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DEDICATION

With the experience of my gratitude, I dedicate this modest work to those who whatever the terms embraced; I would never be able to express my sincere love to them.

To the man, who owes my life, my success and all my respect my dear father Belkacem

To the woman who suffered without letting me suffer, who never said no to my demands and who spared no effort to make me happy: my adorable mother Zahia

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Without forgetting all the class of master 2 materials of the year 2020_2021

NOURHANE

DEDICATION

I dedicate this work in the first place to the dearest persons to my heart, my grandfather Omar and my uncle Samir who were eagerly waiting for this day my God have mercy on their souls.

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This work is dedicated to all the people I love, who have left a positive impact on my personality, Thank you all.

MAROUA

ملخص

هذه الأطروحة مخصصة لدراسة صياغة وخصائص الملاط والسكريد الخفيف الوزن بإستخدام الطين الممدد، الملاط خفيف الوزن، هو جزء من مجموعة الملاطات الخاصة. ما يميز الملاط الخفيف عن الملاط العادي هو كثافته المنخفضة. يساهم استخدام ملاط منخفض الكثافة في تقليل وزن العناصر، مما يؤدي إلى تقليل القوى المنقولة إلى الأرض بواسطة الأساسات، وبالتالي تقليل أبعاد الأخيرة مما يسمح بالبناء على تربة ذات قدرة تحمل منخفضة يتميز الملاط الخفيف الوزن بتوصيل حراري منخفض وعزل صوتي جيد. لذلك، يمكنهم تقديم حل تقني مثير للاهتمام للغاية لمشكلة العزل الحراري والصوتي في المباني. في دراستنا الحالية، اخترنا الملاط الخفيف الوزن المصنوعة من مجاميع الطين الممدد، الذي تم اختياره لهذه الدراسة بناء على الخصائص المثيرة للاهتمام حيث أن هذا الأخير مادة مسامية وخفيفة (أخف بخمس مرات من الرمل)، تمتص الحرارة الزائدة خلال النهار، في الصيف. يوفر مساحة قوية ومستقرة، ويزيل الرطوبة التي يمكن أن تتكثف على الجدران

الكلمات المفتاحية: ملاط، ملاط خفيف الوزن، الطين الموسع، اعمال البناء، توصيل حراري، السكريد

ABSTRACT:

This thesis is devoted to the study of the formulation and properties of lightweight mortar and screed using expanded clay . lightweight mortar are part of the special goup of mortars . what distinguishes light mortars from ordinary mortars is their low density . the use of low density mortar contributes to reducing the weight of the elements, which leads to a reduction in the forces transmitted to the ground by the foundations , lightweight mortar is characterized by low thermal conductivity and good sound insulation , so they can provide a solution a very interesting technique for the problem of thermal and acoustic insulation in buildings . in our current study we chose a lightweight mortar made with expanded clay aggregates , which was chosen for this study based on the interesting properties as the latter is porous and light material (five times lighter than ordinary sand) , absorb excess heat during the day , in summer provides strong and stable space and removes moisture that can condense on the walls .

Key words: mortar, lightweight mortar, expanded clay, thermal conductivity, screeds.

Résumé

cette thèse est consacrée a l'étude de la formulation et des propriétés des mortiers légers et des chapes à base d'argile expansée . les mortiers légers font parties du groupe particulier des mortiers . ce qui distingue les mortiers légers des mortiers ordinaires est leur faible densité contribue à réduire le poids des éléments . ce qui entraine une diminution des efforts transmis au sol par les fondations . et ainsi réduire les dimensions de ces dernières permettant la construction sur des sols à faible portance . mortier se caractérise par une faible conductivité thermique et une bonne isolation phonique . ils peuvent donc apporter une solution une technique très intéressante pour le problème de l'isolation thermique et acoustique dans les bâtiments . dans notre étude actuelle . nous avons choisi un mortier léger composé d' argile expansé . qui a été choisi pour cette étude en fonction des propriétés intéressantes car ce dernier est un matériau poreux et léger (cinq fois plus léger que le sable ordinaire) . absorbe l'excés de chaleur pendant la journée . en été . offre un espace solide et stable et élimine l'humidité qui peut se condenser sur les murs .

Mot clé : mortier, mortier léger, argile expansée, conductivité thermique, chapes.

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ABREVIATION LIST

LWM: lightweight mortar

LWA: lightweight aggregate

OM: ordinary mortar

OA: ordinary aggregate

NA: nodular aggregate

CA: crushed aggregate

Rc: compressive strength

Rf: tensile strength

W/C: water cement ratio

ES: sand equivalent

VB: methylene blue test

INTRODUCTION:

In the field of construction and building; concrete and mortar are essential materials. The mortar consists of cement, water, gravel and sometimes admixture. Its dosage and its constituents can be adopted according to the performance and the desired use.

