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Department of: **Civil Engineering & Hydraulics**

Course Book:

Technology of Building Materials 1

Intended for first-year architecture students

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Foreword

This handout meets the ministerial outline of the Technology of Building Materials 1 course taught in the first year of Architecture.

The purpose of this handbook is to describe construction materials, to study their properties to enable student architects to choose construction materials in the best conditions of consistency, safety and durability. Also to become aware of the diversity of materials and their use in construction.

This course consists of seven chapters. The first chapter presents generalities on the architecture-materials relationship, as well as on the classification and properties of materials: chemical, physical and mechanical properties. In the second, third and fourth chapters we present in detail the binders namely cement, lime and plaster respectively. The fifth chapter is devoted to aggregates (origin, classification and characteristics) nevertheless the main characteristics will be treated in the form of practical work in the laboratory. In the seventh chapter we are interested in mortar: definition, constituents, types and field of use, while its characteristics will also be studied in the laboratory. The document is finally closed by a list of bibliographical references used for the writing of this course. Finally, we hope that this document will be a useful support for our students.

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General Introduction

Rapid developments in costruction technologies and materials provide unprecedented opportunities in modern architecture. Their choice is made according to the imperatives of durability, efficiency, aesthetics and cost. The architect must learn about the different properties of materials and the techniques of their use as well as their innovations in order to push the limits of what is architecturally possible. In this course, we present a state of the art of some commonly used materials in construction. We start with hydraulic and aerial binders such as cement, lime and plaster, then aggregates then mixing water and we will finish with mortars. This content meets the ministerial framework of the course Construction Materials Technology1 taught in the first year of Architecture. This course is composed of seven chapters. The first chapter presents general information on the architecture-materials relationship, as well as the classification and properties of materials: chemical, physical and mechanical properties. In the second, third and fourth chapters, we present in detail the binders namely respectively cement, lime and plaster. The fifth chapter is devoted to aggregates (origin, classification and characteristics). The main characteristics of aggregates (sand and gravel) will be addressed in the form of practical work in the laboratory. In the sixth chapter, the role, quality and characteristics of mixing water will be detailed. In the seventh chapter we focus on mortars: definition, constituents, types and field of use. This chapter will be completed by practical work: formulation and characterization test in the fresh and hardened state. The document is finally closed by a list of bibliographical references used in its writing. Finally, we hope that this document will be a useful support for our students.

Chapter 1: Introduction to the Technology of Building Materials (TBM)

1.1. General

The choice and implementation of construction materials have always been guided by technical and architectural criteria. In addition to these, economic and environmental criteria are not also considered.

The key materials in the history of architecture are: wood, stone, glass, steel, concrete, hydraulic binders and recently polymers.

1.2. Architecture and materials

In the Middle Ages, wood became a primary choice in architecture notably due to its many advantages : coste- effective, robust : resistant to both compression and bending, easy to assemble and offering good thermal insulation. Over time, however, its use became less commen: as cities grew and houses were built closer together, the risk of fires increased and the flammable properties of wood became disadvantage; nevertheless, the material continued to be used for certain specific elements.

Since prehistory, stone has been used to create various objects. Behind the term "stone" lies wide range of materials, some natural and others artificial. The most commonly used natural stones in architecture are: granite, millstone, slate, marl, limestone and marble**.** Natural stones are particularly valued for their aesthetic qualities, especially marble and limestone. The majestic Greek temples are the oldest trace of the use of natural stone in architecture. In this case, the stone used to build these temples is marble. In ancient Greece, marble was the most prestigious and sought-after stone, prized for its polished finish and beautiful light.

In the Middle Ages, stonemasons emerged as a craft. A true art form, the expertis of stonemasons added a new dimension to the use of this material. Stone was used with increasing refinement. Gothic cathedrals, especially those in the flamboyant Gothic style, showcase the full power of the stonemasons' work. Architectural innovations related to the use of stone also allowed buildings to reach greater height. The elegant pointed arches, ribbed vaults and flying buttresses are characteristic of this architecture. The use of stone persisted for centuries until the late 20th century, when new materials were introduced. artificial stones became increasingly popular, particularly concrete and bricks, which became essential components of modern architecture.

Since its invention around 1850, concrete has become one of the most widely used construction materials. Architects have seen it as the symbol of modern architecture. It allows for various technical solutions: the framework, the cantilever, thin shells and walls...

Modern concrete is the result of a series of inventions and innovations, beginning with the creation of Roman cement and culminating in the establishment of the first reinforced concrete regulations in France in 1906. The invention of reinforced concrete was a true revolution for architecture due to its aesthetic quilities and remarkable strength.

Before making its way in to architecture in the 19th century, metal was primarily used to create objects. Known since antiquity, metal became an key element in new architectural considerations, particularly due to the industrial revolution. Initialy used for constructing infrastructures, such as bridges, and in engineering, metal was later employed for frame works and floors. The use of metal helped reduce the reliance on wood, thus limiting fire risks.



The birth of modern steelmaking allowed for the improvement of metal, which became increasingly stronger, sometimes even stronger than concrete. It is also resistant to temperature changes and corrosion. As a result, metal ganed an essential place in architecture, sharing the spotlight with concrete and glass. The transcendent beauty of glass has been recognised for centuries.

In prehistory, glass was known in ist natural form: obsidian. As early as 1500 BC it was shaped by firing in a kiln to create jewelry and small objects. In the medieval period, glass madeits way into architecture, highly valued for its transparency. Religious buildings particularly embraced it, and stained-glass windows multiplied and became more colorefull over time. However, despite its high aesthetic qualities, glass is a fragile material, rare in its natural form, and complex to manufacture. It was therefore used with caution and in moderation.

It was in the 19th century that the use of glass took a new turn, particulary thanks to the industrial revolution. The industrial production of glass, combined with the use of concrete and metal, opned up new possibilities for architecture. Glass brought light and space. Used on building facades, it has a mirror effect: the sky and surrounding environment are eflected in it. Architects could build taller structures without distorting the landscape: the blue of the sky takes possession of the glass, giving buildings a particular light aesthetic.

In response to new environmental conserns, there are now fresh challenges regarding the use of materials in architecture: preserving raw materialsand reducing the environmental impact of construction; as a result, more and more architects are working with recycled materials or those produced in an eco-responsible way.

1.3. Properties

Consruction materials, like any other material, are differentiated by their properties or characteristics. There are **mechanical, physical and chemical properties.**

1.3.1. Mechanical properties

When a material is subjected to a load, it deforms: its shape and dimensions change. Different materials deform in different ways:

- **Elastic materials**
- **Plastic materials.**

Material properties are determined in specialist laboratories using standardised test specimens.

1.3.1.1. Notion of constraint

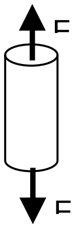
A cylindrical body subjected to two forces F1 and F2, of equal value but opposite sign F= |F1|=|F2| is said to be in simple traction (شــد).

If this body is cut by a plane perpendicular to the line of action of the forces, in order to keep it in equilibrium, a series of forces **dF** must be exerted on the cutting surface **S,** the sum of which is equal to **F**.

The section **S** is said to be subjected to a tensile stress defined by the relation:

$$\sigma = \frac{dF}{dS} = \frac{F}{S}$$

Expressed in N/mm^2 or MPa or Bar.



1.3.1.2. Notion of deformation

When a cylindrical body is subjected to traction, it elongates. The ratio of elongation to initial length is called longitudinal strain ε_l .

$$\varepsilon_l = \frac{dh}{h}$$

In the other direction, the body shrinks, **and** the ratio of the shrinkage to the initial width is called the transverse deformation **ε_t :**

$$\varepsilon_t = \frac{db}{b}$$

The two deformations are linked by the Poisson's ratio:

$$\nu = -\frac{\varepsilon_t}{\varepsilon_l}$$

The results of a test are generally given in the form of a graph (curve)

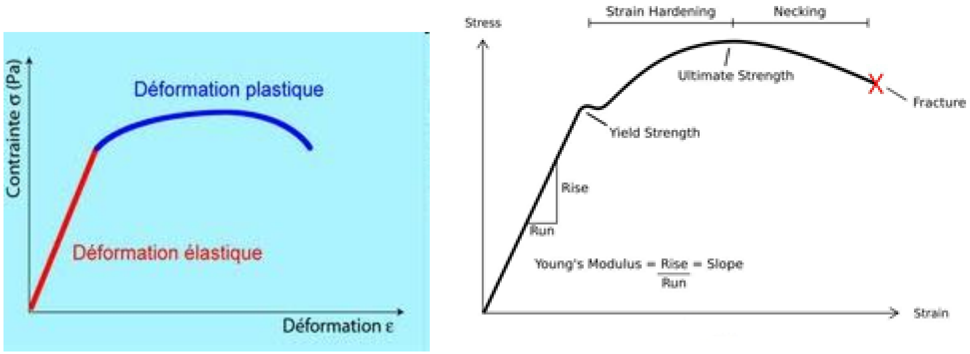


Fig 1.1: Mechanical characteristics of a material.

