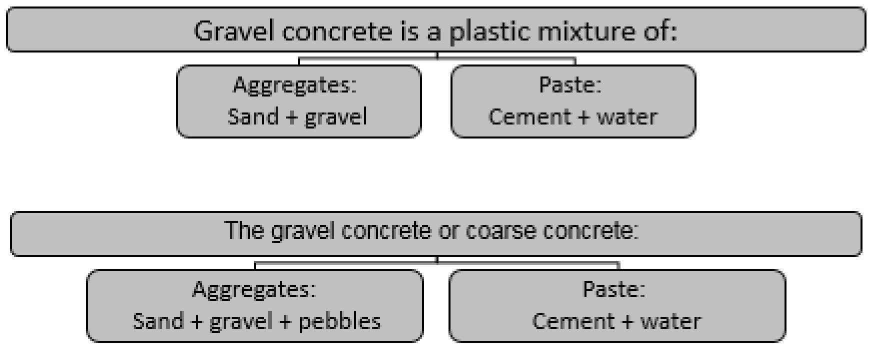

Fig 37. Concrete components (source: Author, 2025)

3. Nature and Effects

3.1. Setting and Hardening

Setting accelerator: decreases the setting time of concrete.

Hardening accelerator: speeds up the hardening time of concrete.

Setting retarder: slows down the setting time of concrete without altering it.

3.2. Workability of Concrete

3.2.1.Plasticizer: improves the workability of concrete without altering it.

Water-reducing plasticizer: reduces the water content to increase the strength of the mix while maintaining good workability.

3.2.1. Super plasticizer

Fluidifying function: (normal water dosage) improves workability but decreases strength.

Reducing function: (very low water dosage) results in a significant reduction in water content while maintaining good workability.

3.3. Modification of Certain Properties

Air-entraining agent: allows the formation of small air bubbles distributed evenly, increasing workability and freeze-thaw resistance of solid-state concrete.

Waterproofer: improves the impermeability of concrete by sealing the pores.

Pigments: offer the possibility to change the color of concrete.

3.4. Curing Products

Applied to the surface of fresh concrete, they protect it against potential risks of drying out.

4. Classification of Concrete

The classification of concrete is based on several criteria: **density, type of binder used, mechanical strength, frost resistance, and final application.**

The primary classification of concrete is based on its density; thus, we distinguish between: **heavyweight concrete** (with a density exceeding 2500 kg/m³), **normal-weight concrete** (with a density ranging from 1800 to 2500 kg/m³), **lightweight concrete** (with a density of 500 to 1800 kg/m³), and **ultra-lightweight concrete**, with a density below 500 kg/m³ (used for thermal insulation).

Depending on the size of aggregates used, concrete is subdivided into fine aggregate concrete, with aggregate dimensions not exceeding 10 mm, and coarse aggregate concrete, with maximum aggregate dimensions ranging from 10 to 150 mm.

The most important characteristics of concrete are its **mechanical strength and durability**. Based on compressive strength, concrete is divided into strength classes. Heavyweight concrete has strength classes ranging from 100 to 600, lightweight concrete from 25 to 300, and ultra-heavyweight concrete from 100 to 200.

Concrete durability is assessed based on its frost resistance, with frost resistance marks (Rg) ranging from 50 to 300 for **heavyweight concrete** and from 10 to 200 for **lightweight concrete.**

Depending on the type of binder used, several types of concrete are distinguished:

- Cement concrete, made with hydraulic binders such as Portland cement and its variants.
- Silicate concrete, composed of lime binders in combination with silicates or aluminates.
- Gypsum concrete, using anhydrite plaster binders.
- Organic binder concrete.

Concrete based on mineral binders is further subdivided:

- Heavyweight concrete is formed of cement and ordinary compact aggregates.
- Lightweight concrete uses cement with natural or artificial porous aggregates.

- A variety of lightweight concrete is cellular concrete, a mixture of binder, water, dispersed alumina components, and a substance promoting pore formation, with a porosity of 80 to 90%.
- Silicate concrete is produced from a mixture of lime and quartz sand, with subsequent hardening of shaped products in an autoclave, under pressure and at high temperature.

Depending on their final use, several types of concrete are distinguished: **ordinary concrete** (for load-bearing elements in concrete and reinforced concrete), **hydrotechnical concrete** (for dams, locks, canal linings), **lightweight concrete** (for walls and intermediate floors), for floors, coverings, and road foundations, and **special-purpose concrete**, such as acid-resistant concrete, heat-resistant concrete, and ultra-heavyweight concrete, made with cement and special high-density aggregates.

5. Establishing the Concrete Composition Project

The establishment of concrete composition aims to determine the quantity of materials required per cubic meter of fresh concrete, ensuring the attainment of a workable paste, concrete with the required strength, and in some cases, necessary frost resistance, impermeability to water, and endowed with special properties.

The composition of fresh concrete is defined by a ratio of masses (rarely volumetric ratio, less precise) between the quantities of cement, sand, and crushed gravel (or gravel), with the indication of the water-cement ratio.

The quantity of cement is used as the unit of measurement. Thus, typically, the composition of concrete is expressed by the ratio cement: sand: crushed gravel = 1:2:y for W/C = z (for example, 1:2; 4:4.35 for W/C = 0.45). **Two concrete compositions are distinguished:**

the nominal composition (from the laboratory), based on dry materials, **and the exploratory composition (on-site),** based on materials at natural humidity. Before proceeding with the composition calculation, it is necessary to determine the quality of the original materials: cement, water, sand, and crushed gravel (gravel), in accordance with standards.

5.1. The formulation of concrete composition

Involving the proportion of cement, water, sand, and gravel or crushed stones, begins with a calculated estimate, which is then refined through experimental dosage tests.

5.1.1. The process of calculating concrete composition follows these steps

first, the ratio between cement and water is established to ensure the desired strength of the concrete. Then, the necessary amount of water is determined, followed by the calculation of the required amount of cement, gravel (or crushed stones), and sand. The fluidity and consistency of the mixture are then checked against the project specifications, and the composition is adjusted if necessary. Subsequently, samples are prepared to assess the strength, and tests are conducted within the specified timeframe. Finally, a new evaluation of the composition is carried out.

Following expressions:

a) For concretes with C/W ratio < 2.5
Hence, the following results:

$$C/E \leqslant 2{,}5$$

$$R_b = AR_c\left(\frac{C}{E} - 0{,}5\right),$$

$$\frac{C}{E} = \frac{R_b}{AR_c} + 0{,}5;$$

b) For concretes with C/W ratio > 2.5
Hence, the following results:

$$C/E > 2{,}5$$

$$R_b = A_1R_c\left(\frac{C}{E} + 0{,}5\right),$$

$$\frac{C}{E} = \frac{R_b}{A_1R_c} - 0{,}5.$$

5.1.2.Determining the water quantity: The optimal amount of water in a concrete mix (l/m3) must ensure the necessary fluidity (or consistency) of the mixture.

5.1.3.Determining the cement quantity: After defining, using the formula, the value of C/E, which represents the cement-to-water ratio, and knowing the required water quantity E for the concrete mix, the approximate amount of cement per m3 of concrete is calculated as follows: C = C/E * E.

The cement quantity per m3 of concrete must not fall below the minimum limits allowed by standards. If the cement quantity is below the permissible level, it is necessary to increase it to meet the standard or introduce a finely ground admixture.

5.1.4.Determining the aggregate quantity (sand and crushed stones or gravel per m3 of concrete): To determine the quantity of sand or crushed stones (gravel), two conditions must be met:

1-The sum of the absolute volumes of all components of the concrete (in liters) equals 1 m3 (1000 liters) of the compacted concrete mixture:

$$\frac{C}{\rho_c} + \frac{E}{\rho_e} + \frac{S}{\rho_s} + \frac{PC}{\rho_{pc}} = 1000,$$

C, E, S, PC represent respectively the content of cement, water, sand, and crushed stones (gravel), in kg/m3; (Pc, Pe, Ps: specific mass densities of these materials, in kg/m3).

2-The cement-sand solution fills the voids between the coarse aggregates with a certain spacing of the grains.

$$\frac{C}{\rho_c} + \frac{S}{\rho_s} + E = V_{cav\ pc\ (gr)} \frac{PC\ (GR)}{\gamma_{vol\ pc\ (gr)}}\ \alpha.$$

By simultaneously solving these two equations, we obtain the expression to determine the necessary quantity of crushed stones or gravel.

$$PC\ (GR) = \frac{1000}{V_{cav\ pc\ (gr)} \frac{\alpha}{\gamma_{vol\ pc\ (gr)}} + \frac{1}{\rho_{pc(gr)}}},$$

After defining the quantity of crushed stones or gravel, we calculate the quantity of sand in kg/m3 as the difference between the volume of the concrete mixture defined by the project and the sum of the absolute volumes of the coarse aggregate, cement, and water.

$$S = \left[1000 - \left(\frac{C}{\rho_c} + E + \frac{PC\ (GR)}{\rho_{pc\ (gr)}}\right)\right] \rho_s.$$

If the gravel or crushed stones consist of several fractions, it is essential to establish beforehand the optimal ratio between them, using the optimal granulometry diagram or by choosing a composition where the void quantity is minimized.

5.1.5. Control of the fluidity of a concrete mixture: After performing the preliminary calculation of the concrete composition, a trial mix is conducted to determine the slump cone's collapse. If the mixture is not sufficiently fluid, a certain quantity of cement and water is added without altering the cement-to-water ratio. If fluidity increases, sand and coarse aggregates are gradually added while maintaining their constant ratio. This approach allows achieving the required fluidity.

6. Development of the theoretical composition of concrete using trial mixtures

A theoretical composition of concrete is established through trial mixtures. For this purpose, trial concrete mixes are prepared for three different values of the water-to-cement ratio, one of which is the calculated theoretical ratio, while the other two differ from it by 10 to 20%. The quantity of cement, water, sand, and crushed stones (or gravel) for a concrete mix with a water-to-cement ratio different from the theoretical ratio is determined using the method described earlier. Three specimens, 20 x 20 x 20 cm cubes, are prepared from each mixture and stored under normal conditions. These specimens are then subjected to tests for 28 days, during which the concrete's strength class is determined (or at other specified intervals). Based on the results obtained, a diagram of concrete strength as a function of the water-to-cement ratio is plotted. This diagram is used to select the water-to-cement ratio that ensures the attainment of the desired concrete strength class.

7. Types of Concrete

Table 4. Different Types of Concrete, (Source: https://www.angi.com/articles/types-of-concrete.htm ,2025)

Concrete Types	Characteristics	Examples of Mixtures for 1m³ of Concrete	Applications
Lightweight Concrete	Composed of low-density aggregates, possible use of air-entraining admixtures. Hollow blocks, partitions, renovation of old buildings, fillings	Cement: 400 kg; EPS Beads: 350 L; Sand: 950 kg; Water: 170 L; Admixture: 1 to 4%	Hollow blocks, partitions, renovation of old buildings, fillings
Heavyweight Concrete	Composed of high-density aggregates (lead, magnetite, hematite)	Cement: 250 kg; Hematite 0/1 mm: 1000 kg; Hematite 0/5 mm: 900 kg; Hematite 8/25 mm: 1700 kg; Water: 120 L	Radiation shielding, production of counterweights
Self-Compacting Concrete	Addition of admixtures such as super plasticizers and viscosity agents in the mix. Very fluid concrete that sets in place without the need for vibration	Cement: 350 kg; Sand: 800 kg; Gravel: 900 kg; Fines: 200 kg; Water: 180 L. Slabs,	foundations, industrial floors
Fiber-Reinforced Concrete	Addition of fibers of various natures, dimensions, and shapes. Uniformly distributed in the mix, these fibers enhance certain characteristics of concrete (tensile strength, fire resistance).		. Slabs, industrial floors, beams, pipes
Decorative Concrete	Their composition varies depending on the desired characteristics.	Washed concrete: Cement: 300 kg; Aggregate: 800 kg; Semi-fine sand: 400 L; Water: 160 L.	. Walls, terraces, slabs, driveways, sidewalks

High-Performance Concrete	Concrete with increased strengths, very low porosity. More durable.	. Depends on the HPC	. Bridges, nuclear power plants, large-scale structures

7. Formulation Method:

1. Bolomey Method.
2. Fuller Method.
3. Valette Method.
4. Faury Method.
5. Sherbrooke University Method in Canada.
6. Computer Method (BétonlabPro software from LCPC).
7. Dreux – Gorisse Method.

8. Property of concrete

The essential properties of concrete are primarily related to two aspects:

1. The placement of concrete.

2. Strengths, primarily compressive strength.

8.1. The placement of concrete.

8.1.1.Workability

Workability is the essential property of concrete in its fresh state, which allows it to be maneuverable while maintaining its homogeneity. In practical terms, this translates into ease:

- of placement in formwork;
- of encasing reinforcement steel;
- of achieving an acceptable surface finish, whether it be horizontal or vertical.

Workability depends on:

- the proportion of fine materials,
- the cement content,

- the water content, without excess,
- the rounded shape and size (coarseness) of aggregates.

Workability or maneuverability can be assessed in various ways, particularly through plasticity measurements.

8.1.2. Measurement of workability

There are numerous tests and various methods available for measuring certain characteristics on which workability depends (Table 5). We will mention only two of them, which are the most commonly used in practice.
1-Abrams cone slump test: 2- Slump flow test

8.1.2.1. Abrams cone slump test

This test is standardized under NFP 18-451, and we outline below only its essential principles: concrete is filled into a truncated metal cone mold (D = 20 cm, d = 10 cm, h = 30 cm); filling is done. In three compacted layers using a 16 mm diameter steel rod with a rounded end, with 25 strokes per layer; the mold is then carefully lifted, and the slump is measured. Assessment of concrete consistency.

Table 5. Concrete consistency.(Source: R.dupain,2009)

Consistency Class	Slump (cm)	Tolerance
Stiff S	0 to 4	±1 cm
Plastique P	5 to 9	±2 cm
Very plastique VP	10 to 15	±3 cm
Fluid F1	16	

8.1.2.2. The table spread test

The table spread test (Flow-test) involves using a shock table, equipped with a vertical movement metal plate. On this table is placed a truncated cone mold along with the material under study, whether it's mortar or concrete.

After leveling and demolding (by lifting the mold), the table is subjected to fifteen shocks in fifteen seconds, activated by a crank. The material spreads to form a disc with two perpendicular diameters measured. The spread (in %) is calculated using the following formula:

$$E = (D - 25)/25 \times 100$$

8.2. Strength

Strength, a predominant aspect, primarily focuses on the material's ability to withstand compression, meaning to support loads that tend to compress it. However, it also encompasses its tensile strength, which measures its ability to resist pulling forces that seek to deform it by pulling it in opposite directions. Regarding tests and measurements to assess these properties, a key focal point is compressive strength, measured using various standardized methods and specialized instruments.

- **Non-destructive testing:** Standardized methods used to assess the quality of concrete in buildings or structures only consider destructive tests on specimens cast at the same time. The main disadvantages of these methods are as follows: results are not obtained immediately, the concrete in the specimens may differ from that in the structure because the curing or compaction may be different, and the strengths of the specimens also depend on their dimensions and shapes. Several non-destructive evaluation methods have been developed.

These methods are based on the fact that certain physical properties of concrete can be related to strength and can be measured by non-destructive methods. These physical properties of concrete include hardness (rebound capacity), the ability to transmit ultrasonics, and resistance to pull-off, among others. Here, two tests are mentioned:

1. **NFP 18-417 Sieve test,**
2. **NFP 18-418 Sonic auscultation test.**

9. Transport of prepared concrete

Transporting prepared concrete to the site of its implementation must ensure the preservation of its homogeneity and fluidity level. During prolonged transport, the concrete paste thickens due to cement hydration, water absorption by aggregates, and evaporation. However, the concrete's fluidity at the time of implementation must remain consistent with that established by the project. The choice of transport mode depends

1 -on the distance to be traveled,

2-transport speed,

3-the fluidity degree of the mixture,

4-and the cost of the chosen transport mode.

At the plant, fresh concrete transport is facilitated by distributors, self-propelled carts, and conveyor belts. In medium and low-flow plants, it is carried out using electric hoists and electric carts. Fluid mixtures can be transported over long distances in concrete pipelines using compressed air installations.

On the construction site, fresh concrete is delivered by tipper trucks or concrete mixer trucks, where the concrete is mixed approximately 5 minutes before reaching its destination.

For each quantity produced, the concrete plant issues a matrix sheet containing information such as the company name and address, sheet number and date of issue, mixture quantity, cement consumption per cubic meter of fresh mixture, particle size of crushed stones and gravel, fluidity and rigidity, concrete class, and results of concrete strength tests on control samples. In recent years, fully automated high-flow concrete.

plants have experienced significant development, producing commercial concrete and mortar with an average worker efficiency 2.5 times higher than that of mechanized enterprises. This expansion is also accompanied by improved product quality and reduced production costs. In these automated concrete plants, all equipment is technological.

10. Placement of prepared concrete

Use of concrete mixers or concrete distributors for placement in a mold or formwork.

Fill the mold without leaving voids, especially in corners and restricted areas. Concrete compaction:

10.1. Compaction methods: vibration, vibro-stamping, rolling, centrifugal force treatment, or vacuum. Vibration: the most common method. Factors influencing the degree of compaction: frequency, amplitude, and duration of oscillations. Types of vibrators: electromechanical, electromagnetic, pneumatic. Surface vibrators for large open surfaces. Internal vibrators for massive constructions of great depth: Needle vibrators. High-frequency vibrators.

10.2. Improving concrete quality through vacuum treatment:

- Aspiration of excess water and air from the mixture.
- Increase in atmospheric pressure for better compactness.
- Advantage of vibrating the mixture a second time after vacuum treatment to close pores and improve compactness.

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10. REINFORCED CONCRETE

Summary

1.Definition

Concrete is a pre-established mixture of binder (cement), aggregates (sand, gravel, crushed stones), and water, blended in defined proportions. Reinforced concrete is characterized by the embedding of carefully arranged steel within concrete. These steel reinforcements, called rebars, are categorized into longitudinal reinforcements, aligned with the axis of the component, and transverse reinforcements, arranged perpendicular to this axis (Neville & Brooks, 2010).

2. Challenges faced by the constructor:

The challenge lies in ensuring the structural equilibrium against various forces:

- Permanent loads, such as the dead weight of the construction (walls, columns, beams, floors, etc.), the weight of adjacent elements (roof, partitions, cladding), soil pressure, etc.
- Variable loads, including live loads (furniture, occupants), climatic loads, and the effect of temperature.

Accidental loads, such as earthquakes, vehicle impacts, and falling objects. Additionally, consideration must be given to the upward forces exerted by the soil on the foundations(Mindess, Young, & Darwin, 2003).

3. Structural components:

These include the following elements:

- **Horizontal:**

For example, floors can be constructed with: Pre-stressed precast beams; Thick slabs (with a thickness of 18 to 25 cm); Slabs with ribs; Slabs with ribs and beams.

- **Vertical or inclined, such as:**

Reinforced concrete columns; Medium-thickness walls (from 18 cm to 20 cm); Walls.

4.The distribution of forces in load-bearing elements:

Let's consider a beam as an example. Material tends to compress on one of its faces (for example, the upper face) and to stretch on another (for example, the lower face). Thus, in the beam, there is an area subjected to compression (in our case, the upper part) and another subjected to tension (in our case, the lower part). (Mehta & Monteiro, 2014) (Fig 38).

Fig 38. Beam on supports
Source: https://civilengghub.com/types-of-beams-in-structural-design/, 2025

5. Properties

Reinforced concrete is so named due to the combined use of steel and cement concrete. Reinforced concrete is primarily used for components subjected to bending. Indeed, in the phenomenon of bending of components, tensile forces occur on one face of the beam, while compressive forces occur on the other face. On one side, the compressive strength of concrete can reach a value of 450 kg/cm^2, allowing, for an average mix, a practical permanent strength of 50 kg/cm^2. On the other hand, steel is a metal that performs very well under tension, as it can safely withstand a load of 12 to 16 kg/mm^2.

Hence the idea of associating the two materials and obtaining the strength of a beam, under bending, by a sufficient mass of concrete to withstand compression and incorporating metal into the parts of this beam subjected to tension (Nilson, Darwin, & Dolan, 2010). To achieve practical results in such a combination, it is necessary for the metal to bond with the mass of concrete. The bond between steel and concrete is considerable and reaches 40 to 47 kg/cm^2 of contact surface. It has often been observed that steel undergoes no alteration in cement.

Therefore, walls and pillars are not exposed to being overturned as in metal constructions. Moreover, from experiments that have been conducted, it has been found that the coefficient of expansion of concrete is substantially the same as that of steel, so that, under the action of fire, the two elements expand equally without causing any disintegration in the mass. As special properties of reinforced concrete, it is not frost-resistant, it poorly conducts heat, sound, and electricity, it has high hardness, and it can be easily molded. Dead loads are low, and it provides economical constructions, especially in large-scale projects.

6. Materials Used

6.1. Cement Concrete

Four mixtures are recommended according to the usage:

1-For concrete used in heavy masses, with the use of large aggregates and a low percentage of reinforcements... 250 kg/m3

2-For standard concrete, controlled and not exposed to weather or aggressive actions... 300 kg/m3

3-For concrete with less controlled manufacturing or for unprotected elements (framework, exposed structure, etc.)... 350 kg/m3

4-For concrete intended for structures in aggressive atmospheres... 400 kg/m3

The French ministerial circular of 1934 limits the dimensions of sand to a maximum of 5 mm and those of gravel to 25 mm.

Metal: The N.B.N. 179 standard provides the following table summarizing the required characteristics of steel used in the form of smooth reinforcements.

6.2. STEEL

The N.B.N. 179 standard provides the following table summarizing the required characteristics of steel used in the form of smooth reinforcements (Table 6)

Table 6. Summarizing the required characteristics (Source: v. Davidovici, 1974)

	R kg/mm²	R_e minimum en kg/mm²			Coefficient de qualité R + 2,5 A' ou R + 2,2 A'' minimum	Simple pliage à froid		
						Épais. de la cale		Angle de pliage
		$d \leqslant 12$	$12 < d \leqslant 16$	$d > 16$		$d \leqslant 20$	$d > 20$	
	mm	mm	mm					
A00	≤ 50	—	—	—	—	4d	4d	180°
A37	37-45	24	22	22	100	0,5d	d	180°

R_e : limite d'élasticité.
A' : allongement sur éprouvette : $L_o = 8,16 \sqrt{S_o}$.
A'' : allongement sur éprouvette : $L_o = 5,65 \sqrt{S_o}$.

Re: Yield limit. A': Elongation on test piece A'': Elongation on test piece

6.2.1. Mechanical Characteristics of Steel

The steels commonly used for reinforced concrete are classified into three categories:

- Smooth bars of soft, medium, and hard grades (natural hardness).
- High-adhesion bars of medium or hard grade obtained through cold work by twisting or pulling.

- Welded meshes.

Smooth Round Bars

- The diameters of the reinforcement bars, expressed in millimeters, are selected from the following series of standardized diameters: 5, 6, 8, 10, 12, 14, 16,

Welded Meshes

- Welded meshes are grids made of smooth drawn wires, assembled at the crossing points by electric welding.
- **Welded Meshes**
- Characteristics:
- Nominal yield strength:
- — for Ø<6mm . ∂= 5,200 bars (5,300 kgf/cm^2),
- — for Ø >6mm . ∂ = 4,410 bars (4,500 kgf/cm^2).
- Cracking coefficient: n = 1.
- Diameters of wires used for both load-bearing and distribution wires (in mm): 3 3.5 4 4.5 5 6 7 8 9 10 12. Spacing between wire axes:
- — load-bearing (in mm): 75, 100, 125, 150, 200
- — distribution (in mm): 50, 100, 150, 200, 250, 300.

7. Comparison between steel and concrete

Concrete

- Concrete can withstand considerable compressive forces, ranging from 20 to 60 MPa.
- However, it poorly resists tensile forces, only 1.5 to 3.5 MPa.
- In tensile zones, it is prone to failure, so the rule is to disregard tensile concrete in calculations.

Steel

- Steel is equally strong in compression as it is in tension.
- The ultimate tensile strength of the steel used, even the weakest, ranges from about 400 to 500 MPa.

- Note: In the case of compression, concrete remains more economical than steel. Steel is placed in tension zones.

8. Principle of Reinforced Concrete

The principles of reinforced concrete applied to construction elements such as: foundations - columns - beams - slabs - balconies, etc., Result from:

- criteria for economy and safety.
- the conditions for the proper functioning of structures,
- the characteristics of concrete and steel,

➢ **Economic and Functional Criteria**

- Concrete primarily balances compressive forces in the compressed zones of reinforced concrete structures.
- Steel primarily balances tensile forces; it is placed in tension zones.

➢ **Conditions for Proper Operation of Structures**

- Concrete and steel are combined through the mutual adhesion of materials

➢ **Safety Criteria**

- The tensile strength of concrete is not considered in calculations.
- Safety factors are applied to the potential strengths of concrete and steel.

9. Application

Beams and lintels

The flexural beam is subjected to both:

- A compressive force (at the top)
- A tensile force (at the bottom)
- An oblique shear due to vertical actions of opposite directions: support
- action directed upwards load
- action directed downwards

To address this, it is necessary to have:

1. main steel bars (longitudinal reinforcements) (Fig 39).
2. frames or stirrups (transverse reinforcements)

3. installation bars

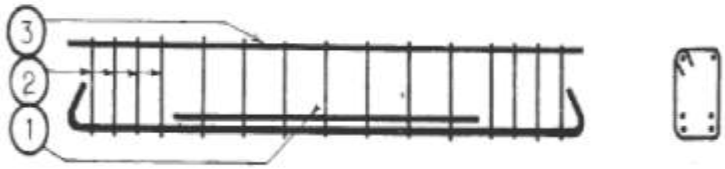

Fig 39. Main steel bars (Source: v. Davidovici, 1974)

11. PRE-STRESSED CONCRETE

Summary

1. Definition

Pre-stressed concrete stems from the following reasoning: concrete is currently the most economical construction material. Although it exhibits excellent compressive strength, its tensile strength is very low (Zhou et al., 2022). Therefore, it is necessary to construct using concrete while avoiding excessive tension that could lead to cracks (Fig 40). To achieve this, it is necessary to artificially and continuously compress it in areas subjected to external tensile forces, so that the concrete remains overall compressed (or slightly tensed to avoid cracks) and thus resistant to loads. The intentionally applied compressive force for this purpose is called pre-stressing force (or simply pre-stress). Consequently, our structure is active from the outset as it is subjected to pre-tensioning efforts even before being loaded. In 1928, its inventor, Eugène Freyssinet, defined pre-stress in this manner.

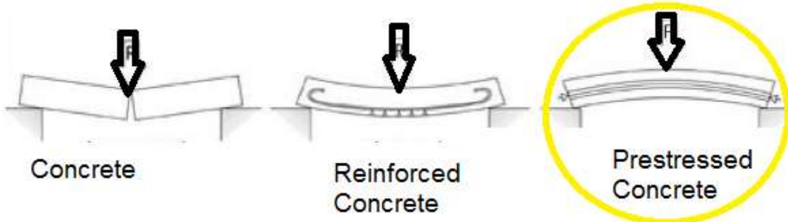

Fig 40. Concrete and its uses
(Source: https://www.ergoninfra.com/prestressing-system/,2025)

2. Principle of Prestressed Concrete

Let's consider, for example, a reinforced concrete beam resting on two simple supports. When subjected to a load, it deforms. The cross-section at the point of application of the load is compressed on the upper fiber and stretched on the lower fiber. When the load becomes too high, cracks form at the bottom of the beam.

In this beam, let's suppose that the traditional tensile reinforcement is removed and replaced with a curved duct following the beam's deformation, containing prestressed cables. By pulling on the cables, we compress the beam. Thus, in the cross-section, the upper fiber stretches and the lower fiber compresses.

When a load is applied, the tensile forces neutralize the compressive forces created by the prestressing, and all fibers remain compressed. This pre-compressed beam will withstand without damage the loads that would cause the rupture of a reinforced concrete beam of the same dimensions and span.