<u>Main mechanical properties</u>

1- Yield strength: Applied stress required to cause permanent plastic deformation of a material. Noted R_e .

2- Breaking strength: Applied stress required to cause a material to break. Noted R_p

The materials differ in their mechanical characteristics.

3- Young's modulus of elasticity:

This is the property usually used to characterise rigidity. If this value increases, the force required to deform the material is also increased. The elasticity modulus is noted **E** and

$$E = tg\alpha = \frac{\sigma}{\varepsilon}$$

expressed in **N/mm^2** or **MPa** or **Bar.**

4- Hardness: Hardness is a measure of a material's ability to resist to the penetration. There are several types of hardness: (Barcol, Bercovich, Bicholz, Leeb, Meyer, Monnin, Mohs...)

Mohs hardness scale:

1: Talc; 2: Gypsum; 3: Calcite; 4:Fluorite; 5:Apatite; 6:Orthoclase; 7:Guartz; 8:Topaz; 9:Corundum; 10:Diamond

1.3.2. Physical properties

apparent density : This is the mass of a materials per unit of apparent volume in its natural state, after drying at 105 ±5°C, noted **Mvapp** and expressed in (gr/cm^3 ; kg/m^3 ; t/m^3).

Absolute density: This is the mass of a body per unit absolute volume of solid matter (volume of matter alone, excluding pores inside the grains), after oven drying at 105°C, noted ρ and expressed in (g/cm^3 , kg/m^3 or t/m). ^{3}

Porosity: This is the ratio of the empty volume to the total volume**.**

Compactness: This is the ratio of the volume absolute to the total volume. ***:***

Water content: This is the ratio between the mass of water and the dry mass of the material.

Coefficient of thermal expansion: the coefficient of expansion measures the relative increase in volume of a material when pressure or temperature changes.

Thermal conductivity coefficient: Expresses the capacity of a material to allow heat to pass through its thickness = the quantity of heat passing through a sample of material 1 m thick 1m^2 in surface area for 1 hour and TD = 1 °C.

1.3.3. Chemical properties

Resistance to chemical corrosion

Resistance to acid attack

1.4. Classification of construction materials

Construction materials can be classified into two classes:

1.4.1. Resistant materials: aggregates, binders, steel, etc.

1.4.2. Protective materials : plaster, paint, varnish, etc.

Chapter 2: Cements

2.1. Introduction

The NA442/2013 standard defines cement as a hydraulic binder, which means a finely ground mineral material that, when mixed with water, forms a paste that sets and hardens due to hydration reactions and processes. After hardening, it retains its strength and stability, even when submerged in water. Cement that conforms to the NA442/2013 standard, referred to as CEM cement, when mixed with aggregates and water in the appropriate manner, should produce a mortar or concrete that retains its workability for sufficiently long time. After specified curing periods, it must achieve the required strength levels and also demonstrate long-term volume stability. The hydraulic hardening of CEM cement is primarily due to the hydration of calcium silicates, but other chemical compounds, such as aluminates, can also be involved in the hardening process.

2.2. Cement manufacturing process

Cement is produced by grinding clinker and calcium sulfate (gypsum). The clinker is obtained by calcining a mixture composed of about 20% clay and 80% limestone at a high temperature (around 1450 °C). If needed, iron ore, bauxite, and sand are added to this mixture to achieve the desired composition. After this high-temperature calcining process, the clinker is rapidly cooled and then ground with about 5% calcium sulfate and any additional minerals to form the cement.

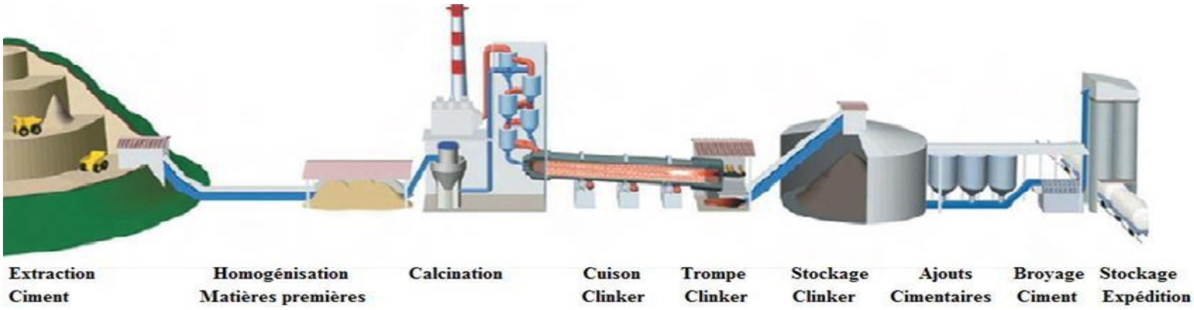


Fig.2.1. Cement manufacturing process.

2.3. The main constituents of cement

2.3.1. Clinker

Portland clinker appears as hard nodules composed of lime (CaO), silica (SiO_2), alumina (Al_2O_3), and ferrite (Fe_2O_3).The formulated clinker must meet specific chemical composition criteria, which are outlined in Table 2.1

Table 2.1: Oxide composition of clinker.

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	$K_2O + Na_2O$	SO_3
Limit content (%)	60÷69	18÷24	4÷8	1÷8	< 5	< 2	< 3

The combination of these oxides by cacining at a temperature of 1450°C in the oven gives the formation of the four anhydrous phases, phases presented in the following Table 2.2.

Table 2.2: Anhydrous phases of clinker

Mineralogical phases	Formula	Simplified notation	%
Tricalcium silicate	$3CaO.SiO_2$	C_3S	50 to 75
Dicalcium silicate	$2CaO.SiO_2$	C_2S	10 to 30
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	2 to 15
Alumino -ferrite tetracalcium	$4CaO.Al_2O_3 .Fe_2O_3$	C_4AF	5 to 15

The calcining process takes place at a temperature close to 1450°C in a rotary kiln, which rotates at a speed of 1.5 to 3 revolutions per minute and is slightly inclined with regard to the horizontal (3.5%). Its rotary motion ensures continuous homogeneity of the reactions and, consequently, of the final product.

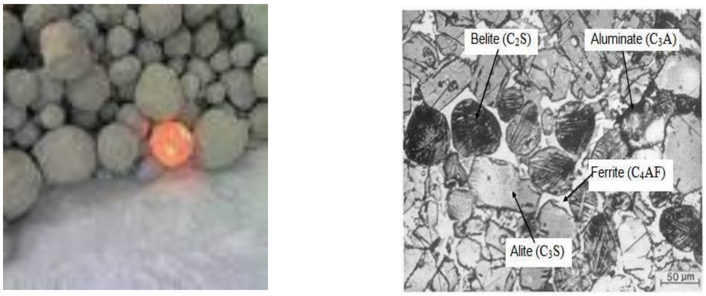


Fig.2.2. Image of clinker

2.3.2. Additions

Additives can be natural or artificial, inert or active. These additives may react as hydraulic, latent hydraulic, or pozzolanic materials, or they may act as fillers. They are classified according to their reactivity as follows:

2.3.2. 1. Active additions

- **Calcium sulfate (** Gypsum **)**

Gypsum can be found in the form of:

- Gypsum ($\mathbf{CaSO_4.2H_2O}$)or dehydrated calcium sulfate.
- From hemihydrate ($\mathbf{CaSO_4.\ 1/2H_2O}$).
- Anhydrite ($\mathbf{CaSO_4}$)or anhydrous calcium sulfate.

Fig.2.3. Calcium sulfate

These forms of calcium sulfate all exhibit the same final solubility when dissolved in water, but their dissolution rates may differ. It is composed of 92 to 94% of ($CaSO_4 \cdot 2H_2O$), 2 to 3% of ($CaCO_3$), and 2 to 4% of other elements such as (SiO_2, MgO, R_2O).

- **Blast furnace slag (S)**

In the iron production process in blast furnaces, the slag that floats on top of the molten iron is immediately cooled after casting and is therefore rapidly vitrified. The majority of elements such as Ca, Mg, Si, and Al are in the form of an amorphous (non-crystalline) phase. Once ground to around 400 to 500 m^2/kg, this product develops good cementitious properties.

The mineralogical composition of the slag depends on its cooling method. The faster the cooling, the more vitreous the slag becomes. The slag cools in the form of granules or pellets and requires grinding to be used as a mineral additive. Slag particles smaller than

10 µm contribute to early-age strength (up to 28 days), while particles between 10 and 45 µm contribute to the development of later strength. Particles larger than 45 µm have difficulty to be hydrated.