It is possible to determine the necessary prestressing force to keep the beam always compressed, regardless of the applied load

3. Methods of implementing prestressing

1). Inflation of jacks resting on fixed abutments: In this method, jacks are placed between the abutments and the concrete piece cast between them. The inflation of the jacks shortens the piece, compressing it accordingly. Wedges are then inserted between the abutments and the piece to keep it compressed. This method is cost-effective when the abutments are affordable, typically when natural rock formations can replace them. Otherwise, the two abutments can be connected by a tie, often a steel cable, to prevent them from moving apart during the action of the jacks.

2). Tensioning of steel cables by jacks supported on the concrete of the piece to be prestressed: In this method, steel cables are tensioned by jacks resting on the concrete of the piece to be prestressed. Under the action of the jack, the cable elongates and stretches, exerting a compressive force on the concrete equal to the prestressing force. Once tensioned, the cable is anchored to the concrete, ensuring the permanence of compression. This operation is performed after the concrete has been poured and has sufficiently hardened to withstand the prestressing force, which is called post-tensioning.

3).Prestressing by bonded tendons: This method, also known as pretensioning, involves first tensioning the tendons between two fixed abutments. Then, concrete is poured around the tendons, and once it has sufficiently hardened, the tension in the tendons is released. Their shortening is hindered within the piece by bond, which significantly reduces tension loss in the steel and ensures the compression of the concrete. This method is primarily used for the factory prefabrication of series of identical pieces, typically with straight tendons.

4. Pre-stressing Methods

To carry out the prestressing operation, there are two possibilities:

- Pre-tension: cables tensioned before concrete casting
- Post-tension: cables tensioned after concrete casting

4.1. Pre-stressing by Pre-tension

In this process, the prestressing cables are tensioned between two firmly anchored blocks before the concrete is poured .This technique is mainly used on prefabrication benches to produce repetitive elements.

4.1.2. General Steps of Execution

1. Tensioning of the cables.
2. Pouring of the concrete.
3. Releasing of the cables after the concrete has hardened.
4. Through adhesion, the compressive prestress is transferred to the concrete (Fig 41).

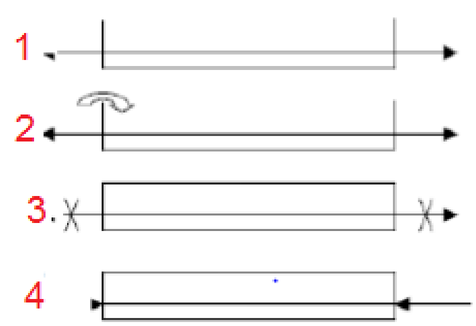

Fig 41. General Steps of Execution
(Source: https://www.ergoninfra.com/prestressing-system/ ,2025)

In a more detailed manner, the pre-tensioning prestressing method follows the following cycles:

- Cleaning of the molds;
- Application of form release oil on the molds;
- Unrolling of the active reinforcements and securing them at the ends in plates;
- Placement of passive reinforcements;
- Placement of the molds in their final position;
- Installation of any deflectors;
- Tensioning of the reinforcements by hydraulic jacks;
- Placement of concrete using overhead crane or gantry crane;
- Smoothing of the upper part;
- Vibration of the concrete;
- Curing or heating of the concrete;
- Stripping of the molds;
- Relaxation of the active reinforcements;
- Cutting of the wires between two prefabricated elements;
- Handling and storage.

4.2. Post-tensioning Prestressing

This process involves tensioning the prestressed cables after pouring and hardening of the concrete, using the structure as a compression member . This technique is employed for significant structures and is typically implemented on-site.

Post-tensioning prestressing comes in two forms:

- Internal post-tensioning prestressing
- External post-tensioning prestressing

4.2.1. General steps of implementation

- Placement of ducts (sheaths) in the formwork.
- Pouring of concrete.
- After the concrete has hardened, tensioning of the cables.

- Blocking is achieved using various systems of wedges on a fretted concrete area.
- Injection of a cement grout.

Injection is an extremely important operation as it serves a dual role:

1. Protection of prestressed reinforcements against corrosion.
2. Enhancement of the bond between reinforcements and ducts.

4.2.2. Prestressing Equipment

The complete set of prestressing equipment typically includes the following elements (Fig 42) :

1) **Anchoring Device:** Two main types of anchoring are distinguished:

Active anchoring, located at the end where tensioning occurs.

Passive anchoring (dead anchorage), situated at the opposite end to the tensioning.

2) **Couplers:** Devices allowing for the extension of reinforcements.

3) **Tensioning Equipment:** Hydraulic jacks, injection pumps, jack feeding pumps, etc.

4) **Accessories:** Ducts, injection tubes, etc.

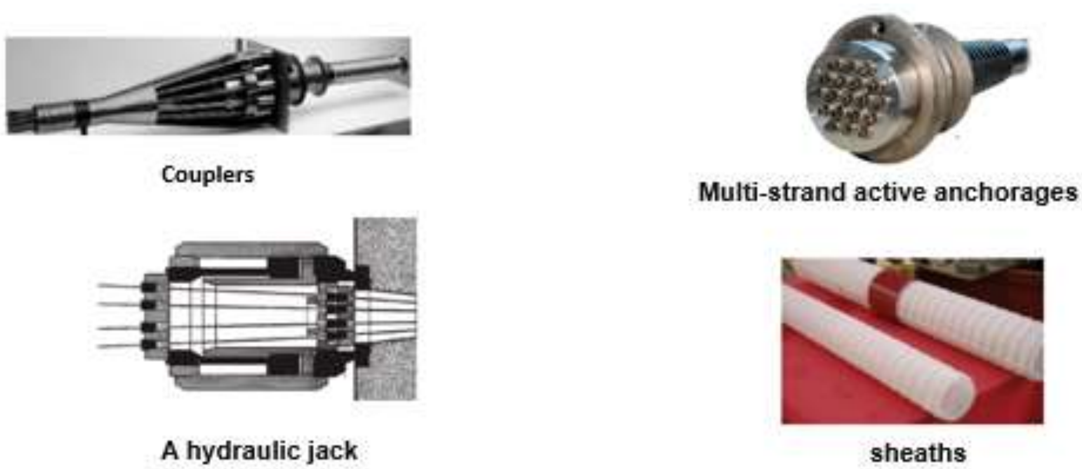

Fig 42. Prestressing Equipment
Source : https://srgglobalproducts.com.au/wp-content/uploads/2023/09/srgg-prestressing-technology-2020-12_e.pdf ,2023

5. The domains of prestressing application

5.1. Post-tensioning

The initial applications, which later expanded, primarily focused on medium to long-span bridges:

- The cable-stayed bridge of Barrios de Luna spans 440 meters. More commonly, lightweight concrete cores and the use of external prestressing allow spans ranging from 50 to 250 meters.
- Prestressing also facilitates the construction of reservoirs. Some hydrocarbon reservoirs reach capacities of 100,000 m3; water reservoirs and silos, with more modest volumes, also extensively utilize prestressing.
- Additionally, prestressing is employed in offshore platforms, nuclear reactor containment structures, and the use of external prestressing in the repair of bridges or dams. In the realm of building construction, post-tensioning prestressing, although less common, is utilized for long-span beams or relatively thin-section floor slabs in comparison to their spans: parking structures, industrial or commercial buildings.

5.2. Pre-tensioning

This technique is primarily used for standardized prefabricated elements, where it is justified by the concept of mass production.

The building industry constitutes the most common field of application for these elements: beams, floor beams , precast slabs, hollow core floor slabs, or large-sized cladding panels (10 to 15 meters in length) for industrial, commercial, or agricultural buildings.

Pre-tensioning is also employed for various types of poles (telegraph or electrical poles, fences, etc.) or railway sleepers.

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12. BUILDING STONES

Summary

1. Definition
2. Natural Stone Masonry
3. The Separation Technique
4. Production of Dimension Stone
5. Extraction of Natural Stone
5.1. Explosives Blasting
5.2. Helical Wire Sawing
5.3. Extraction with Steel Wedges or Spigots
5.4. Working of Natural Stone
5.5. Commercial Form of Natural Stone
6. Characteristics, Properties, and Uses
7. General Principles of Natural Stone Execution
8. Stone Masonry

9. Stone Dressing
10. Arrangement of Stones in a Wall
10.1. Types of Stones Used

1. Definition of Building Stones

Building stones are natural materials used in construction to erect walls, foundations, facades, and other structural elements. They are primarily extracted from quarries and chosen for their physical and aesthetic properties suitable for construction. The main characteristics of building stones are their strength, durability, and ability to withstand structural loads. They can be made of various types of rocks, including limestone, sandstone, granite, marble, basalt, and other rock formations. Building stones can be used in different forms, whether rough, partially cut, or fully cut depending on the requirements of the construction project. They can be shaped into different dimensions and finishes to suit the specific needs of architectural design. Building stones are therefore natural and versatile construction materials used to create strong, durable, and aesthetically pleasing structures. They are essential in many types of construction projects, from individual homes to commercial and institutional buildings (Ashurst & Dimes, 2012).

2. Natural Stone Masonry

Natural stone masonry refers to structures built using uncut or partially cut natural stones. This method of construction is ancient and has been widely used throughout history to erect buildings, retaining walls, fortifications, and other types of structures. Here are some important characteristics and aspects of natural stone masonry:

- **Materials:** Natural stone masonry is built from natural rocks such as granite, limestone, sandstone, basalt, marble, and other types of stones that can be found locally. The stones can be used as they are, with their natural shape and size, or partially cut for better fit in construction(Goodman, 1993).
- **Assembly:** Stones are assembled using traditional construction methods such as mortar or "dry" stacking, where stones are simply stacked on top of each other without mortar. Assembly can be done using stones of varying sizes to create a rustic look or using stones of similar size for a more uniform appearance.
- **Joints:** Joints between stones can vary in thickness and finish, depending on architectural style and aesthetic preferences. Joints can be filled with mortar to strengthen the structure and prevent water infiltration, or left open for a more rustic look.
- **Molding:** Although stones used in natural stone masonry are generally not carved to include sculpted or profiled details, some stones may feature interesting natural shapes that add ornamentation to the structure.
- **Stability:** Natural stone masonry can be very stable and durable, especially when stones are carefully selected and assembled. However, stability can be affected by factors such as material quality, soil conditions, and structure design (Lazzarini, 2012).

- **Maintenance:** While natural stone masonry is generally robust, it requires regular maintenance to prevent damage from weathering, vegetation growth, and other factors. This may include repointing damaged joints, cleaning stone surfaces, and repairing structural damage.

Natural stone masonry is often used in the construction of historical buildings, retaining walls, fences, and other structures where their natural beauty and strength contribute to creating an authentic and enduring ambiance.

3. The Separation Technique

Dimension stone refers to natural rock extracted and cut to specific dimensions. Its separation requires precise and meticulous methods such as sawing and precision drilling.

4. Production of Dimension Stone

The production of dimension stone begins with the extraction of large blocks of natural rock through cutting or separation. The size of each block depends on various factors such as the homogeneity of the stone, the skills of the quarry operator, and the intended final use. The physical characteristics of the rock, market size, and financial resources of the operator influence the design and capacity of the quarry (Bell, 2020).

Blocks are handled carefully to avoid fragmentation, then transported to processing plants. After various processing stages, the blocks are cut to the required dimensions, then polished or sharpened (Fig 43). Quarries often cater to local demand and may have multiple sites for different types of stone. Stone waste is recycled into construction aggregates.

Fig 43. Production waste in dimension stone industry

Source:https://www.google.com/search?q=Production+waste+in+dimension+stone+industry&oq=Production+waste+in+dimension+stone+industry&aqs=chrome.,2025

5. Extraction of Natural Stone

Extraction of Natural Stone is extracted from quarries, and this operation can be carried out using various methods such as explosives blasting, helical wire sawing, and the use of steel wedges (Fig 44 - 45).

5.1. Explosives Blasting: Numerous deep and narrow holes are drilled into the rock. At the bottom of these holes, explosives (TNT) are placed and connected to a detonator by wires or fuses for ignition. This process is suitable only for extracting rough-cut stones intended for use in:coarse masonry construction,rockfilling,crushing and cement manufacturing. Indeed, this method weakens the structure of the stone

Fig 44.Explosives Blasting
Source: https://www.wikiwand.com/en/articles/Drilling_and_blasting ,2025

5.2. Helical Wire Sawing

This involves an steel wire that cuts through the rock, while a jet of water carrying rough sand is directed into the saw cut; it is actually the sand that cuts through the rock, not the wire.

5.3. Extraction with Steel Wedges or Spigots

Holes are first drilled along the chosen separation line, then steel wedges (spigots) are driven in using a hammer weighing around twenty kilograms.

5.4. Working of Natural Stone

The large blocks extracted are then cut by splitting or sawing using saws arranged on a single frame (armature) or a diamond dust-coated disc saw. Natural stone can then be shaped according to its nature and intended use. Thus, a stone block can be worked with a bush hammer, a chisel, etc. The surface of the stone can also be planed, smoothed, honed, or polished to a matte or glossy finish (Siegesmund & Török, 2014).

Fig 45. helical wire sawing, and the use of steel wedges
Source: https://sangvarehstone.com/how-stone-blocks-are-extracted/,2025

5.5. Commercial Form of Natural Stone

Generally, natural stone is cut or sawn into large blocks, either at the quarry or in the workshop; it is sawn into slabs or slices, primarily in thicknesses of 2, 3, and 4cm for stones to be polished; and 5, 6, 8, 10, 12, 15, 16, 18, 20, 22, 25, 28, and 30 for stones to be carved. In commerce, the cubic meter (m3) is used as the unit for construction stones, and the square meter (m2) is used for polished stones.

6. Characteristics, Properties, and Uses

The use of rocks must meet the following requirements:

- Homogeneity of constitution
- Compression resistance
- Resistance to atmospheric agents' attack
- Resistance to water absorption

Workability, i.e., the stones must be easily workable.

7. General Principles of Natural Stone Execution

The execution of natural stone involves several general principles to ensure a quality and durable final result. Here are some of these principles:

- **Material selection:** Choosing the right types of natural stone based on their physical and aesthetic characteristics, as well as their suitability for the specific project. This may include considerations such as abrasion resistance, compression strength, flexural strength, as well as porosity and color.
- **Planning and design:** Developing detailed plans and precise specifications for the use of natural stone in the project. This includes designing stone elements, construction details, as well as coordinating with other materials and components of the project.
- **Substrate preparation:** Ensuring that the surface on which the natural stone will be installed is clean, flat, sturdy, and properly prepared to receive the stone coverings. This may involve leveling work, structural reinforcement, and application of appropriate primer coatings.
- **Proper installation:** Following the installation techniques recommended by natural stone manufacturers, which may vary depending on the type of stone, its format, and its specific application. This may include the use of special mortars or adhesives, as well as laying methods such as mortar bed, sand bed, or mechanical fixing system.
- **Joint management:** Properly managing joints between stone elements to ensure a watertight and aesthetic installation. This may involve choosing the appropriate type of joint (e.g., open joints, closed joints, expansion joints) and using jointing materials compatible with the stone and its environment.

- **Protection and maintenance:** Implementing appropriate protection measures to prevent damage during construction and delivery, as well as regular maintenance programs to ensure the long-term durability and beauty of natural stone.
- **Environmental considerations and sustainability:** Ensuring that the use of natural stone complies with environmental and sustainability standards, promoting responsible extraction practices, waste recycling, and the use of environmentally friendly products and techniques (Prikryl & Smith, 2007). Projects involving natural stone can benefit from high-quality, durable, and aesthetically pleasing installation.

8. Stone Masonry

Stone masonry is a traditional construction technique that involves the use of carefully cut and assembled natural stones to form strong and durable structures. Here are some important aspects of stone masonry(Fig 46).

- **Stone selection:** Stones used for stone masonry are chosen based on their quality, shape, and size. They must be strong enough to bear structural loads and withstand weathering. Stones are often cut according to their specific use in construction.
- **Stone cutting and preparation:** Stones are cut to the required dimensions for construction. This may involve the use of traditional tools such as chisels and hammers, as well as modern machinery for more precise cuts. Stones are also often prepared to create regular and aesthetic joints between them.

Fig 46. Stone Masonry
Source : https://stonearchbridges.com/2025/05/23/choosing-stonecutting-hammers/,2025

- **Stone assembly:** Cut stones are assembled to create solid and stable walls. Different assembly techniques may be used, such as "mortar bed" where stones are fixed with mortar, or "dry" where stones are simply stacked on top of each other without mortar.
- **Joints:** Joints between stones are often filled with mortar to reinforce the structure and prevent water infiltration. Joints can be finished in different ways for varied aesthetic results, such as "flush joint" or "tooled joint."
- **Finishing:** Once stone masonry is completed, finishes can be applied to enhance the aesthetic appearance and durability of the structure. This may include brushing, sanding, or chiseling stone surfaces to create interesting textures.

- **Maintenance:** Stone masonry requires regular maintenance to ensure its longevity. This may include repointing damaged joints, cleaning stone surfaces, and repairing damage caused by weathering or normal wear and tear.

Stone masonry is valued for its durability, beauty, and timeless character, and it is often used in the construction of historical buildings, monuments, and prestigious architectural structures.

9. Stone Dressing

Stone dressing refers to the arrangement and organization of cut stones in a masonry structure, typically to form walls, arches, or other architectural elements (Ashurst & Dimes, 2012). Here are some common principles and techniques used in stone dressing:

- **Regular vs Irregular Dressing:** Regular dressing involves using stones of similar dimensions, uniformly arranged to create clean lines and regular patterns. Irregular dressing, on the other hand, employs stones of varied sizes, arranged more freely, often resulting in a rustic and organic appearance.
- **Courses and Joints:** Stones are laid in horizontal rows called courses. The joints between stones can vary in thickness and finish depending on the structure's style and aesthetic preferences. Joints may be filled with mortar or left open, based on architectural style and design requirements.
- **Moldings:** Moldings refer to the sculpted or profiled details of stones, such as chamfers, moldings, and projections, which add ornamentation and character to the structure.
- **Corner Assembly:** The corners of the structure are often reinforced using specially cut stones called cornerstones or quoins. These stones are often shaped to fit snugly into the corners, ensuring the solidity and stability of the structure.
- **Alignment and Leveling:** Precise alignment of stones and proper leveling of courses are essential to ensure the stability and aesthetics of the structure. Tools such as string lines, bubble levels, and other measuring instruments are often used to ensure correct dressing.
- **Types of Dressing:** There are different types of stone dressing, such as opus incertum (randomly arranged stones of varied sizes and shapes), opus quadratum (rectangular stones laid in regular lines), and opus reticulatum (stones arranged in diamonds or lattice patterns).
- **Finishes:** Stones can be left in their natural state or undergo various finishes such as brushing, polishing, chiseling, or sandblasting to create decorative textures and patterns.

Stone dressing is a craft that requires expertise and precision to create solid, aesthetic, and durable structures. It is often used in the construction of historical buildings, monuments, and prestigious architectural structures for its traditional appearance and timeless character.

10. Arrangement of Stones in a Wall

Appareillage, also known as masonry layout, refers to how stones are arranged to form a wall. This practice plays a crucial role in the aesthetics, stability, and durability of the construction (Bell, 2020).

10.1. Types of Stones Used

Various stones can be used to construct the facing of a wall, each offering distinct characteristics and diverse aesthetic possibilities.

- **Panneresse:** This type of stone features a face whose dimensions fall between the smallest and largest. This intermediate face is typically chosen as the facing, providing a uniform and regular surface for the wall.
- **Parpaing:** Parpaings are stones that offer facing on each side of the wall. In other words, these stones traverse the entire thickness of the wall, providing a uniform appearance on both sides.

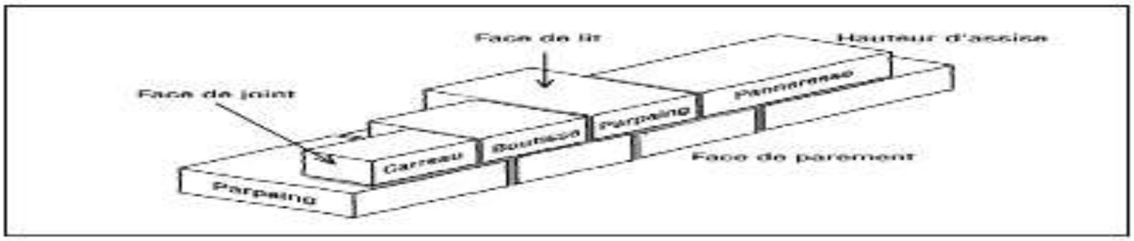

Fig 47. Arrangement of Stones in a Wall
Source : http://liremaville.com/curiosite7.html,2025

- **Boutisse:** Boutisses are characterized by a face with reduced dimensions that is used as facing. This arrangement gives the wall a textured and rustic appearance, adding character to the structure.
- **Carreau:** Unlike other types of stones, carreaux are distinguished by significantly larger facing dimensions compared to joint or tail dimensions. This arrangement creates a striking visual effect and can be used to highlight patterns or architectural details.

Craftsmen can create walls that not only meet structural requirements but also add a distinct aesthetic to the built environment.

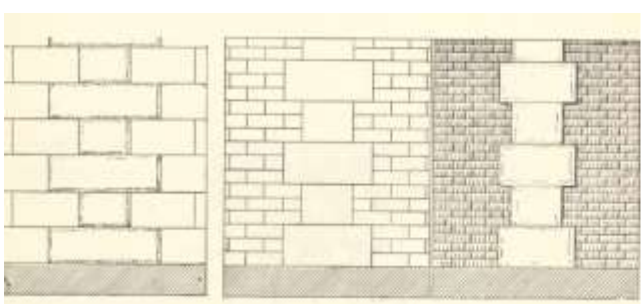

Fig 48. Arrangement of Stones in a Wall
Source : https://www.constructioncost.co/brick-bonds-types-and-patterns.html,2025

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13. WOOD

Summary

1. Overview and Classification

Wood is a natural and versatile material widely used in construction, furniture making, the production of various products, and many other fields (Forest Products Laboratory, 2021). It is classified into two main categories: hardwood and softwood. This classification is based on the structure of the tree from which the wood comes.

- **Hardwood:** These are deciduous trees such as oak, beech, cherry, walnut, etc. They are generally denser and harder than softwoods (Bowyer et al., 2019).
- **Softwood:** They come from evergreen trees such as pine, spruce, cedar, etc. They are often less dense than hardwoods and generally contain more resin.

2.Wood structure

The structure of trees and wood is fundamental to understanding their properties and their use in various applications. Here is an explanation of wood structure, both at the macroscopic and microscopic levels (Bodig & Jayne, 1982):

2.1.Macrostructure of wood

- **Tree trunk:** The tree trunk is the main part that supports the crown and transports nutrients between the roots and the leaves.
- **Crown:** The crown of the tree includes the branches and leaves that grow above the trunk.
- **Roots:** Roots are responsible for anchoring the tree in the soil, absorbing water and minerals, and transferring these nutrients to the trunk.

2.1.1.Parts of the trunk

- **Bark:** The outer protective layer of the tree.
- **Phloem:** The layer just beneath the bark that transports sap (nutrients) produced by the leaves to other parts of the tree.
- **Cambium (or sapwood):** The layer of newly formed wood between the phloem and the heartwood. It is where the growth and development of the tree occur.
- **Heartwood (or core):** The innermost and oldest part of the tree's wood.
- **Pith:** The central part of the trunk, often present in young trees but disappearing with age (Haygreen & Bowyer, 1996).

2.1.2. Wood Cuts

- **Transverse:** Cut across the tree trunk, revealing the circular structure of the wood.
- **Longitudinal Radial:** Cut along the diameter or radius of the tree, showing variations in the wood structure from the bark to the core.

- **Longitudinal Tangential:** Cut along the chord of the tree, showing variations in the wood structure on a surface tangent to the tree's growth (Fig 48).

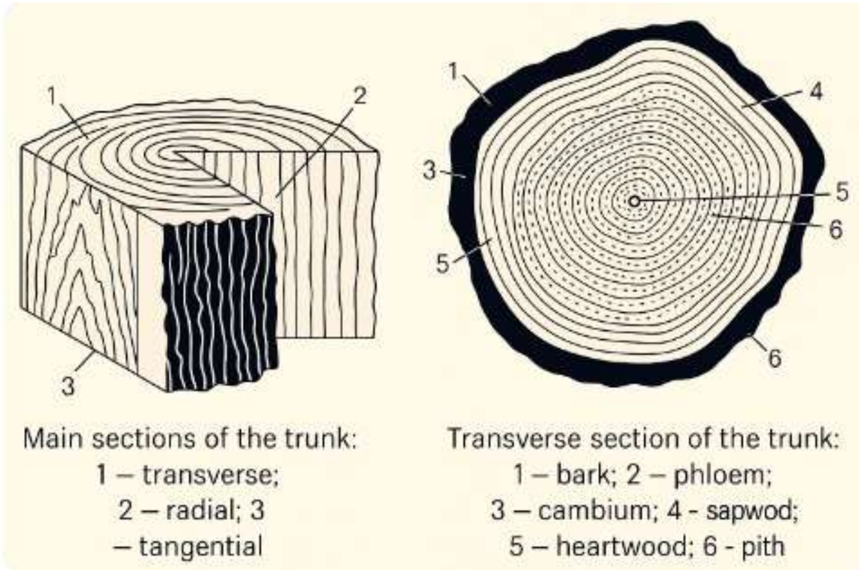

Fig 48. Wood Cuts
Source: https://www.tedtodd.co.uk/guides/timber-cuts/,2025

2.2.Wood Microstructure:

The microstructure of wood, visible under a microscope, reveals the anatomical details of the cells and vessels that compose wood, including parenchyma cells, fibers, and conducting vessels. Understanding both the macrostructure and microstructure of wood is essential for its effective use in construction, woodworking, and other applications (Panshin & de Zeeuw, 1980). The microstructure of wood, observed under a microscope, reveals a complex composition comprising various dead and living cells. Here is a detailed explanation of the components and types of cells present in wood:

2.2.1. Composition of Living Cells

- **Cell Wall:** The main cell wall, primarily composed of cellulose. As the cell grows, variations in structure and composition occur, which can lead to its transformation into wood, cork, or mucilage.
- **Protoplasm:** A thick, granular, transparent mucus called plant albumen, composed of carbon, hydrogen, oxygen, nitrogen, and sulfur.
- **Nucleus:** An oval structure distinguished from the protoplasm by the presence of phosphorus.

2.2.2. Transformations of the Cell Wall

- **Formation of Lignin:** When the cell transforms into wood, a substance called lignin forms in its cell wall, thereby increasing its strength and resistance.
- **Formation of Corky Substances:** When transformation into cork occurs, substances with lower oxygen content than lignin form in the cell wall. This gives cork resistance to rot and water impermeability.
- **Transformation into Mucilage:** When transformation into mucilage occurs, the cell wall partially or completely dissolves in water, forming openings through which cells can come together to form vessels.

2.2.3. Types of Cells

- **Conductive Cells:** Responsible for transmitting nutrients from the roots to the branches and leaves of the tree.
- **Mechanical Cells:** These cells have an elongated shape, thick walls, and narrow internal cavities, imparting high mechanical strength to the wood.
- **Reserve Cells (or Parenchyma):** Mainly located in the medullary rays, they store and transmit nutrients to living cells in a horizontal direction.

Understanding the microstructure of wood is essential for comprehending its physical and mechanical properties, as well as for optimizing its use in various applications (Fig 49).