- **Silica fume (F)**

Silica fume is a by-product of the manufactured silicon or various ferrosilicon alloys. It is produced during the reduction of a very pure quartz by coal in an electric arc furnace at a temperature of 2000°C

Fig 2.4. Silica fume

Silica fume appears as fine spherical particles with an average diameter of around 0.1 µm. Its specific surface area is about 20 to 25 m²/g. The vitreous silica content ranges from 75% to 95%. The fineness and vitreous form of silica fume give it pozzolanic properties. Additionally, this fine particle size allows it, during concrete mixing, to fill the spaces between cement grains, thereby reducing the water content required. Finally, as it hydrates, silica fume forms hydrates, contributing to an increase in mechanical strength. Its color is typically light gray.

- **Fly ash (C)**

During its combustion in thermal power plants, pulverized coal passes through a very high-temperature zone in the furnace. The volatile components and carbon are burned, while the mineral impurities such as clay, quartz, and feldspar melt.

Fig. 2.5. Fly ash.

The molten products are quickly carried to the cooler zone, where they solidify into small glass spheres with diameters ranging from 1 to 100 µm (50% < 20 µm). The shape and particle size of the fly ash have a significant effect on the workability and water demand of fresh concrete. The majority of these spheres are carried away by the gas flow to the exterior.

From a mineralogical standpoint, fly ash is divided, according to the American standard ASTM C-61894-a, into two classes, which differ primarily in their CaO content:

- **Class F**: Containing less than 10% CaO produced from the combustion of anthracite and bituminous coal.
- **Class C**: Containing between 15% and 35% CaO, produced from the combustion of lignite.

The majority of fly ashes (both Class F and C) contain approximately 60% to 85% glass, 10% to 30% crystalline phases, and about 10% unburned carbon. They have a high proportion of silica and alumina, making them aluminosilicate glass. Their vitrification is often partial.

- Natural pozzolan

Pozzolan is a natural rock corresponding to volcanic projections, primarily basic in nature. Its color is typically black or red, depending on the degree of iron oxidation. It is composed of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). The sum of these three oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) must be greater than 70% according to the American standard ASTM C-618.

2.3.2.2. Inert mineral additions

These are almost inert materials, either natural or synthetic, specifically selected for their particle size distribution, which enhances the physical properties of Portland cement: workability and water retention capacity. Among these additives, we distinguish between limestone fillers and calcined shales.

- Fillers (F)

Fillers are inorganic mineral materials, either natural or artificial, specially selected for use in cement production. They can be inert or possess weakly hydraulic properties. Fillers are obtained by fine grinding or spraying of certain rocks (limestone, basalt, slag, bentonite, fly ash). The incorporation of these materials into the cement composition, with appropriate granulometry and preparation, improves the physical properties of the cement, such as workability and water retention capacity.

- Calcined Shales (T)

Calcined shales are shales produced in a kiln at 800°C. They contain clinker phases, small amounts of free lime (CaO), calcium sulfates, and a higher quantity of oxides. When finely ground, calcined shales exhibit strong hydraulic properties as well as pozzolanic activity.

- Limestone (L)

When limestone is used in proportions exceeding 5% by mass (as a primary constituent), it must meet the following requirements:

- **Limestone content**: $CaCO_3 \geq 75\%$ by mass.
- **Clay content**: Methylene blue adsorption ≤ 1.20 g/100g.
- **Organic matter content** (TOC): $\leq 0.50\%$ by mass.

2. 4. Classification of cements

2.4.1. Classification according to their normal resistance

Three classes are defined based on the normal 28-day strength, and "R" sub-classes are associated with these three main classes to designate cements with high early-age strength. These classes are denoted as Class 32.5, Class 42.5, and Class 52.5. They must meet the specifications and guaranteed values as outlined in Table 2.3.

Table 2.3: Mechanical and physical specifications of cements

Class	Compressive strength (MPa)				Shrinkage at 28 days (µm/m)	Start of setting (min)	Stability (mm)
	At a young age		At 28 days				
	2 Days	7 Days	Min	Max			
32.5	-	-	≥ 32.5	≤ 52.5	≤ 800	≥ 90	≤ 10
32.5R	≥ 13.5	-			≤ 1000		
42.5	≥ 12.5	-	≥ 42.5	≤ 62.5		≥ 60	
42.5R	≥ 20	-					
52.5	≥ 20	-	≥ 52.5	-	-		
52.5R	≥ 30	-					

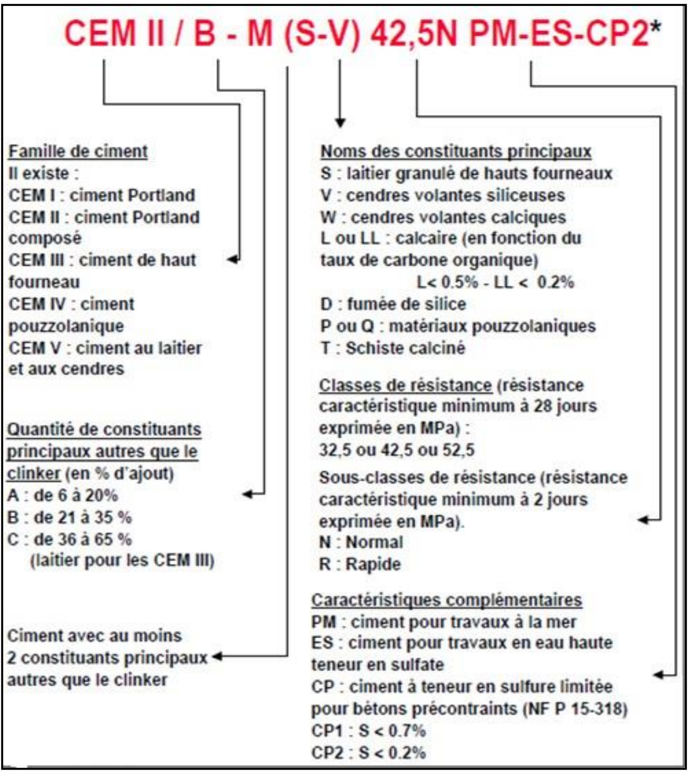
2.4.2. Classification according to their composition

Cements are classified, according to their composition, into five main types according to the Algerian standard NA442 . They are noted CEM and numbered from 1 to 5 in Roman numerals. They are grouped in Table 2.4.

Table 2.4. Types of cement and composition.

Cement by mass (%)	Rating	K	S	D	Z	Fly ash		T	L	CS
						V	W			
Portland cement	CPA-CEM I	95-100	-	-	-	-	-	-	-	0 – 5
Blinded portland cement	CPJ-CEM II/A	80 – 94	6 – 20							
	CPJ-CEM II/B	65-79	21 – 35							
Blast furnace slag cement	CHF-CEM III/A	35-64	36-65	-	-	-	-	-	-	0 – 5
	CHF-CEM III/B	20-34	66-80	-	-	-	-	-	-	0 – 5
	CLK-CEM III/C	5-19	81-95	-	-	-	-	-	-	0 – 5
Pozolanic cement	CPZ-CEM IV/A	65-90	-	10 - 35			-	-	-	0 – 5
	CPZ-CEM IVI/B	45-64	-	36-55			-	-	-	0 – 5
Cement to the slag and to the ashes	CLC-CEM V/A	40-64	18-30	-	18-30		-	-	-	0 – 5
	CLC-CEM V/B	20-39	31-50	-	31-50		-	-	-	0 – 5

Cement brand



CEM II / B - M (S-V) 42,5N PM-ES-CP2*

<u>Famille de ciment</u>
Il existe :
CEM I : ciment Portland
CEM II : ciment Portland composé
CEM III : ciment de haut fourneau
CEM IV : ciment pouzzolanique
CEM V : ciment au laitier et aux cendres

<u>Quantité de constituants principaux autres que le clinker</u> (en % d'ajout)
A : de 6 à 20%
B : de 21 à 35 %
C : de 36 à 65 %
(laitier pour les CEM III)

Ciment avec au moins 2 constituants principaux autres que le clinker

<u>Noms des constituants principaux</u>
S : laitier granulé de hauts fourneaux
V : cendres volantes siliceuses
W : cendres volantes calciques
L ou LL : calcaire (en fonction du taux de carbone organique)
L< 0.5% - LL < 0.2%
D : fumée de silice
P ou Q : matériaux pouzzolaniques
T : Schiste calciné

<u>Classes de résistance</u> (résistance caractéristique minimum à 28 jours exprimée en MPa) :
32,5 ou 42,5 ou 52,5

Sous-classes de résistance (résistance caractéristique minimum à 2 jours exprimée en MPa).
N : Normal
R : Rapide

<u>Caractéristiques complémentaires</u>
PM : ciment pour travaux à la mer
ES : ciment pour travaux en eau haute teneur en sulfate
CP : ciment à teneur en sulfure limitée pour bétons précontraints (NF P 15-318)
CP1 : S < 0.7%
CP2 : S < 0.2%

Chapter 3: LIME

3.1. History

Lime is a natural product known since the earliest antiquity. The first traces of the organized production date back to 10,000 years BC in Mesopotamia. Most ancient peoples were familiar with lime: the Egyptians, Etruscans, Phoenicians, Greeks, Romans. It was used as a binder in construction, as well as in the manufacture of plasters and the creation of frescoes.