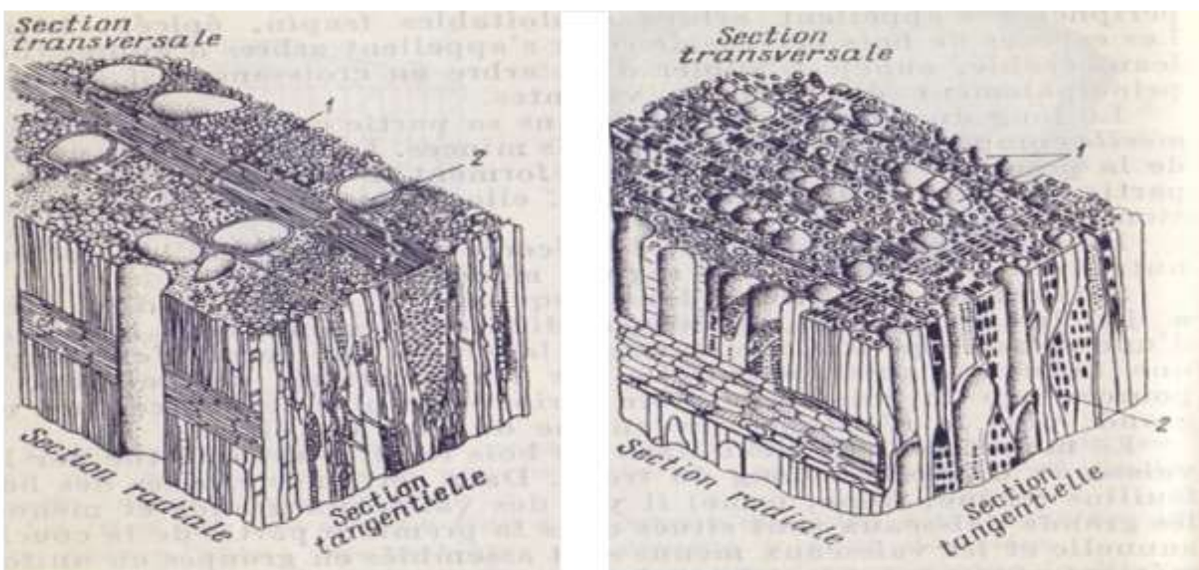

Fig 49. Types of Cells

Source : https://oertx.highered.texas.gov/courseware/lesson/1767/overview,2025

3. Physical Properties

The physical properties of wood vary depending on the species and tree structure, but generally, wood possesses the following characteristics:
• **Density:** Hardwood is typically denser than softwood.
• Hardness: Hardwood is harder than softwood.
• **Strength:** Hardwoods often have better tensile and compressive strength than softwoods.
• **Moisture Resistance:** Some softwoods like cedar have natural resistance to moisture, while other woods can be treated to enhance their resistance to rot and insects (Kollmann & Côté, 1968).

➢ **Density:** Wood density is a measure of its mass per unit volume. This density can vary depending on various factors, including tree species, tree growth, growing conditions, and even the specific part of the tree used.

Here are some additional explanations regarding the difference in density between hardwood and softwood:

- **Cellular Structure:** Hardwoods and softwoods have different cellular structures. Hardwoods are characterized by denser, more closed, and often more compact cells, contributing to a higher density. In contrast, softwoods tend to have more open and less dense cells, resulting in a lower density.
- **Moisture Content:** Hardwoods generally have lower moisture content than softwoods. This may be due to a different cellular structure and distinct water absorption properties between the two types of wood. A lower moisture content contributes to a higher density.
- **Chemical Composition:** Hardwoods and softwoods have slightly different chemical compositions. For example, softwoods often contain more resin, which can slightly affect their density.
- **Growth and Age:** Growing conditions and the age of the tree can also influence wood density. For example, hardwood from an older tree may be denser than hardwood from a younger tree due to slower growth and accumulation of woody material.

The density of hardwood is generally higher than that of softwood due to differences in structural, compositional, and growth conditions.

➢ **Hardness:** Generally, hardwood is recognized to be harder than softwood. This difference in hardness is due to several factors:

- **Cellular Composition:** Cells in hardwood tend to be denser and have thicker cell walls compared to softwood. This increased density and thickness of cell walls contribute to greater strength and therefore greater hardness of hardwood.
- **Resin Content:** Softwoods often contain a higher amount of resin, which can make the wood softer. Conversely, hardwoods generally have less resin, contributing to their increased hardness.
- **Types of Fibers:** Fibers in hardwood tend to be longer and stiffer than those in softwood, making them more resistant to deformation and thus harder.

- **Specific Species:** It's worth noting that hardness can vary significantly from one wood species to another, even within the categories of hardwood or softwood. Some hardwoods, such as oak and beech, are particularly known for their high hardness, while some softwoods, such as pine, can be relatively soft.

The increased hardness of hardwood compared to softwood stems from its denser cellular structure, lower resin content, and the nature of the fibers present. However, it's important to note that this generalization may vary depending on the specific characteristics of each wood species.

- **Strength:** Hardwoods tend to exhibit better tensile and compressive strength compared to softwoods. This difference in strength stems from the intrinsic characteristics of these two types of wood.
- **Hardwoods**, such as oak, beech, and ash, are generally denser and have a more complex cellular structure, which gives them increased tensile and compressive strength. Their fibers are often longer and tighter, making them stronger and capable of bearing heavier loads in different directions.
- **On the other hand, softwoods**, like pine and spruce, tend to be less dense and have shorter, less tight fibers. Although they are often used in construction due to their availability and ease of processing, their tensile and compressive strength is generally lower than that of hardwoods.

The difference in strength between hardwoods and softwoods is mainly attributable to their cellular properties and density, with hardwoods typically having better tensile and compressive strength.

- **Moisture Resistance:** Moisture resistance varies depending on the wood species. Some softwoods, such as cedar and cypress, exhibit high natural resistance to moisture and decay due to their content of natural oils and protective chemical compounds. These properties make them particularly suitable for outdoor use, such as in deck construction, fencing, and exterior siding.

However, most woods, including hardwoods, can be prone to rot and degradation when exposed to humid conditions for extended periods. To enhance their moisture and decay resistance, it's common to treat them with antifungal and insecticidal chemicals.
This process, known as pressure treatment, involves injecting these products into the wood under high pressure, allowing them to penetrate deeply into the wood fibers.
Pressure treatment can significantly extend the wood's durability, making it more suitable for outdoor or humid environments. However, it's important to note that even with proper treatment, no wood is entirely immune to moisture and decay, and regular maintenance is often necessary to maintain its durability over time.

4. Traditional Wood Products

Traditional wood products encompass a wide range of items made from this natural material for millennia. Here's an explanation of some of these products:

- **Furniture:** Wood is widely used in furniture making for its durability, beauty, and versatility. From chairs and tables to cabinets and beds, wood is a material of choice for a wide variety of furniture.
- **Tools:** Many traditional tools are made of wood due to its sturdiness and ability to be shaped into various forms. Tool handles such as hammers, axes, and chisels are often made of wood.
- **Timber Framing:** Wood has long been used in timber framing to support the structures of buildings. Wooden beams provide structural strength and flexibility, making them a popular choice for timber framing.
- **Musical Instruments:** Many musical instruments are made of wood due to its unique acoustic properties. From guitars and violins to flutes and pianos, wood plays an essential role in creating harmonious sounds.
- **Sculptures:** Sculptors often use wood as a preferred material to create beautiful and expressive works of art. Its ability to be sculpted and shaped makes it an ideal medium for expressing artistic creativity.
- **Decorative Objects:** Decorative items such as bowls, trays, photo frames, and decorative sculptures are made of wood to add a touch of natural warmth and beauty to a space.
- **Ships and Boats:** Before the era of modern materials, wood was the primary material used in shipbuilding. From fishing boats to majestic sailboats, wood was used to create vessels capable of navigating the oceans.

4.1. Assemblages

In furniture making, wooden structures, and other products, various assembly techniques are used to join wooden pieces together in a strong and durable manner. Some commonly used assembly techniques include:

4.1.1. Mortise and tenon: A traditional method where a portion of one piece of wood is shaped into a projecting member (tenon) that fits into a corresponding slot (mortise) in another piece. The mortise and tenon joint is a traditional and widely used method in woodworking. Here's a more detailed explanation of this technique (Fig 50):

Fig 50. various assembly techniques
Source: https://en.wikipedia.org/wiki/Mortise_and_tenon,2025

- **Tenon:** A tenon is a rectangular or square projection carved at the end of a piece of wood. It is usually sized to fit snugly into a corresponding mortise in another piece of wood. The tenon is often narrower than the main wood piece to allow for a precise fit into the mortise.
- **Mortise:** A mortise is a notch or opening carved into a piece of wood to receive the tenon. It is typically chiseled out using a wood chisel, a mortising saw, or other specialized tools. The mortise is designed to perfectly match the tenon to form a tight and strong joint.
- **Assembly**: To assemble two pieces of wood using the mortise and tenon method, the tenon is inserted into the mortise. Then, the tenon can be glued into the mortise to reinforce the joint. In some cases, wooden dowels may also be used to lock the tenon in place.
- **Advantages:** This assembly method offers several advantages, including:
- **Strength:** Mortise and tenon joints are known for their strength and durability, making them suitable for applications where strong adhesion is required**.**
- **Aesthetics:** Mortise and tenon joints often provide an attractive aesthetic, especially when the tenons are visible on the surface of the assembled piece.
- **Longevity:** Due to their strength, mortise and tenon joints are generally durable and can withstand the test of time.
- **Applications:** This technique is widely used in furniture making, timber framing, fine woodworking, and other woodworking projects where strong and aesthetic joints are required.

4.1.2. Dovetail: Dovetail joints are cut into two pieces of wood that interlock to form a strong joint.Dovetail joinery, also known as dovetailing, is a traditional woodworking technique used to create strong and aesthetic joints. Here's a detailed explanation of this method:

- **Dovetails:** Dovetails are triangular-shaped cuts, often resembling the tail of a dove or a beaver's tail, cut at the end of the pieces of wood to be joined. There are different types of dovetails, including straight dovetails and dovetails with tapered tails, each with its own characteristics and uses.
- **Assembly:** To assemble two pieces of wood using dovetails, tails are cut at the end of one piece (the tail), and corresponding notches (the pins) are cut into the other piece. When the two pieces are assembled, the tails interlock with the pins, creating a strong and durable joint. This configuration creates a larger contact surface between the two pieces, thus reinforcing the joint.
- **Advantages:**
  - **Strength:** Dovetail joints offer great strength and are known for their durability. They are often used in the construction of drawers, boxes, and other furniture requiring robust joints.
  - **Aesthetic:** Dovetails are appreciated for their attractive appearance. When properly cut, they add an aesthetic touch to the assembled piece and can be used as a decorative element.
  - **Self-locking:** Due to their specific shape, dovetails tend to tighten further when pressure is applied in the direction of the assembly, thereby strengthening the joint.

- **Applications:** This technique is commonly used in furniture making, especially for assembling drawers, boxes, and high-quality frames. It is also used in fine woodworking and other projects where strong and aesthetic joints are needed (Fig 51)

Fig 51. Various assembly techniques
Source : https://en.wikipedia.org/wiki/Dovetail_joint,2025

4.1.3. Biscuit joint

Wooden or plastic biscuits are inserted into grooves cut into the pieces of wood to be joined, reinforcing the glued joint.

The biscuit joint is a commonly used assembly method in woodworking to strengthen glued joints between two pieces of wood. Here's how this technique works (Fig 52):

Fig 52. Various assembly techniques
Source: https://www.ironmongerydirect.co.uk/product/timco-wooden-jointing-biscuits-no.-20-pack-of-100-342510,2025

- **Biscuits:**Biscuits are small rectangular pieces made of wood or plastic, often from beech or maple. They are inserted into grooves cut into the pieces of wood to be joined. These grooves are typically cut using a router equipped with a biscuit cutter specifically designed for this purpose.
- **Assembly:**To assemble two pieces of wood using biscuits, grooves are cut into the joining faces of both pieces. The biscuits are then inserted into these grooves. When glue is applied

to the contact surfaces of the wood pieces, the biscuits swell slightly as they absorb the glue. This creates a stronger bond between the two pieces, reinforcing the joint.

- **Advantages:**
  - ➢ **Reinforcement of the joint:** Biscuits add surface contact between the two pieces of wood, strengthening the glued joint.
  - ➢ **Alignment:** Biscuits can also help align the wood pieces during assembly, which is particularly useful for larger pieces.
  - ➢ **Ease of use:** The biscuit joint is relatively easy to make and requires only basic woodworking skills and simple tools such as a router equipped with a biscuit guide.
- **Applications:**This technique is often used in furniture making, especially for assembling wood panels to form tabletops, cabinets, and other furniture elements. It is also used in other woodworking projects where strong and durable glued joints are needed.

4.1.4. Half-lap joint

Wood pieces are cut in such a way that the ends of each piece interlock together (Fig 53).

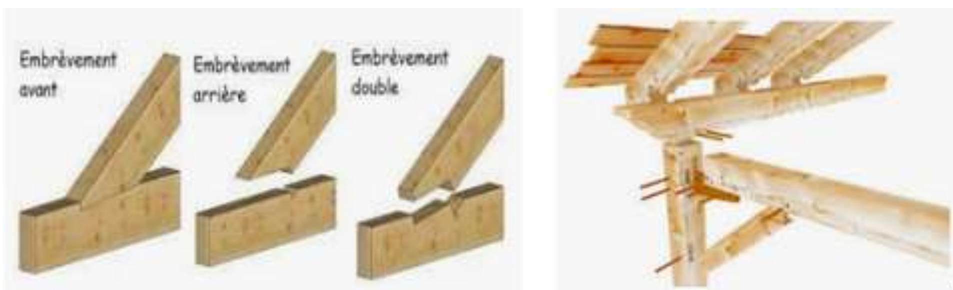

Fig 53. Various assembly techniques

Source : https://www.instructables.com/Easy-Half-Lap-Joints/,2025

Half-lap joint is a traditional and robust method for joining two wood pieces by interlocking them together at their ends. Here's how this technique works:

- **Principle:** In a half-lap joint, each wood piece is cut in a way that rectangular sections are removed from their ends. When these pieces are then assembled, these removed sections interlock with each other, creating a solid and stable joint.

- **Manufacturing:** To create a half-lap joint, typical steps include:

Measurement and marking: Wood pieces are accurately measured, and the locations of the cuts to be made are marked on each piece.

- ➢ **Cutting:** Rectangular sections are cut from the ends of the wood pieces, typically using a table saw, radial saw, or hand saw, depending on the size and complexity of the pieces.
- ➢ **Fitting:** The pieces are carefully fitted to ensure that the cuts interlock perfectly with each other.

- **Assembly:** Once the pieces interlock correctly, glue can be applied to the contact surfaces to reinforce the joint. Wooden dowels can also be used to further secure the assembly.

5. The different materials, elements, and constructions in wood are

- **Round wood materials (logs):** Used in the construction of various structures, including load-bearing elements of houses and bridge decks. Their moisture content and quality must be controlled, and they must be stored properly to prevent deterioration.
- **Sawn timber:** Produced by longitudinal sawing of wood, it includes planks, battens, and joists used in various construction applications. Specifications are provided for dimensions and allowable moisture content.
- **Wood blanks:** These sawings conform to the dimensions required for further machining. They are classified based on their thickness and machining.
- **Flooring materials:** Include materials such as parquet, floorboards, and wooden pavers, with specifications on the types of wood used and allowable moisture levels.
- **Plywood and roofing materials:** Different types of plywood are described, as well as roofing materials such as chips, shingles, and wooden panels, with specifications on their dimensions and uses.
- **Joinery elements:** Includes the elements necessary for doors, windows, partitions, etc., with details on the materials used and manufacturing methods.
- **Wooden construction elements:** Describes prefabricated wooden construction elements for different types of houses and structures, with specifications on materials and construction methods.
- **Reception, transportation, and storage:** Guidelines are provided for inspecting the quality of materials, protecting them during transportation, and properly storing them on-site.

6. Positive properties of wood

- **Relatively high mechanical strength:** Wood offers good resistance to loads and can be effectively used in the construction of structures.
- **Moderate density:** Wood has a relatively low density compared to its strength, making it an attractive construction material for many applications.
- **Low thermal conductivity:** Wood has relatively low thermal conductivity, making it efficient for thermal insulation in construction.
- **Ease of machining:** Wood is easy to work with, allowing for efficient handling and processing during construction.

7. Defects of wood

- **Anisotropy:** Wood exhibits variation in mechanical and thermal properties depending on the direction of the fibers, which can lead to inconsistencies in its behavior in certain situations.

- **Hygroscopicity:** Wood readily absorbs and releases moisture from the air, leading to dimensional changes and alterations in its properties over time.
- **Susceptibility to rot and ignition:** Wood is prone to biological decay (rot) and can easily catch fire when exposed to heat sources or fire.

Wood defects are abnormalities in its normal structure or alterations affecting its technical properties, which may occur during its growth, storage, or utilization. These defects are classified into several categories based on their causes: structural anomalies, mechanical damage, alterations by fungi, and defects caused by insects.

Structural anomalies include twisted grain, characterized by obliquely oriented fibers, which decreases the strength of the wood. Compression wood is also observed in softwoods, as well as trunk curvatures and constrictions, reducing the yield of finished products. The presence of two piths in the cross-section of the trunk is called double pith, which decreases the quality of the assortment. Knots, varying in size and appearance, can be sound or defective, with some being sites of decay. Cracks, such as checks and shakes, may form during drying or due to various environmental causes. Checking can be simple or cross, depending on the arrangement of the fissures on the wood's cross-section.

8. Wood defects caused by plant pests

Mainly fungi are diverse. They include abnormal color alterations and rot, resulting from the action of fungi feeding on wood cells. Fungi thrive in conditions of oxygen, water, and favorable temperature. Wood with less than 20% moisture, as well as that submerged or exposed to freezing, is less susceptible to decay. Some fungi specifically affect living trees, others only cut wood, while some attack both. Their impact varies: some simply change the wood's color, while others deteriorate and rot it.

Examples of destructive fungi include white or brown rot, as well as white rot in hardwoods, which continue to degrade the wood even after its conversion into construction material. House fungi, such as dry rot, can also cause significant damage (Fig 54). When wood is dry, the decay process ceases, and all fungi die. Insects, like wood borers, can also cause defects, such as woodworm, especially in freshly felled or dried wood. Bark beetle damage, caused by wood borers and other insects, is a superficial defect that can spread if the affected wood is used without proper treatment.

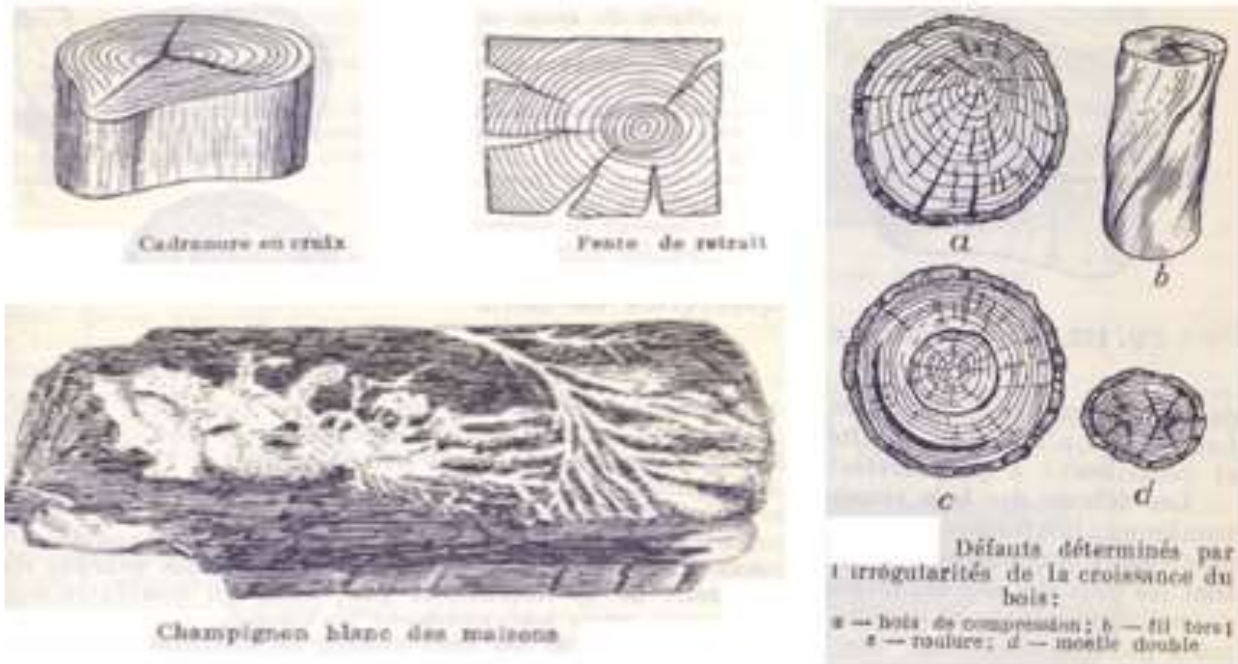

Fig 54. Wood defects caused by plant pests

Source: https://civiconcepts.com/blog/defects-in-timber#google_vignette,2025

9. Wood protection against alterations caused by fungi and insects

Wood protection against alterations caused by fungi and insects is crucial, whether it is for wood used in construction or stored in a warehouse. Different wood species have varying resistances to these attacks. Dense woods rich in summerwood and tannic substances are generally more resistant, while debarked wood can be stored in dry and well-ventilated premises for an extended period.

To increase the durability of wood, several methods are used, including avoiding its exposure to moisture through structural measures, painting or coating, as well as drying and impregnating it with antiseptic agents. Painting, coating, and drying help extend the lifespan of wood by protecting it from the elements. Applying oil-based paints, varnishes, or linseed oil forms a protective barrier on the wood surface. Coating with dry tar can also be effective. Drying wood in cold water or during floating removes plant saps and reduces the risk of rot. Antiseptics are substances toxic to fungi responsible for wood decay. They are classified based on their solubility in water, oily nature, or in paste form. Water-soluble antiseptics, such as sodium fluoride and sodium fluosilicate, are used to treat wood that will not be exposed to water. Oily antiseptics, like tar oil, are used to protect wood exposed to air, soil, or water. Antiseptic pastes, composed of different ingredients such as sodium fluoride and peat powder, are used to cover elements exposed to moisture and weathering.

Wood treatment methods with antiseptics include several approaches such as surface treatment, impregnation in hot-cold baths or high-temperature baths, as well as pressure soaking.

- **Surface treatment:** This method involves coating or spraying wood with an antiseptic solution to protect its surface.
- **Impregnation in hot-cold baths:** Wood is immersed in a bath containing a hot antiseptic (98 °C) for several hours, then transferred to a cold antiseptic bath (15-20 °C for water-soluble antiseptics and 40-60 °C for oily antiseptics) for some time. This method is effective for slightly dried wood with sapwood moisture below 30%.
- **Impregnation in high-temperature baths:** Used for treating green wood, this method involves immersing the wood in a bath of melted liquid petrolatum (120-140 °C) for heating and drying, followed by a bath of oily antiseptic at a temperature of 65-75 °C for 24 to 48 hours.
- **Pressure soaking:** Wood is placed in cylindrical steel boilers under pressure (0.6-0.8 MPa) with aqueous or oily antiseptics. After impregnation, the pressure is reduced, and the antiseptics are drained. Additionally, to protect wood against inflammation, it is possible to cover it with coatings or fire-resistant materials such as plaster or asbestos cement sheets. Fire-resistant paints are also used, classified into different categories such as silicate, casein, oil, and vinyl chloride paints, providing fire protection by forming a fireproof layer on the wood. Furthermore, impregnation with flame retardants, special chemicals, is an effective method to reduce the flammability of wood in the presence of high temperatures.

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14. THE CERAMIC PRODUCTS

Summary

1. Generalities about ceramic products
2. Properties and uses of ceramic products
3. The different types of bricks (solid and hollow)
4. Ceramic products laying patterns
5. Different types of ceramic tiles
6. Ceramic product coatings

1- Generalities about ceramic products

Ceramic products are materials made from inorganic and non-metallic raw materials, typically minerals or metal oxides (Callister & Rethwisch, 2020).
Two classes of ceramics are distinguished (Fig 55).

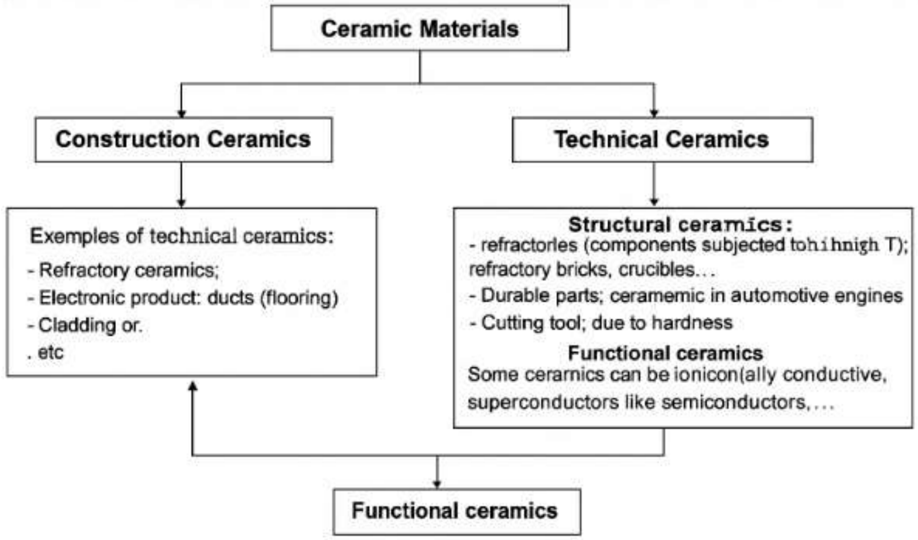

Fig 55. Classes of ceramics

Source: https://www.youtube.com/watch?v=LtlxTDOcbXI,2025

- **Composition:** Ceramics can be composed of various materials, such as clay, sand, feldspar, kaolin, silica, alumina, etc. These materials are mixed in specific proportions depending on the desired properties for the final product (Kingery, Bowen, & Uhlmann, 1976).
- **Manufacturing:** The manufacturing of ceramic products typically involves shaping, drying, and firing processes. Forming techniques include molding, extrusion, and pressing. Drying removes moisture, while firing (or vitrification) at high temperatures fuses particles to form a solid structure (Rahaman, 2017).
- **Types of ceramics:**There are different categories of ceramics, including traditional ceramics (pottery, tiles, bricks), technical ceramics (advanced ceramics used in aerospace, electronics, medical applications), and advanced ceramics (such as carbide, nitride, oxide-based ceramics, used in extreme environments) (Barsoum, 2013).
- **Properties:** Ceramics generally have properties such as hardness, heat resistance, corrosion resistance, electrical insulation, and chemical stability. However, they can be brittle and prone to fracture under stress (Norton, 1974).
- **Applications:** Ceramic products are widely used in many fields, including construction (tiles, bricks), electronics (insulators, substrates), aerospace (heat-resistant components), medical (prosthetics, implants), and automotive (catalysts, spark plugs) (Richerson & Lee, 2018).
- **Innovations:** Research and development in ceramics have led to significant advances such as high-performance technical ceramics, ceramic composites, and more efficient manufacturing processes (Rahaman, 2017).

2. Properties and uses of ceramic products

Ceramic products have a variety of properties that make them attractive for many applications (Barsoum, 2013).

- **Heat resistance:** Ceramics can withstand high temperatures without deforming or degrading, making them ideal for refractory linings, spark plugs, and heat-resistant tiles (Rahaman, 2017).
- **Electrical insulation:**Due to their low electrical conductivity, ceramics are used as insulators in circuit boards, high-voltage systems, and component casings (Kingery et al., 1976).
- **Corrosion resistance:** Some ceramics resist chemical corrosion, suitable for chemical containers, coatings, and oil and gas components (Callister & Rethwisch, 2020).
- **Hardness:**Ceramics' extreme hardness makes them useful in cutting tools, bearings, and wear-resistant coatings (Richerson & Lee, 2018).
- **Biocompatibility**:Certain ceramics are biocompatible and used for bone implants, dental prosthetics, and medical devices (Hench & Wilson, 1993).
- **Lightweight**: Many ceramics are strong yet light, ideal for aerospace and automotive structures (Barsoum, 2013).
- **Translucency or opacity**: Ceramics can be transparent, semi-transparent, or opaque, used in glassmaking and optics (Kingery et al., 1976).

3. The different types of bricks (solid and hollow)

Bricks are commonly used building elements in the construction industry to erect walls and other structures. There are different types of bricks, including solid bricks and hollow bricks (Fig 56-57). Here's an overview of each:

- **Solid Bricks:**

Fig 56. The different types of bricks
Source: https://www.ultratechcement.com/for-homebuilders/home-building-explained-single/descriptive-articles/types-of-bricks-and-its-properties,2025

1).Composition: Solid bricks are made from clay or other ceramic materials. They are typically formed by pressing clay into molds and firing them at high temperatures (Callister & Rethwisch, 2020).