In the 18th century, the Englishman Black and the Frenchman Lavoisier described the chemical reactions occurring during its production, later, scientists like Vicat, Debray and Le Chatelier completed their work in the following century and explored its potential applications.

The birth of the industrial era, with the development of steel production, lead to a significant demand for lime. Since then on, its production methods have constantly improved, and its quality criteria have become more precise, as well as its applications, which continue to diversify. Used in agriculture and construction since its discovery, lime is now employed in many industrial processes and plays an essential role in pollution control.

3.2. Lime manufacturing

Lime is obtained by heating limestone. A chemical reaction occurs during this process: limestone decomposes into quicklime and carbon dioxide.

$$\mathbf{CaCO_3 \longrightarrow CaO + CO_2}$$

After heating, the lime retains the same physical appearance but has a low apparent density. The resulting lime has numerous applications: In agriculture, road construction, and in industry. It can be used as is, or granulated or ground form.

Quicklime reacts when it come into contact with water, releasing a significant amount of heat and transforming into a white powder called slaked lime (Calcium hydroxide)

$$\mathbf{CaO + H_2O \longrightarrow Ca(OH)_2}$$

Slaked lime is used in many fields such as construction, industry,environmental remidiation.

Slaked lime hardens by absorbing carbon dioxide from the air, reforming into calcium carbonate. $Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$

3.3. Types of lime

3.3.1. Air lime

Air lime is produced by heating almost pure limestone. It is a quicklime that was traditionally slaked in large vats of water and only sets in the air, forming a paste (which is very easy to store in this form). Today, it is slaked artificially by vaoorisation (an industriel technique) and then packaged.

- ✓ Quicklime **(CaO):** produced by heating nearly pure limestone to 850°C.
- ✓ Slaked lime **$Ca(OH)_2$**: produced by heating nearly pure limestone between 900°C and 1000°C, followed by slaking by vaporization.

Air lime is fire-resistant, with a refractory resistance varies between 1800°C and 2000 °C. It sets slowly, with a setting time of 600 minutes (10 hours).

Advantages of air lime

- High flexibility and properties similar to stone; it offers homogenous behavior by ollowing it to breathe and transport water.

- Its use for limewashing due to its setting exclusivement in air (it will not set when in water).

- Natural color.

- Slaked lime is an excellent thermal and sound insulator.

3.3.2. Hydraulic lime

Natural hydraulic lime XHN: Is obtained by teating limestone that contains 15% to 20% clay. It sets partially due to water, which gives it the "hydraulic" property, but also sets through air, as it contains at least 80% air lime.

There are also artificial hydraulic limes **XHA**, which result from the simultaneous grinding of clinker, cement, and limestone fillers.

Advantages of hydraulic lime:

- It remains flexible and its characteristics are close to stone.
- The hydraulic setting makes it easier to apply and sets more quickly.

Major disadvantages:

- Its color is less white than air lime and a noticeably harder.
- It cannot be used for limewash due to its hydraulic setting.

3.3. Use of lime

The use of lime depends on its type.

3.3.1. In construction

- Air lime is primarily used for plasters and decoration, while hydraulic lime is preferred for building stone or rubble walls, as well as for creating basements, slabs,…etc
- Apart from concrete, lime can be applied to all types of substrate: earth, stone, brick, wood, etc. It has the unique property of being air-permeable and water-resistant and preventing condensation.
- Lime mortars are used both indoors and outdoors. They are employed for repointing and plastering new or restored buildings. They are also relatively flexible and prevent micro-cracks that could allow water to penetrate the interior of walls.

Ready-to-use, lime paints, available in specialized stores, are an excellent replacement for traditional limewashes.

- Cellular concrete: Light and an excellent insulator, cellular concrete is made from a mixture of quicklime, sand, cement, alumina powder and water. The lime/alumina reaction forms tiny gas bubbles. These bubbles are trapped in the mass, giving the blocks their insulating properties.

3.3.2. In road techniques

- Drying : Quicklime is spread on wet soils to reduce their moisture content, facilitating the work of earth-moving equipment.
- Stabilization: Quicklime, mixed with clay soils, chemically react with them. The clay then changes from a plastic consistency to a granular, stable one that is very resistant to water.

3.3.3. In the environmental application

Water treatment : In drinking water or some industrial processes, lime is used as a precipitating and flocculate agent. It is also used in wastewater treatment to flocculate organic matter, phosphates from detergents, precipitate heavy metal salts from industrial water, and act as a bactericide by raising the pH.

Lime is also used to dehydrate, sterilize and stabilize sludge resulting from water treatment.

Fuue gas treatment : Fuels, such as heavy fuel oil or coal, naturally contain sulfur in varying amounts depending on their origin. Household waste and some industrial waste also releases sulfur or chlorine during incineration. These sulfur and chlorine emissions are the cause of acid rain. Lime can be used as neutralize of these acid gas emissions.

Chapter 4: Plaster

4.1. History

Plaster is one of the oldest building materials used by humans after transformation. Its use may date back to the eighth millennium BC, when plaster was already used to make floors, decorative frescoes and even containers. In Algeria it was used early on by the Berbers of Mzab valley to build dams and irrigation channels.

Until the eighteenth century, plaster production remained empirical and rudimentary. The scientific study of plaster is owed to Lavoisier, who in 1768 presented analysis to the Academy of Sciences of the phemonome underlying the preparation of plaster. It was the industrial evolution of the twentieth century that brought profound transformations in the processes and equipment used in plaster production.

4.2. Origin of plaster

Plaster is a white powder, that has the property of setting when mixed with water, making it a hydraulic binder. It is derived from the heating of a sedimentary rock, gypsum (or plaster stone) which is a dehydrated calcium sulfate. Plaster stone also occurs in the form of natural anhydrite. Gypsum is a saline rock that formed through deposition following the evaporation of salt lagoons. If the gypsum is pure it is colorless, otherwise it can be white, yellow or red , with the coloration bening due to the impurities it contains.

4.3. Plaster manufacturing

Plaster manufacturing involves several stages:

4.3.1. Stone crushing

Gypsum from the quarry can contain large blocks, often reaching up to 50 cm in size, so it is passed through a crushing and screening circuit. These circuits are highly varied due to the different characteristics of the gypsum. For example, it may include a first crusher that reduces the stones to a maximum size of 15 cm, followed by a second crusher that produces a fine powder of 8 mm. The crushed product is then stored in large warehouses while waiting its calcination.

4.3.2. Gypsum heating

The purpose of calcination is to dehydrate the gypsum to a greter or lesser extent. The temperature of the calcination is chosen depending on the origin of the gypsum and the desired product.

The different products of calcination depending on the temperature are:

- Between 130° and 180°C, we obtain ordinary or semi-hydrated plaster;
- Between 180° and 250°C, we obtain a quick-setting plaster;
- Between 250° and 900°C, the plaster obtained is unusable, it is inert;
- Between 900° and 1450°C, soluble anhydrite is obtained which sets very slowly.

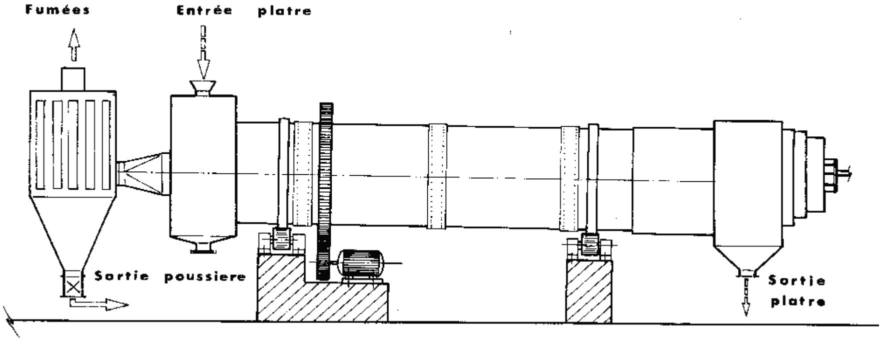


Fig 4.1:Rotary kiln

4.3.3. Cooling

Cooling serves to stabilize the plaster and makes it manipulable; it is essential when the further processing of the plaster requires the addition of chemicals that are sensitive to heat . Several techniques are used for this purpose one of which involves placing the plaster into an air circulation cooler after it has been calcined. This method ensures an even and controlled cooling process, preventing any premature setting or degradation of the material and allowing it to be safely handled for subsequent stages of production.

4.3.4. Grinding

The cooled plaster undergoes a final grinding to increase its homogeneity and achieve the desired fineness. The mills used are typically hammer mills or pin mills, and they are usually coupled with a screening station. This combination ensures that the plaster is ground to the correct size and thatany larger, undesirable particales are removed, resulting in a uniform product ready for use.

4.3.5. Mixing

At the mixing station, carefully measured amounts of semi-hydrates and by-products are blinded to produce plasters with the desired setting times. It is also possible to add precise control over the plaster's performance, ensuring that it meets specific requirements for various applications, whether for slow or fast setting.