2).Appearance: Solid bricks have a solid and uniform structure throughout their length and width. They are generally heavier than hollow bricks due to their density.

3).Uses: Solid bricks are often used in applications where high strength and good thermal insulation are required. They are ideal for constructing load-bearing walls, chimneys, foundations, and other structures requiring great strength.

- **Hollow Bricks**

Fig 57. The different types of bricks
Source: https://www.ultratechcement.com/for-homebuilders/home-building-explained-single/descriptive-articles/types-of-bricks-and-its-properties,2025

1).Composition: Hollow bricks are similar to solid bricks in terms of the base material, but they have cavities inside that reduce their weight and density (Neville, 2011).

2).Appearance: Hollow bricks have a U or H-shaped structure with cavities inside. They are lighter than solid bricks due to their hollow design.

3).Uses: Hollow bricks are often used in applications where weight is a significant factor, such as constructing non-load-bearing walls, interior partitions, facade claddings, and boundary walls. They also provide better thermal and acoustic insulation due to their internal cavities.

4. Ceramic products laying patterns

The laying pattern of ceramic products refers to the arrangement or layout of ceramic elements, such as bricks, tiles, blocks, etc., during their installation in a construction project. (Fig 59).The laying pattern can have aesthetic, structural, and functional impacts on the final outcome of the construction(Ching, 2014).. Here are some commonly used types of laying patterns for ceramic products:

Fig 59. Ceramic products laying patterns
Source : https://sacmi.com/en-US/ceramics,2025

- **Stretcher Bond:**Ceramic elements are arranged in rows or lines to form parallel horizontal or vertical rows. This is one of the simplest and most common laying patterns, often used for brick walls and tiled flooring.
- **Running Bond:**In this pattern, each row of bricks or tiles is offset from the previous row, creating a diagonal pattern. This helps reinforce the structural stability of the wall while adding an interesting visual aspect.
- **Herringbone:**Ceramic elements are arranged to form a V-shaped or herringbone pattern. This laying pattern is often used for wood or ceramic flooring to create a distinctive herringbone pattern.
- **Checkerboard:**Ceramic elements are alternated to form a checkerboard pattern, with rows of tiles of contrasting colors. This pattern is popular for ceramic tile flooring.
- **Fishscale:**In this pattern, ceramic elements are arranged to form a fishscale pattern, where tiles are laid at right angles to each other. This creates a visually interesting pattern.
- **Random Bond:**This laying pattern involves arranging ceramic elements randomly, without a specific or regular pattern. This creates a rustic and organic look, often used for natural stone or brick walls.
- **Arches:**Ceramic elements are arranged to form arches or arch-shaped patterns, often used for facade cladding or vaulted passages.

These examples represent only a fraction of the many possible laying patterns for ceramic products. The choice of laying pattern often depends on factors such as architectural style, desired aesthetics, functionality, and structural constraints of the construction project.

5. Different types of ceramic tiles

There is a wide variety of tiles available on the market, each with its own characteristics, advantages, and specific applications (Barsoum, 2013; Rahaman, 2017).. Here are some of the most common types of tiles Fig (59-60-61):

Fig 59. Different types of ceramic tiles
Source : https://archello.com/fr/product/flat-10-ceramic-roof-tile-nature-red,2025

Here are some of the most common types of tiles:

- **Glazed Ceramic Tiles:**These tiles are coated with vitrified enamel, giving them a smooth and glossy finish. They are available in a wide range of colors and patterns, making them popular for flooring and walls in kitchens, bathrooms, and living spaces.
- **Unglazed Ceramic Tiles (Terracotta):**Unglazed ceramic tiles, often called terracotta tiles, are made from fired clay without enamel. They have a rustic and porous appearance and are often used for outdoor flooring, patios, and garden spaces.
- **Subway Ceramic Tiles:**These rectangular tiles became popular in the 1900s in New York subway stations. They have a distinctive appearance with beveled edges and are often used for kitchen backsplashes, bathroom walls, and wall coverings.
- **Hexagonal Ceramic Tiles:**These tiles are formed in hexagons and offer a unique geometric look. They are available in a variety of colors and sizes and are often used to create eye-catching floor or wall patterns in indoor and outdoor spaces.
- **Travertine Ceramic Tiles:**Inspired by natural travertine, these ceramic tiles mimic the appearance of natural stones with their warm tones and varied textures. They are used for indoor and outdoor flooring, as well as shower walls and kitchen backsplashes.
- **Porcelain Ceramic Tiles:**Porcelain ceramic tiles are made from fine ceramic paste and are fired at high temperatures. They are extremely durable, moisture-resistant, and stain-resistant, making them ideal for high-traffic indoor and outdoor floors.
- **Mosaic Ceramic Tiles:**These tiles are typically small in size and are assembled to form patterns, images, or decorative borders. They are used to add artistic details to floors, walls, pools, and shower spaces.

Each type of ceramic tile has its own aesthetic and functional characteristics, offering a variety of options for interior and exterior decorating projects.

6. Ceramic product coatings

Ceramic product coatings offer a wide variety in terms of types, styles, and applications (Richerson & Lee, 2018). Here are some of the most commonly used coatings:

- **Floor tiles:**Ceramic floor tiles are popular for their durability, ease of maintenance, and wide range of styles and patterns. They are used in kitchens, bathrooms, hallways, and other high-traffic indoor and outdoor spaces.

Fig 60. Different types of ceramic tiles
Source: https://jandjfarmsgc.com/blog/types-ceramic-tile,2025

- **Wall tiles:**Ceramic wall tiles are available in a variety of finishes, colors, and sizes, and are used for indoor and outdoor walls. They are commonly used in kitchens for backsplashes, bathrooms for showers and tubs, and building facades for their aesthetics and durability.

Fig 61. Different types of ceramic tiles
Source: https://www.thespruce.com/how-to-install-ceramic-wall-tile-1824817,2025

- **Backsplash tiles:**Ceramic backsplash tiles are installed on walls between countertops and cabinets in kitchens and bathrooms to protect surfaces from splashes and spills. They also add a decorative touch to the space.
- **Pool tiles:**These tiles are specially designed to withstand wet conditions and chemicals present in pool water. They provide a non-slip surface and can be used for residential and commercial pools.
- **Terrace and patio tiles:**Ceramic tiles for terraces and patios offer a durable and aesthetic alternative to concrete or wood. They withstand weather conditions and can be found in a variety of finishes to create different outdoor landscaping styles.
- **Artistic faience:**Faience is a form of decorative ceramic that often involves hand-painted patterns or intricate designs. It is used to create artistic pieces, mural panels, decorative tiles, and other art objects.
- **Facade cladding tiles:**These tiles are designed to be used as exterior cladding for buildings. They offer a combination of durability, aesthetics, and performance, and can be found in a range of finishes and styles to meet specific architectural requirements.

These examples represent only a fraction of the possible applications of ceramic product coatings. The choice of coating will depend on the specific functional, aesthetic, and budgetary needs of the project.

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15. INSULATORS

Summary

1. Generalities on insulators

are materials used to reduce or prevent the transfer of heat, sound, or electricity between different environments. They play an essential role in construction and industry by improving energy efficiency, providing thermal and acoustic comfort, and ensuring electrical safety(ASHRAE, 2021; Kosny, 2015).

Here are some generalities about insulators:

2. Types of insulators:

Insulators can be classified into several categories based on the type of heat they are designed to block:

1).Thermal insulators: They reduce the transfer of heat between hot and cold spaces(Zhang et al., 2018).

2).Acoustic insulators: They reduce sound transfer between rooms or from outside to inside(Caniato et al., 2016).

3).Electrical insulators: They prevent the passage of electric current and ensure the safety of electrical installations (Callister & Rethwisch, 2020).

3. Insulating materials

Insulators can be made from a wide variety of materials, including:

- **Mineral fibers:** such as glass wool, rock wool(Papadopoulos, 2005).
- **Foam insulation:** such as expanded polystyrene (EPS), polyurethane (PUR), polyisocyanurate (PIR) (Jelle, 2011).
- **Natural materials:** such as sheep's wool, cellulose, cork (Asdrubali et al., 2015)..
- **Synthetic materials:** such as extruded polystyrene (XPS), cross-linked polystyrene (XPS) (Pérez et al., 2019).

4. Properties of insulators

Insulators are characterized by several important properties, including:

- **Thermal conductivity:** a measure of a material's ability to conduct heat.
- **Thermal resistance:** a material's ability to resist heat transfer.
- **Sound absorption:** a material's ability to absorb sound.
- **Flammability:** a material's reaction to exposure to fire.
- **Durability:** an insulator's ability to retain its properties over a long period (Kosny, 2015; Papadopoulos, 2005).

5. Applications of insulators

Insulators are used in a wide variety of applications, including:

- **Thermal insulation of buildings:** walls, roofs, floors, doors, and windows.
- **Sound insulation:** walls, ceilings, floors in studios, theaters, cinemas.
- **Electrical insulation:** electrical cables, transformers, electric motors.
- **Industrial insulation:** pipes, tanks, industrial equipment. (Jelle, 2011; ASHRAE, 2021).

Structure and classification of insulators Insulators can be classified based on their structure, properties, and specific applications. Here is a general structure and classification of insulators:

6. Structure of insulators

Insulators can have different structures depending on their physical form and how they are manufactured.

6.1. The main structures include

- **Fibrous:** composed of mineral or synthetic fibers, such as glass wool, rock wool, fiberglass, etc.
- **Cellular:** composed of closed or open cells, often manufactured in the form of foams, such as expanded polystyrene (EPS), polyurethane (PUR), extruded polystyrene (XPS), etc.
- **Granular:** composed of insulating particles, such as polystyrene beads, perlite, vermiculite, etc.
- **Layered structure:** composed of layers of insulating materials, such as reflective films (Papadopoulos, 2005).

6.2. Classification of insulators based on their properties

- **Thermal insulators:** designed to reduce the transfer of heat between hot and cold environments.
- **Acoustic insulators:** designed to reduce sound transmission through materials.

Electrical insulators: designed to prevent the transmission of electric current through materials.

- **Fire-resistant insulators:** designed to resist flames and high temperatures. (Zhang et al., 2018).

6.3. Classification of insulators based on their applications

- **Building insulation:** used for thermal and acoustic insulation of buildings, including walls, roofs, floors, doors, and windows.

Industrial insulation: used for thermal and acoustic insulation of industrial equipment, pipes, tanks, etc.

- **Electrical insulation:** used for electrical insulation of cables, transformers, electric motors, etc. (Caniato et al., 2016).
- **Insulators for special applications:** used in specific fields such as aerospace, automotive, electronic equipment, etc.

Insulators can be classified based on their physical structure, properties, and specific applications. Each type of insulator has unique characteristics that make it suitable for particular needs in thermal, acoustic, or electrical insulation.

7. Thermal Insulation

Thermal insulation is a process that involves reducing or preventing the transfer of heat between environments of different temperatures (Kosny, 2015). It plays a crucial role in energy conservation, maintaining thermal comfort, and reducing heating and cooling costs. Here are some key points about thermal insulation:

- **Basic Principles:**Thermal insulation relies on two fundamental principles: thermal resistance and thermal conductivity (Jelle, 2011).. The thermal resistance of a material measures its ability to slow down the transfer of heat, while thermal conductivity measures its ability to conduct heat.
- **Insulating Materials:**A wide range of insulating materials is available for thermal insulation, including glass wool, rock wool, expanded polystyrene (EPS), polyurethane (PUR), extruded polystyrene (XPS), perlite, cellulose, etc(Asdrubali et al., 2015). Each material has its own thermal properties and is suited to specific applications.
- **Applications:**Thermal insulation is widely used in buildings to insulate walls, roofs, floors, doors, and windows to reduce heat loss in winter and maintain coolness in summer. It is also used in heating, ventilation, and air conditioning (HVAC) systems, industrial equipment, piping, tanks, and electrical appliances to improve their energy efficiency (ASHRAE, 2021)..
- **Thermal Resistance and R-value:** The thermal resistance of an insulating material is measured by its R-value, which is expressed in square meters per degree Celsius per watt

(m²•°C/W). The higher the R-value, the better the thermal insulation of the material (Pérez et al., 2019).The R-value depends on the thickness and type of insulating material used.

- **Factors Influencing Efficiency:** Several factors can influence the efficiency of thermal insulation, including the quality of installation, the presence of thermal bridges, air tightness, adequate ventilation, and local environmental conditions (Zhang et al., 2018).
- **Standards and Regulations:** Many government regulations and standards impose minimum requirements for thermal insulation in new buildings and renovations to promote energy efficiency and reduce greenhouse gas emissions (ISO, 2017).. Thermal insulation is an essential element in the design and construction of buildings and equipment to ensure optimal thermal comfort, reduce energy consumption, and preserve the environment.

8. Acoustic Insulation

Acoustic insulation, also known as soundproofing, is the process of reducing sound transfer between different rooms or environments (Caniato et al., 2016).. It is essential for creating quiet, comfortable, and private spaces, whether in homes, commercial buildings, or industrial settings. Here are some key points about acoustic insulation:

- **Basic Principles:** Acoustic insulation aims to minimize noise transfer by blocking, absorbing, or diffusing sound waves. It can be achieved using a combination of insulating materials, double-wall constructions, absorbent coatings, and appropriate design techniques.
- **Insulating Materials:** Several materials are used for acoustic insulation, including mineral wool (rock wool, glass wool), acoustic foams, expanded polystyrene (EPS), polyurethane (PUR), acoustic panels, high-density materials like lead and rubber, and special coatings such as soundproof membranes.
- **Applications:** Acoustic insulation is used in a variety of contexts, including residential homes, offices, hotels, cinemas, recording studios, performance halls, classrooms, hospitals, conference rooms, restaurants, bars, and industrial spaces.
- **Acoustic Insulation Indices:** The effectiveness of acoustic insulation is measured using several indices, such as the sound reduction index (SRI), airborne sound insulation index (Rw), impact sound insulation index (Ln), and coefficients of sound absorption (α) (Long, 2014). These indices determine a material or structure's ability to reduce noise levels.