4.4. The different plasters

By adjusting the choice of gypsum deposits, the methods calcination, grinding, and finally the use of setting modifiers, the manufacturer tailors the product to market demand. This allows for the production of a wide variety of plaster products, each suited to specific applications. The most common product is construction plaster, also known as ordinary plaster.

4.4.1. Ordinary plaster

It is a white powder, soft to the touch and sticky to the fingers. Its density varies with the grain size (0.65 to 1.65) and its specific weight is 2.75 kg/l. It is generally produced by mixing 50 to 70% of semi-hydrate and 30 to 50% of by-products, with incorporation of a setting retarder.

The fineness of the plaster grind is defined by the residue on the sieve, which varies between 15% to 30%. A finer grind of the plaster helps improve its strength.

When this plaster is mixed with water, hydration occurs and the gypsum is regenerated. The plaster first dissolves up to saturation, then hydrates within the oversaturated solution, causing the precipitation of microcrystals that assemble. Finally, the fine needles intertwine, forming a a solid mass as excess water evaporates.

The reaction is rapid and exothermic. The setting continues progressively, with strengthincreasing over time, up to 7 days after mixing.

$$\left(\mathrm{CaSO_4},\frac{1}{2}H_2O\right)+\frac{1}{2}H_2O \rightarrow \mathrm{CaSO_4},H_2O$$

4.4.2. High-strength plaster

Ordinary plaster, primary composed mainly of β-hemihydrate, requires a large amount of water (60 to 65%) for mixing. The excess water, which exceeds the amount needed for hydration, evaporates, forming pores. As a result, the plaster has a porosity of up to 40% and consequently, it has a low compressine strength.

When gypsum is calcined understeam pressure of 0.3 to 3 MPa, the resulting plaster is α-hemihydrate, with larger crystals. This type of plaster requires less mixing water (40 to 45%), and when it sets, it forms a less porous plaster with higher compressive strength. After 7days, its compressive strength can reach 150, or even 400 bars. This is known as high-strength plaster.

The production of high-strength plaster is minimal, and its use is typpcally reserved for the making molds in metallurgy.

4.4.3. Standardized products

Plasters are marketed under 3 essential categories:

1. Construction plasters;
2. Casting plasters (molds for cast iron, porcelain, etc.);
3. Special plasters (surgical plasters, faux marble, etc.).

Construction plasters are classified according to their granularity into two classes according to French Standard B12.301.

- PGC1 and PGC2 coarse construction plaster;
- Fine construction plaster PFC1 and PFC2.

The standard specifies the setting time ranges according to the Table 4.1.

Table 4.1: Setting time ranges of paster.

Plaster	Start of the setting time	End of setting time
P.G.C.I and P.F.C.1	3 to 8 minutes	10 to 20 minutes
P.G.C.2 and P.F.C.2	6 to 15 minutes	15 to 45 minutes

4.5. Use of plaster in construction

4.5.1. Coatings

When plaster is mixed with slaked lime and sand, it forms a mortar that is widely used as an interior or exterior coating. It is applied in two layers, a base coat and a finishing coat, with a total thickness that can reach up to 8 cm. The presence of lime improves the workability of the mortar, enhances adhesion to the substrate, and, most importantly, makes the plaster highly resistance to weathering due to the carbonation of its surface in contact with air. The coating is applied manually but can also be sprayed with a machine.

Since the processes of mixing and trowelling can be quite labor-intensive, machines have been developed to perform these tasks automatically. The plaster used in this case must meet several criteria: it should have a very long setting time to allow the plastere are designed to carry out these operations automatically. The plaster used in this case meets several criteria which are: a very long setting time to allow the plasterer to apply the sprayed plaster; it must contain a plasticizer to ensure the mortar adheres well to the surface; and if the coating is for exterior use, it must be weather-resistant. To achive this, the plastermust include water-reppellent additives.

4.5.2. Special fire coatings

Plaster is a material particularly suited for protecting structures against fire. Thus, there are plasters on the market that are particularly designed for fire protection.

4.5.3. Prefabricated elements

Prefabrication allows for signicant time savings on construction sites, and the idea of using prefabricated plaster elements to build walls is not new, it date back at least to the 3rd century AD.

Prefabricated plaster elements are intended for partitions or ceilings and are produced in the factories from plaster, possibly with additives. The following elements are distinguished:

- **The plaster tiles**

Used in construction as a partition element, the plaster block can be solid or hollow, typically with smooth faces, and comes in standardized dimensions depending on the country. Its thickness range from 4 to 15 cm, with the most common thicknesses being 5, 6 and 7 cm. These elements are equipped with tenons and mortises for precise assembly, which is done using a plaster-based adhesive.

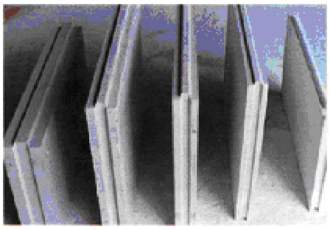


Fig 4.2 : Plaster tiles

- **Plasterboard**

These are extra-thin plaster panels covered on both sides with a special cardboard sheet. They are typically have a width of 1.2 m, a length ranging from 2 to 3.6 m, and a weight between 8.5 and 12 kg.

Depending on the desired performance, such as mechanical properties, fire resistance, or sound insulation, thicknesses can range from 9.5 and 25 mm.

Plasterboard can be used for partitions on wooden or metal frames, or for ceilings in the form of perforated panels.

- **Prefabricated ceiling elements**

These elements can be smooth or textured, and are decorative and sound-absorbing. Their assembly may or may not include visible joints.

- **Special elements**

These are prefabricated elements for special technical or decorative uses, such as ventilation or protection ducts, and formwork elements.

4.6. Characteristics of plaster

4.6.1. Physical characteristics

Absolute density : For the measurement of the density of plaster, the pycnometer method can be used. Tests carried out show that the density of gypsum and plaster are, on average, as follows:

Table 4.2: Absolute densities of gypsum and paster

Types	Gipsum	$CaSO_4$ ½ $H_2O\alpha$	CaSO4½ $H_2O\beta$	$CaSO_4$
Density (g/cm^3)	2.30	2.65	2.75	2.90

Apparent density of plaster powder: Knowing the value of the apparent density gives an idea of the fineness of a plaster.

The apparent density of molding plaster is 0.650 kg/dm^3 and that of fine construction plaster is 0.90 kg/ dm^3 .

Fluidity : It is measured by the device called the "Smith Ring", which is a cylindrical brass ring with an inner diameter of (60 mm±0.1) and a height of (50 mm±0.1).

The paste contained in the ring is released when the ring is lifted, forming a disc, and its diameter is then measured.

The fluidity measurement should be made on the plaster as it is. However, for rapid-setting plasters, a setting retarder (such as citric acid) should be added to the mixing water before the test, so that the setting time is extended by about 5 to 6 minutes.

The current fluidity of plasters (diameter of the cakes) is as follows:

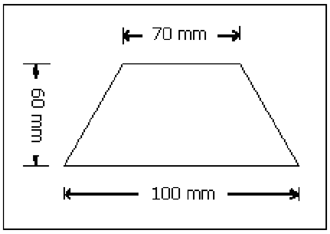
- Casting plaster: (150÷200) mm
- Fine construction plasters: (200÷250) mm

The consistency: The consistency is determined using the shaking table. The saste is placed into a conical mold, which rests with its larger base on the shaking table. Mold dimensions:

Lower inner diameter = 100 mm

Upper inner diameter = 70 mm

Height = 60 mm



After slowly removing the mold, give 15 shakes, at a rate of 1 shake per second, then measure the diameter of the cake thus formed.

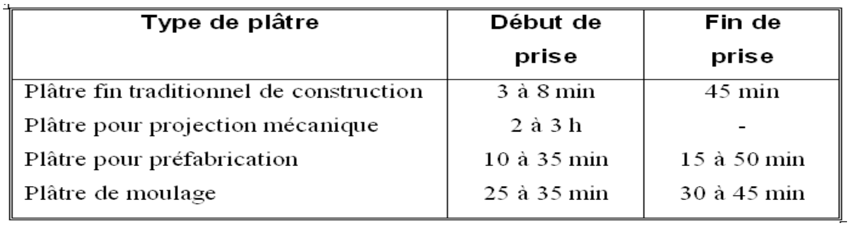
- The usual consistencies are:
- Very high hardness plasters (190 ÷210) mm
- Plasters for mechanical injection = 170 mm
- Glues and coatings (150 ÷170) mm.

Start of setting: The setting start can be measured by several methods, one of wich is the Vicat apparatus. It consist mainly of a vertical mobile piston with a cursor that moves in front of a scale and can hold a Vicat needle at its lower part. The needle is made of a polished metal cylindrical rod with a cross-sectional area of 1 mm^2, and it weighs 300 grams including the movable part.

The setting start is the moment when the needle stops sinking and comes to rest at a distance from the bottom of the mold of between 1 and 5 mm, according to the French standard: NF B 12303.

End of setting :It is determined by finger; it is the moment when pressure from the finger exerted on the surface of the dough no longer causes an imprint to appear.

Table 4.3 : Average setting time of plaster



Type de plâtre	Début de prise	Fin de prise
Plâtre fin traditionnel de construction	3 à 8 min	45 min
Plâtre pour projection mécanique	2 à 3 h	-
Plâtre pour préfabrication	10 à 35 min	15 à 50 min
Plâtre de moulage	25 à 35 min	30 à 45 min

4.6.2. Mechanical characterization (hardened plaster)

The mechanical characteristics measured on hardened plaster are the flexural strength, compressive strength, and hardness. The test apecimens are prisms with dimensions (4x4x16) cm ^{3} obtained by molding a plaster paste mixed with a plaster/water ratio of 1.25, and are kept in a climatic chamber at a temperature of 20°C and a relative humidity of 90%. After storage, the specimens intended for measurement in the wet state must be immediately subjected to testing. Those intended for measurement in the dry state must be placed in a ventilated oven with a regulated temperature of 40-45°C, until they reach a constant weight. The specimen is then stabilized in the laboratory atmosphere for 2 to 3 hours before testing.

Flexural strength: It is determined by 3-point bending of the test piece.

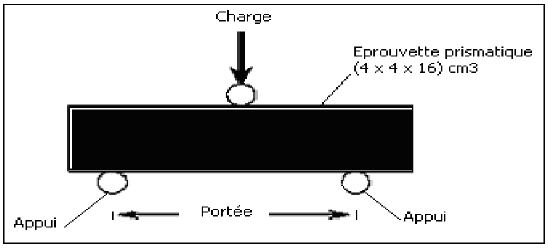


Fig 4.3 : Bending test for plaster specimen

Compressive strength: The compressive strength of plaster is determined on the half prisms resulting from the flexural fracture. The half-prism is compressed on its molded lateral faces with a cross-section of (4x4) cm ^{2} until rupture. The test must last between 20 and 40 seconds.

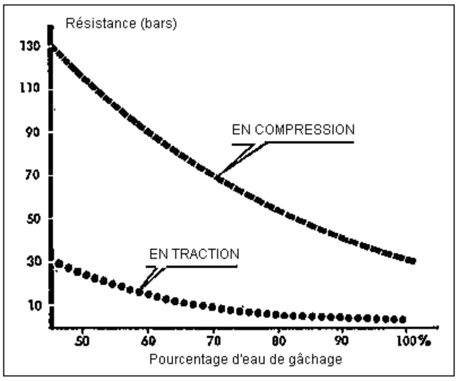


Fig 4.4: Variation of plaster resistances as a function of % water

Hardness plaster

It is measured by ball indentation, a method that involves applying a10 mm diameter steel ball to the lateral face of the specimen with a force of 10 newtons, the force is then increased to 200 newtons over 2 seconds, and maintained at this value for 15 seconds. The depth of the indentation is rmeasured 15 seconds after the force is applied.

The hardness, expressed in N/mm^2, is given by the formula: **$D = 6370/t$**

With *t* : depth of the imprint in micrometers.

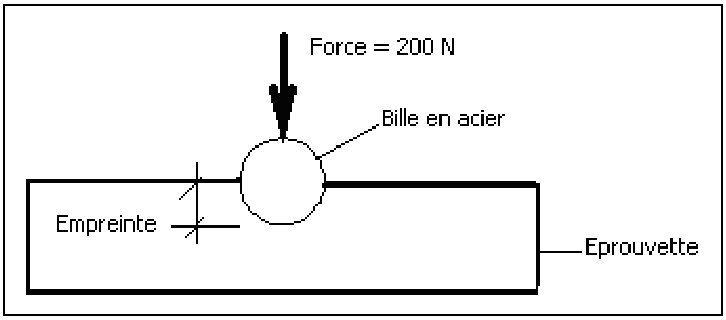


Fig 4.5: Measuring the hardness of plaster

Chapter 5: Aggregates

5.1. Geological origin of stones and aggregates

Stones and aggregates used in construction come from rocks. In nature there are mainly three categories of rocks:

5.1.1. Eruptive rocks

Eruptive rocks: formed from molten magma that came from deep within the earth and hardened as it cooled:

Granite Volcanic tuff. Basalt.

Fig 5.1: Eeruptive rocks.

5.1.2. Sedimentary rocks

Sedimentary rocks: come from the consolidation of sediments or of the precipitation of the minerals in solution, we distinguish: chemical organic and mechanical sedimentary rocks.

Sandstone Limestone

Fig 5.2. Sedimentary rocks.

5.1.3. Metamorphic rocks: They are formed by transformation of eruptive or sedimentary rocks under the influence of high temperatures and pressures and sometimes chemical reactions.

Schist Slate Marble

Fig 5. 3: Metamorphic rocks

5.2. Classification of aggregates

Aggregates are defined as a set of chemically inert grains with dimensions between 0 and 125 mm. It is customary to classify aggregates according to several parameters: origin, granular extent, density, etc.

5.2.1. According to their origin

5.2.1.1. Rolled aggregates: This are in general natural alluvial materials, used directly without treatment mechanical, they are characterized by of the grains of rounded shapes and a surface condition very smooth.

These include: Sand, gravel and pebbles from rivers; Sea sand; Dune sand**.**

Fig 5.4: Natural aggregates

5.2.1.2. Industrial aggregates of natural origin: They come from the crushing of hard rocks such as granite, quartzite, basalt and limestone, they are characterized by an angular geometric appearance, sharp edges and a rough surface finish.

Fig 5. 5: Industrial aggregates of natural origin.

5.2.2. According to their density

- **Aggregates light:** density < 2 t/m^3
- **Aggregates currents:** density 2 t/ m^3 $< r < 3$ t/m^3
- **Aggregates heavy:** density > 3 t/m^3

5.2.3. According to their size

There are fine, medium and coarse aggregates, which are grouped in the following table.

Table 5.1. Standardized classification of aggregates

Granulats		Sieve mesh interval (mm)	Mesh (Maille) (mm)
Fine		$\prec 0,08$	
Sand	Fine	$0,08 \div 0,315$	
	Medium	$0,315 \div 1,25$	
	Coarse	$1,25 \div 5$	
Gravel	Fine		$6,3 \div 10$
	Medium		$10 \div 16$
	Coars		$16 \div 25$
Cailloux	Small		$25 \div 40$
	Medium		$40 \div 63$
	Coars		$63 \div 80$
Moellons			$\succ 80$

5.3. Aggregates properties

In general, the choice of aggregates must be judicious and must be oriented towards hard, clean aggregates, of continuous granulometry, chemically inert, and not containing certain impurities.

5.3.1. Physical properties

The physical properties of aggregates will be studied in the form of practical work (Lab Worck) namely:

- Granulometric analysis
- Densities (absolute density and apparent density)
- Compactness and porosity.
- Water content.
- Cleanliness of the aggregates.
- Sand equivalent.

5.3.2. Mechanics properties

The hardness

The first mechanical property of aggregates is hardness, which is defined as the resistance of a rock sample to breaking under impact. We distinguish

- The Deval test

Le coefficient micro Deval est définit par :

$$\mathbf{M_{DE} = 100\left(\frac{P}{500}\right)} \qquad \mathbf{(5-1)}$$

The micro Deval coefficient is higher as the aggregate is less good.

- Los Angeles test (NA/455)

This test estimates the resistance to fragmentation by impacts and to wear by reciprocal friction. It is practiced on granular classes $[(4/6{,}3); (6{,}3/10); (10/14)]$. The drum of the machine is rotated at a speed between 31 and 33 tr/min. The load consists of 7 to 11 steel balls weighing 417 grams. Recent models are equipped with a protective and insulating cabin.

Fig.5.6. Micro-Deval device

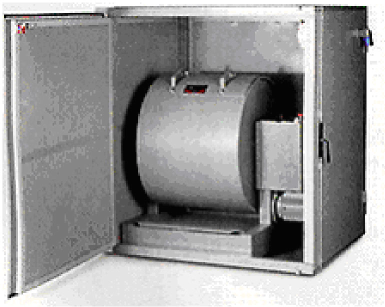


Fig.5.7. Los Angeles device.

For a given aggregate, this resistance is measured by the Los Angeles coefficient, the ratio of the mass of the fragments passing through a 1.6 mm sieve measured at the end of the test to the mass of the sample.

$$\mathbf{L = 100\left(\frac{Passant\ au\ tamis\ de\ 1,6mm}{Masse\ de\ l'\acute{e}chantillon}\right)} \qquad \mathbf{(5-2)}$$

The Los Angeles coefficient is higher as the aggregate is less good.

5.3.3. Chemical properties

Alkali- Reaction: alkali-silica

It is a chemical reaction between the silica of the aggregates and the alkaline paste of the cement; this causes swelling which is detrimental to the strength of the concrete, the alkaline reaction must therefore be anticipated and detected to avoid the concrete bursting.