- **Factors Influencing Efficiency:** Several factors can influence the efficiency of acoustic insulation, including the thickness and type of insulating material used, architectural design, installation quality (Asdrubali et al., 2015), environmental conditions, and the frequency and intensity of noise.
- **Standards and Regulations:** Many national and international standards and regulations establish minimum requirements for acoustic insulation in residential, commercial, and industrial buildings to ensure the comfort and safety of occupants. Acoustic insulation is a crucial aspect of building and space design to ensure a comfortable and productive environment by reducing noise disturbances and preserving privacy (ISO, 2017).

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16. GLASS

Summary

1. Definition of Glass

Glass is a solid and transparent material used in various contexts, such as the manufacturing of windows, containers, decorative objects, and even in optics for making glasses or lenses (Shelby, 2005; Varshneya, 2013).

2. History of Glass

The history of glass dates back several thousand years. The earliest evidence of glassmaking dates back to ancient Egypt, where glass was used to make beads and amulets (Brill, 1999). (Brill, 1999). Glassmaking techniques evolved over time, with significant advancements occurring in Europe during the Middle Ages. The invention of glassblowing in the 1st century BC revolutionized glass production, enabling the creation of more intricate shapes and a wider range of products (Shortland & Eremin, 2006).

3. Manufacturing Process

The manufacturing process includes melting raw materials, shaping, and annealing to reduce internal stresses (Varshneya, 2013; Shelby, 2005).

4. Composition

Raw materials include vitrifiers, fluxes, stabilizers, refining agents, colorants, and opacifiers. Each category has a specific role, such as creating the vitreous structure, melting the vitrifiers, stabilizing the glass, eliminating gases, coloring the glass, and making the glass opaque if necessary (Callister & Rethwisch, 2020; Wondraczek et al., 2020).

5. Main Sectors of the Glass Industry

5.1. Flat Glass: Used for windows and mirrors, manufactured by processes such as drawing, rolling, and floating (Parke & Searle, 2003)..

- **Flat Glass Processing:** Includes tempering for increased strength and laminating for safety (Haldimann et al., 2008).
- **Insulating Glass:** Assembly of glass sheets for thermal and acoustic insulation(Papadopoulos, 2005).
- **Mirrors:** Manufacture of mirrors (Shelby, 2005)..
- **Hollow Glass:** Used in glassware, crystalware, packaging, and various technical applications.

5.2. Technical Glass:

- **Glass Fibers:** Used for textiles, reinforcing plastics, thermal and acoustic insulation (Jelle, 2011).
- **Optical Fibers:** Used in medicine and telecommunications (Hawkes, 2017). (Fig 62).

Fig 62. Optical Fibers
Source: https://www.ofsoptics.com/optical-fibers-bring-new-medical-applications-to-light/?srsltid=AfmBOoqHjuXOrHjvBzit0UgjH71G86iSNrjfz5hMB7iZlMzUz1Hx9dTa,2025

- **Cellular Glass:** Used for building thermal and acoustic insulation (Asdrubali et al., 2015) (Fig 63)..

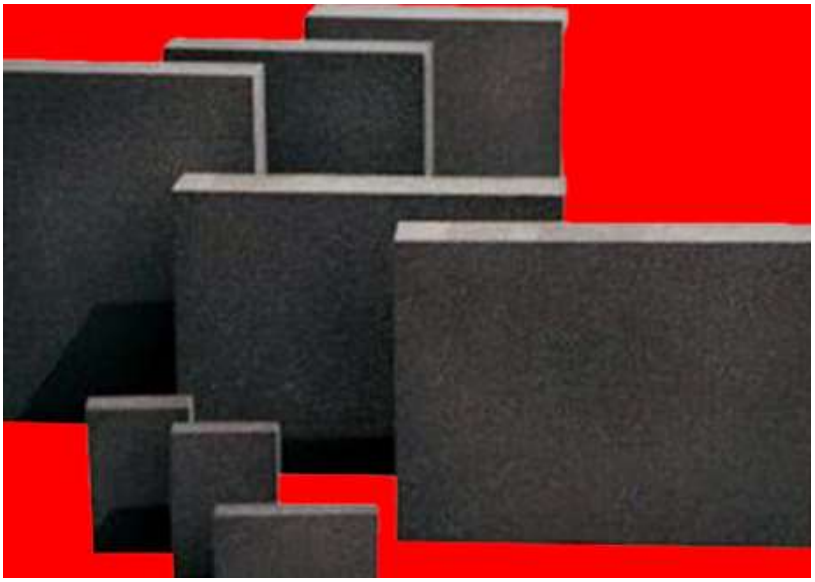

Fig 63. Cellular Glass
Source: https://www.wedge-india.com/product-page/foam-glass,2025

6. Properties of Glass

- **Glass possesses** several properties that make it useful in various fields:

- **Transparency:** Glass allows the passage of light, making it an ideal material for windows and eyeglasses.
- **Hardness:** Although glass is a brittle material, it is also hard and resistant to abrasion.
- **Thermal Insulation:** Some types of glass can be used as thermal insulators, helping to reduce heat loss in buildings.
- **Chemical Resistance:** Glass is resistant to many chemicals, making it suitable for use in corrosive environments (Varshneya, 2013; Wondraczek et al., 2020)..
- **Recyclability:** Glass is 100% recyclable, making it an environmentally friendly material (Papadopoulos, 2005).

7. Glass in Building:

Glass is widely used in the building sector for its aesthetic and functional properties (Jelle, 2011).

7.1. Windows: Glass is used to manufacture windows that allow natural light to pass through while providing thermal and acoustic insulation (Asdrubali et al., 2015).

7.1.1.Glass Windows: In the future, glass windows will continue to advance. Technological advancements, such as smart windows capable of automatically dimming to regulate brightness and heat, are already under development. Moreover, the focus on sustainability and energy efficiency will become increasingly crucial, driving innovation in the design and manufacturing of glass windows (Granqvist, 2014).

In summary, the history of glass windows is a story of continuous evolution. From their humble beginnings in ancient Egypt to the smart windows of the future, these fundamental elements of our homes have come a long way (Zhang et al., 2018). Today, they offer comfort, aesthetics, and practicality. Whether adorning Gothic cathedrals or outfitting modern skyscrapers, glass windows truly embody our technological and artistic progress.

7.1.2.The Pros and Cons of Glass Windows

The choice of windows for constructions influences their appearance, comfort, and energy efficiency. Among the alternatives, glass windows are highly favored for their contemporary aesthetics and ability to let in natural light. However, like any decision, there are both positive and negative aspects to consider; we will explore the key advantages and disadvantages of glass windows.

7.1.3.Advantages of Glass Windows

- **Brightness and Aesthetics:** Glass windows provide exceptional natural light, creating an open and pleasant atmosphere in your living space. Their modern aesthetic adds a contemporary and elegant touch to your interior(Papadopoulos, 2005).
- **Connection with the Outdoors:** They offer views of the garden or surrounding landscape, establishing a visual connection with the outside world, which is beneficial for mental well-being and serenity.
- **Thermal and Acoustic Insulation:** Modern models incorporate advanced insulation technologies, preserving warmth in winter and coolness in summer, while reducing external noise (Caniato et al., 2016).
- **Ease of Maintenance:** They are relatively easy to maintain, requiring just regular cleaning to remain transparent and impeccable.
- **Disadvantages of Glass Windows:**
- **Security:** They may be more vulnerable to intrusions and accidental breakages, but the use of safety glass such as tempered or laminated glass can mitigate these risks.
- **Fingerprints:** They tend to easily show fingerprints and stains, requiring regular cleaning to maintain their clean appearance.
- **Initial Cost:** Their purchase and installation costs may be higher than those of other types of windows, but this should be seen as a long-term investment due to their aesthetic and energy-saving benefits.

Glass windows offer many aesthetic and functional advantages, such as brightness, modern aesthetics, thermal and acoustic insulation, as well as ease of maintenance. However, it's important to also consider the disadvantages such as security and initial cost (Haldimann et al., 2008).

If you opt for glass windows, it's recommended to choose safety glass and carefully assess your needs and budget. By collaborating with experienced professionals, such as Vitrerie-Salonaise, you can be sure to get high-quality glass windows that meet your requirements in terms of energy efficiency, style, and security (Varshneya, 2013).

7.1.4.Types of Glass Windows

Glass windows play a crucial role in bringing natural light and outdoor views into our living spaces. However, there is a variety of glass window types, each with its own advantages and disadvantages. In this article, we will examine the different types of glass windows available on the market.

- **Single Glass Windows:**The most common and affordable. Composed of a single glass panel. Offer limited thermal and acoustic insulation. Suitable for buildings where energy efficiency is not a priority (Papadopoulos, 2005).
- **Double Glass Windows:**More efficient in terms of thermal and acoustic insulation than single windows. Composed of two glass panels with a layer of air or inert gas between them. Reduce heat loss and noise transfer, improving energy efficiency (Zhang et al., 2018).
- **Triple Glass Windows:**Offer even better insulation than double glass windows. Composed of three glass panels separated by layers of air or inert gas. Ideal for cold climates where insulation is crucial (Jelle, 2011).
- **Laminated Glass Windows:**Popular for security reasons. Composed of multiple glass panels bonded by a layer of resilient plastic film. Reduce the risk of injury in case of breakage and provide better protection against intrusions (Haldimann et al., 2008).
- **Tinted Glass Windows:**Aesthetically appealing and offer protection against UV rays. Available in a variety of tints and patterns. Reduce fading of furniture and flooring (Granqvist, 2014).
- **Low-Emissivity (Low-E) Glass Windows:**Designed to minimize heat loss. Coated with a thin, transparent layer that reflects heat indoors in winter and blocks it outdoors in summer. Improve energy efficiency, resulting in savings on heating and cooling bills. The choice of glass window type will depend on your specific needs, budget, and the location of your home or building. Feel free to contact our team of specialized glaziers for personalized and professional advice on the type of glass windows that would best suit your situation (Granqvist, 2014; Pérez et al., 2019).

7.2. Glass Facades

Glass facades have become an iconic feature of contemporary architecture, offering transparent and luminous structures that define the modern aesthetic of buildings (Pérez et al., 2019).

A curtain wall, on the other hand, represents a lightweight outer envelope of a building, ensuring water and air tightness without contributing to its structural stability (Haldimann et al., 2008). Typically composed of an aluminum or steel frame, it holds filling elements such as glazing or solid panels.

Beyond their aesthetic aspect, curtain walls must meet current energy efficiency standards. The choice of glazing, combined with adequate solar protection, is crucial to optimize their thermal performance (Zhang et al., 2018).. For example, certain types of glazing can maximize solar gains in winter while reducing overheating in hot regions during summer.

Glass plays a central role in the functionality of curtain walls, contributing to energy efficiency by limiting heat loss and regulating solar gains. Thus, choosing appropriate glazing can significantly influence the building's energy cost and occupants' comfort, particularly enhancing visual and acoustic comfort (Varshneya, 2013).

Moreover, selecting reinforced or security glazing can enhance the building's safety by protecting it against intrusions and potential damages, such as impacts. Therefore, the curtain wall, through its selection of suitable glazing, contributes to ensuring the overall safety of the building.

7.2.1.Laminated and Tempered Glass

These types of glass offer increased safety in case of breakage, making them ideal for use in doors and shower walls (Haldimann et al., 2008). Custom tempered laminated glass represents a significant advancement in the field of glazing, offering both aesthetic and secure solutions for various applications. Before exploring its numerous advantages and enhanced safety, it is essential to understand its distinctive characteristics compared to other types of available glazing.

7.2.2.Characteristics and Advantages of Custom Tempered Laminated Glass

With its two glass layers, custom tempered laminated glass provides enhanced safety against breakage and falls compared to simple mirrors. Its improved mechanical properties make it an anti-break-in safety glass, with shock resistance five times higher than that of regular glazing

(Shelby, 2005).This resistance is due to the compression of the substrate on its surface during the tempering process.

7.2.3.Different Possible Applications

The robustness and clear transparency of custom tempered laminated glass make it an ideal choice for custom glass balustrades, offering optimal safety. It is also recommended for buildings and homes exposed to shocks and vibrations, as a delayed-action protective glass, thanks to its laminated structure associated with tempered glass. This type of glazing is also appreciated for windows, offering increased resistance to impacts, break-in attempts, or vandalism, as well as improved sound insulation, essential in noisy urban environments. It is also suitable for glass floors, offering safety and brightness (Shelby, 2005)..

7.2.4.Thermal Insulation

Thermal insulation glazing helps reduce heat loss in buildings, thus improving their energy efficiency (Jelle, 2011). Choosing high-performance thermal windows is crucial for optimizing the energy efficiency of constructions.

These windows offer superior thermal insulation thanks to their high-performance glazing. They are often equipped with double or triple glazing, with inert gases such as argon or krypton between the glass panes to reduce heat transmission.

Low-emissivity double glazing, also known as low-e glazing, features a thin, transparent layer of metal oxides on one side of the glass panes, which retains heat. This improvement in the thermal transmission coefficient significantly reduces heat loss, up to 20 to 30% compared to standard double glazing, and even up to 80% compared to single glazing (Granqvist, 2014). Indeed, their insulating capacity is two or three times higher than that of traditional double glazing(Fig 64).

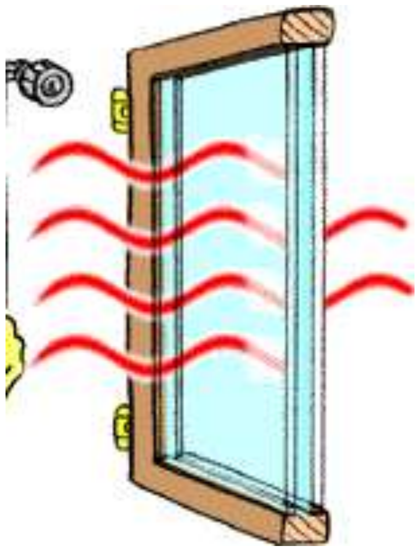

Fig 64. Window double glazing

Source : https://www.familyhandyman.com/article/double-glazed-windows/?srsltid=AfmBOopu71iHh3hrMIf7NKby9EBldovp7ts2LijoIuXYeHJ1nOO1UUEv,2025

While low-e double glazing may be more expensive than traditional double glazing, it allows for significant heating cost savings. In general, this investment pays off in just two years. Similarly, triple glazing offers even higher thermal and acoustic performance, but its cost is also higher (Pérez et al., 2019). However, this investment may be justified for facades particularly exposed to extreme weather conditions.

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