Fig 5.8: Degradation of concrete due to the alkali-silica reaction.

Chapter 6: Mixing water

6.1. Introduction

The water used for the production of concrete mixes must be potable water free from any impurities and odors. In general, all potable waters can be used for concrete production; sea water, although aggressive towards hardened cement, can be used for the production of unreinforced concrete.

6.2. Mixing water functions

Water essentially has two functions:

1- Physical function, which gives the fresh concrete the rheological properties as a liquid (allowing it to flow and be molded),

2- Chemical function as a binder for cement powder. It also used to wets the aggregates, ensuring a good bond with the cement paste.

Water in the hydrated cement paste exists in different forms, including free water, adsorbed water and chemicaly bound water. It is necessary not only for the hydration of the cement but also to give the concrete a sufficiently fluid consistency for it to be workable.

6.3. Effects of Water

To hydrate 100 kg of cement, 25 liters of water are needed (W/C ratio =0.25) however, the W/C ratio used for normal concrete is much higher (usually 0.6-0.7) : the amount of water added is always much greater than the amount required for cement hydration. Excess water leads to :

- Deformations: Shrinkage, swelling.

  creation of capillary networks increased porosity, reduced compactness and segregation.
- Reduction in mechanical performance: lower compressive/flexural strength.
- Increased permeability (greater penetration of external agents).
- Surface defects and sensitivity to evaporation.
- Makes concrete sensitive to freezing: expansion when water transformed to ice.
- Promotes electrochemical reactions (carbonation, corrosion, alkali-silica reaction).
- Favors mold growth and the development of organic matter.

- Dissolves: gypsum, plaster, chloride and it transports: chloride, sulfates, carbon dioxide.
- Moves through gravity, capillarity, and vapor.

6.4. Effect of mixing water temperature

The temperature of the mixing water has a great influence on the temperature of the fresh and hydrating concrete. Typically in cold climates, the mixing water is often heated to prevent the fresh concrete from freezing during and shortly after placement. Similarly, in warm climates, the concrete is often mixed with chilled water or even ice to limit the temperature of the fresh concrete. Any ice added to the mix must be completely melted and mixed before the mixing process is complete.

6.5. Requirements for mixing water: NF EN 1008.

- Potable water: no testing required.

- Waste water: not allowed.

- Water recovered from concrete production.

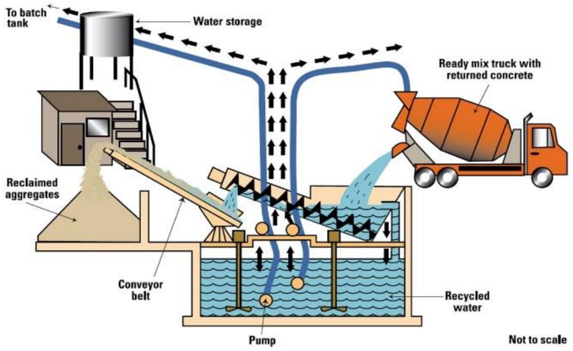


Fig 6.1: Water recovred from concrete manufacturing

- Groundwater.

- Natural surface water or industrial effluent water.

- Sea water: can be used for the production of unreinforced concrete but not for reinforced concrete (RC) or pre-stressed concrete (PC).

The standard specifies three types of requirements:

✓ **Sensory requirements:**

- Visible traces of oil, foam, or generally any organic matter that can reduced the strength of concrete.

- Significant suspended solid.
- Color and odor.

✓ **Chemical requirements**:

Limits for certain undesirable substances:

- **Chlorides** (incompatible with reinforced concrete as they initiate reinforcement corrosion.
- **Sulfates** (risk of secondary expansive ettringite formation).
- **Alkalines** (risk of alkali-silica reaction)
- **lead and zinc salts,**
- **phosphates and nitrates.**

✓ **Mechanical requirements:**

- Initial setting time: must be not less than 1 hour and should not differ by more than 25% compared to the same test with distilled water.
- Final setting time: must be not greater than 12 hours and should not differ by more than 25% compared to the same test with distilled water.
- Compressive strength at 7 days (concrete or mortar): should reach at least 90% of the strengths obtained with distilled water.

Some of the requirements detailed in the norm EN 1008 are shown in the table below.

Table 6.1: Some requirements detailed in EN 1008.

Maximum chloride content	
End use of concrete	Maximum chloride content (mg/l)
Presrressed concrete or groute	500
Concrete with reinforcement or embedded steel	1000
Concrete without reinforcement or embedded steel	4500
Harmful substances	
Substance	Maximum content(mg/l)
Sugars	100
Phosphates(P^2O_5)	100
Nitrates(NO^{3-})	500
Lead(Pb^{2+})	100
Zinc(Zn^{2+})	100
Sulphates(SO_4^{2-})	2000

Chapter 7: Mortars

7.1. Introduction

Mortar is the basis of all masonry work, whether for construction, coating or repair. Mortar is a mixture of sand, water, hydraulic binder (cement or lime) and possibly an additive that hardens like stone. It differs from concrete in the absence of gravel.

7.2. Composition of mortars

The mortar is composed of:

7.2.1. Binder

Generally cement (See chapter 2) or lime (see chapter 3) or a mixture of cement and lime.

7.2.2. Sand

Generally with a fraction between 0.08 mm and 4 mm. Its role is to increase the compactness of the mortar. Its characteristics are studied in chapter 5.

7.2.3. Mixing water

Its role is to hydrate the cement and to obtain the workability necessary for good implementation. Its characteristics are studied in detail in chapter 6.

7.2.4. Adjuvants

They are chemicals that are used in small proportions (around

5% of the weight of cement) to modify the properties of concrete and mortars in the fresh and hardened states.

7.3. Types of mortars

Mortars are distinguished by the used binder, we distinguish:

7.3.1. Cement mortars

Cement mortars are very strong, set and harden quickly. The cement/sand ratio is usually 1:3 volumetrically and the water/cement ratio is about 0.35.

7.3.2. Lime mortars

Lime mortars are less resistant compared to cement mortars (greasy and unctuous). The hardening time of lime mortars is slower than for cement mortars.

7.3.3. Bastard Mortars

These are mortars, whose binder is the mixture of cement and lime.

Generally, lime and cement are used in equal parts, but sometimes a greater or lesser quantity of one or the other is taken depending on the use and the quality sought.

7.3.4. Industrial mortar

These are mortars that are manufactured from dry, well-selected constituents, packaged in bags, factory-controlled and perfectly regular. To use this type of mortar, simply add the necessary amount of water and mix to then implement them.

Mortars can contain various binders and sands as well as certain additives and possibly colorants.

Industrial mortar manufacturers offer a complete range of products to meet all needs

7.4. Use of mortars

Mortars are used to:

7.4.1. Assembly of walls in masonry elements *(* brick, concrete block, cut stone, tiles)

Fig 7.1: Masonry joints.

7.4.2. The coatings

Fig 7.2: Coating application .

7.4.3. Production of screeds

The screed ensures the finishing of the slab: leveling, profile (possible slope shape) and surface regularity. They can also provide thermal or acoustic insulation and waterproofing of the slab. It serves as a support for floor coverings or waterproofing coatings.

. **Fig 7.3:** Application of screed coating.

7.4.4. Seals and shims

Industrial mortars are used in sealing and wedging work.

Fig 7.4: Wedging a steel frame post.

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Practical laboratory work

PW N°1: Absolute density

PW N°2: Apparent density

PW N°3: Water content (moisture content)

PW N°4: Sand Equivalent Test

PW N°5: Determination of particle size distribution by sieving (grain size analysis)

PW N°1: Absolute densities

1.1. Objective

Measurement of absolute density of aggregates (sand and gravel)

1.2. Absolute density

1.2.1. Equipment

- A graduated tube.
- Electric oven (maintain the temperature between 105^0 C to 110^0 C).
- A funnel
- A balance.

1.2.2. Materials required

- A sample of sand
- A sample of gravel
- Water.

1.2.3. Test procedure

Before starting, dry the sand and gravel samples in the oven, let cool, weigh a mass M_1 of each sample then pour a volume of water noted V_1 into the graduated tube, using the funnel pour the mass M1 of the sample into the graduated tube and note the volume V_2 then calculate the absolute density:

$$\rho_{ab} = M_1/(V_2-V_1),$$

finally repeat the measurement three times to obtain an average

$$\rho_{ab\ avg} = (\rho_1 + \rho_2 + \rho_3)/3$$

1.2.4. Calculation and expression of results

Complete the following tables, comment on the results and draw a conclusion.

Absolute density of sand

Designation	Unit	Test 1	Test 2	Test 3	
M_1					
V_1					
V_2					
ρ_{ab}					ρ avg =

Absolute density of gravel

Designation	Unit	Test 1	Test 2	Test 3	
M_1					
V_1					
V_2					
ρ_{ab}					ρ_{ab} avg =

PW N°2: Apparent density

2.1. Objective

Measurement of apparent density of aggregates (sand and gravel)

2.2. Equipment

- A container of known volume.
- Electric oven (maintain the temperature between 105^0 C to 110^0 C).
- A funnel
- A balance
- A metal ruler

2.3. Materials required

- A sample of sand
- A sample of gravel

2.4. Test procedure

Weigh the empty container and note M_1, then pour the dry aggregates into the container in layers and without compacting using the funnel or using your hands (as a funnel). Level off using the metal ruler and weigh the filled container and note M_2.

The apparent density is calculated using the following formula:

$$\rho_{app} = (M_2-M_1)/V.$$

Repeat the measurement three times to obtain an average;

$$\rho_{app\ avg} = (\rho_{app1} + \rho_{app2} + \rho_{app3})/3$$

2.5. Calculation and expression of results

Complete the following tables, comment on the results and draw a conclusion.

Apparent density of sand

Designation	Unit	Test 1	Test 2	Test 3	
M_1					
M_2					
V					
ρ_{app}					$\rho_{app\ avg}$ =

Apparent density of gravel

Designation	Unit	Test 1	Test 2	Test 3	
M_1					
M_2					
V					
ρ_{app}					$\rho_{app\ avg}$ =

PW N°3: Water content (moisture content)

3.1. Objective

Determine the water (moisture) content of aggregates (sand and gravel)

3.2. Equipment

- Non-corrodible air-tight container
- Electric oven (maintain the temperature between 105^0 C to 110^0 C).
- A Balance.
- Spatula
- Gloves

3.3. Materials required

- A sample of sand
- A sample of gravel.

3.4. Test procedure

Weigh a mass $\mathbf{M_h}$ of each sample (sand and gravel) and place it in the oven. After drying, we weigh it a second time note it as $\mathbf{M_s}$.

- Calculate the water content:

$$\omega\,(\%) = 100\text{x}\,(M_h - M_s)/M_s$$

- Finally repeat the measurement three times to obtain an average: $\omega_{avg} = (\omega_1 + \omega_2 + \omega_3)/3$.

3.5. Calculation and expression of results

Complete the following tables, comment on the results and draw a conclusion.

Water content of sand

Designation	Unit	Test 1	Test 2	Test 3	
M_h					
M_s					
ω					ω_{avg} =

Water content of gravel

Designation	Unit	Test 1	Test 2	Test 3	
M_h					
M_s					
ω					ω_{avg} =

PW N°4: Sand Equivalent Test

4.1. Objective

The Sand Equivalent Test is essential to assess fine aggregate quality and controlling clay content in soils and aggregates.

4.2. Equipment

- Stainless steel sieve with 5 mm opening
- A graduated plastic cylinder with a rubber stopper
- Irrigator tube
- A Balance.
- Spatula.
- Metal ruler.
- Plastic funnel.
- Mechanical Sand Equivalent Shaker
- Weighted foot assembly

4.3. Materials required

- A sample of sand
- Concentrated solution for the sand equivalent determination

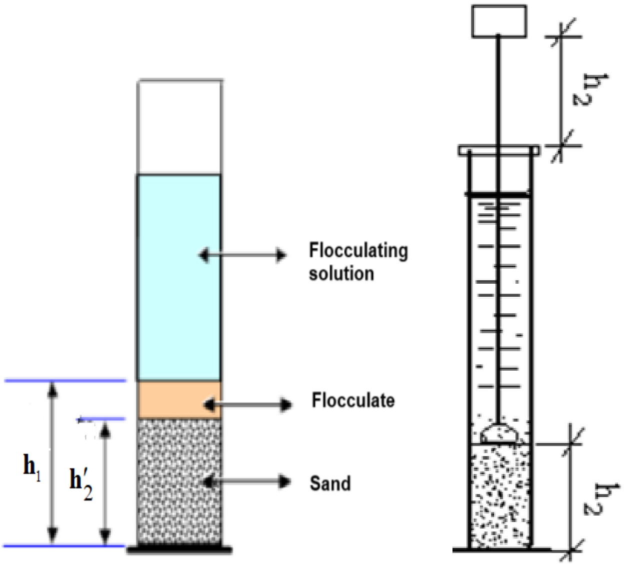
4.4. Test procedure

- A sample of aggregate (sand) passing the 5 mm opening sieve
- A small flocculating solution is poured into a graduated cylinder with approximately 120 g of aggregates (sand).
- Leave the mixture for 10 minutes
- Shake the cylinder horizontally to loosen the clay-like coatings from the sand particles.
- It is allowed to stand for a 20-minutes sedimentation period
- The sample is then rinsed with additional flocculation solution forcing the clay-like material into suspension above the sand.
- The height of flocculated clay (h_1) and the height of sand (h_2) are determined, and the sand equivalent is expressed as the ratio of the height of sand to the height of clay.
- Higher sand equivalent values indicate “cleaner” (less fine dust or clay-like materials) aggregates. The visual sand equivalent value

(VES) is defined as **VSE (%) = $(h'_2 / h_1) \times 100$**

- Clay Reading is usually clear to read; however, sand reading can be cloudy and difficult to read, thus it will be better to use the weighted foot assembly to find the sand reading (h_2).
- When using the weighted foot assembly with no sand reading indicator, gently lower it in the cylinder until it rests on the sand.

- The sand reading can be obtained by subtracting 0.9 cm from the weighted foot reading.



The sand equivalent value by using the weighted foot reading is defined as:

$$\mathbf{SE\ (\%) = (h_2 / h_1) \times 100}$$

4.5. Calculation and expression of the results

Complete Table 1 and determine the cleanliness of sand according to Table 2.

Table 1: Sand Equivalent Results

	h_1	h'_2	VSE	h_2	SE
Test 1					
Test 2					
Test 3					

Table 2: Classification of sand according to cleanliness

VES (%)	ES (%)	Sand quality
VES< 65	ES< 60	Clayey sand: risk of shrinkage or swelling to be rejected for quality concrete
65 ≤ VES< 75	60 ≤ ES< 70	Slightly clayey sand: acceptable cleanliness for common quality concrete when shrinkage is not particularly feared
75 ≤ VES≤ 85	70 ≤ ES≤ 80	Clean sand with a low percentage of clayey fines, ideal for high-quality concrete
VES ≥ 80	ES > 80	Very clean sand: almost total absence of clayey fines risks leading to a lack of plasticity in the concrete which will have to be corrected by an increase in the water dosage

PW N°5: Determination of particle size distribution by sieving (grain size analysis)

5.1. Objective

To determine the particle size distribution by sieving (Grain size analysis) and to determine the fineness modulus of sand, effective size, and uniformity coefficient. Classifying the aggregates' type (sand and gravel) is required.

5.2. Equipment

- Non-corrodible air-tight container
- Gloves.
- Electric oven (maintain the temperature at 105^0 C).
- A Balance.
- Set of sieves with different mesh sizes including the lid and the pan.
- Mechanical sieve shaker
- Trays and sieve brushes

The particle size distribution analysis can be conducted using the following Sieves of sizes as shown below:

For sand: 0.063 mm, 0.16 mm, 0.315 mm, 0.63 mm, 1.25 mm, 2.50 mm, 5 mm.

For gravel: 3 mm, 5 mm, 8 mm, 10 mm, 16 mm.

5.3. Materials required

- A sample of sand (2000g)
- A sample of gravel (2000g).

5.4. Precautions

- Clean the sieves set so that no soil particles were struck in them
- While weighing put the sieve with the aggregate sample on the balance in a concentric position
- Check the electrical connection of the sieve shaker before conducting the test
- No particle of soil sample shall be pushed through the sieves.

5.5. Test procedure

1. Take a representative sample of the aggregates and dry it in the oven.
2. The maximum mass of the aggregates taken for analysis may not exceed 2000 g.
3. Prepare a stack of sieves. Set the sieves one over the other with an ascending order (sieves having larger opening sizes are placed above the one with smaller opening sizes).
4. A pan is attached to the lowest sieve to collect the portions passing the lowest sieve.
5. Fit the nest to a mechanical shaker.

6. The whole nest of sieves is given a horizontal shaking for 5 min in sieve shaker till the aggregates retained on each sieve reaches a constant value.

7. Determine the mass of aggregates retained on each sieve including that collected in the pan below.

- Calculate the fineness modulus of sand (Fm):

Fm = [∑Cumulative retained (%) 0.16, 0.315, 0.63, 1.25, 2.50, 5mm] /100

5.6. Calculation and expression of results

Complete the following tables, draw the particle size curves, determine the fineness modulus of sand (Fm), comment on the results, and draw a conclusion.

Table 1: Sand

Opening size (mm)	Mass retained (%)	Cumulative mass retained (%)	Finer (%)
5			
2.5			
1.25			
0.63			
0.315			
0.16			
0.063			
Pan			
Total			

Table 2: Gravel

Opening size (mm)	Mass retained (%)	Cumulative mass retained (%)	Finer (%)
16			
10			
8			
5			
3			
Pan			
Total			