There are different types of mortar. The main purpose of using mortar is to protect masonry or reinforced concrete from water pentation and also provide insulation to the building. Lightweight mortar based on expanded clay or other types of lightweight aggregates could be an alternative to ordinary mortar and screed. The first lightweight aggregates used for making mortars or concrete were natural aggregates from volcanic rocks such as pumice characterize by a density less than 2. Light aggregate mortar has a low density which results in significant benefits in terms of permanent load of the structure; the mortar in fact significantly reduces the coefficient of thermal conductivity, thus providing better thermal insulation.

This is why this study was carried out on the performance of these aggregates in mortar and screed. The lightweight aggregates used were from a local factory in the Wilaya of Blida.

The purpose of this study is to obtain mortars or screeds with better insulating properties, while maintaining sufficient mechanical performance for structural applications. Our study will focus on the behavior of mortars and screeds based on local expanded clay aggregates.

Our dissertation is divided into three chapters. The first of which is devoted to bibliographic research which deals with a synthesis of different types of lightweight aggregates, their physical, thermal and mechanical properties, also mortars based on these aggregates. The second chapter presents the characterization of the materials used as well as the physical and mechanical tests carried out at the laboratory of the company ALGXPAN and LAFARGE laboratory on aggregates, mortars and screeds in the fresh and hardened state.

Chapter 3presents the fresh and hardened mortar and screed test results and their analysis and discussion. Finally, a general conclusion is given as well as proposals for further investigations.

CHAPTER I: LITTERATURE REVIEW

I.1.INTRODUCTION

This chapter presents a literature review on lightweight expanded clay aggregates as well as their influences on the performances of mortars and screeds in the fresh and hardened state.

I.2.DEFINITION OF AGGREGATES

An aggregate is a set of mineral grains its size range between 0 and 125 mm. They are obtained by: exploiting terrestrial sand and gravel deposits or marine silt, crushing massive rocks, or recycling products such as demolition concrete. They are used directly without binder (railroad ballast embankments, sub layers of road structures) or combined with a binder (cement for concrete and mortar or bitumen for asphalt mixes).

Aggregates are selected in the concrete mixture according to their bearing capacity and workability. The aggregates must be clean and solid and their particles free from chemicals, clay and other fine materials. In Algeria the state of Setif occupies the first place in the production of aggregates with more than 5 million m^3 or 8.4% of the total national production [1].

I.3.TYPES OF AGGREGATES

I.3.1. NATURAL AGGREGATES

I.3.1.1. VOLCANIC ORIGIN

After the volcanic lava is cooled, a well calcified sponge hike substance is formed due to the sudden cooling of the melt, the substance freezes, and the molten magma cools suddenly without crystallization, and the material is glassy structure. the process is similar to the production of the glass knows as obsidian

Lava is a boiling melt which may contain air and gases and once it cools down it freezes to a spongy porous mass. In alternative words it produces light weight material that is porous and reactive. This type of material is known as volcanic aggregates are made by mechanical handling of lava, i.e. crushing, sieving and grinding [1].

I.3.1.2. ORGANIC ORIGIN:

The use of agricultural residue as aggregates in the manufacture of building materials has several practical and iconic advantages. An example of organic aggregates are palm oil shells.

The production of palm oil is important in many countries such as Malaysia, Indonesia and Nigeria it generates a lot of waste that can be utilized in the production of building materials. Palm oil shells are made in massive quantities by the oil mills and may be used as aggregates within the production of lightweight concrete. The palm oil shells are hard and are received as crushed items as a result of the process used to release palm oil shells have a bulk density of 620 kg/m^3 and a specific gravity of 1.25 [1].

I.3.2. SYNTHETIC AGGREGATES:

Aggregates are said to be synthetic if their origin is related to an industrial process. For example: thermal transformation (industrial byproducts, refractory aggregates). Synthetic aggregates are a man-made material and their properties are directly related to the method of their manufacture and the raw materials used. These materials can be divided in two groups

- Natural materials such as perlite, vermiculite, clay, shale, and slate
- Industrial by products like fly ash, expanded slag, cinder, bed ash, etc

The aim of producing synthetic aggregates is to make a material with high porosity as well as being strong and with a good structural performance [1].

I.3.3. RECYCLED AGGREGATES

Their origin is either from site waste or demolition waste.

Site waste is mainly composed of waste from building and public works sites and industrial activities devoted to the manufacture of construction materials. They are defined as inert wastes that do not decompose or burn, they do not produce any other physical or chemical reaction with which they come in contact in a manner likely to cause pollution of the environment or to harm human health [1].

Demolition waste includes all construction or rehabilitation materials. Since concrete accounts for 75% of the weight of all building materials high proportions of demolition waste are concrete. Recycled aggregates have a lower density than that of virgin materials and higher water absorption. Aggregates recycling saves natural resources and reduce the amount of materials that are sent to landfill. Recycled aggregates conserve energy and they are less expensive [1].

I.4. VARIETIES OF AGGREGATES ACCORDING TO THEIR DENSITY

I.4.1. HEAVY WEIGHT AGGREGATES

This type of aggregates is characterized by their high density. In general aggregates with specific gravity of 2400 kg/m³ and more are considered heavy weight. They are used in heavy concrete for radiation shielding units, structure near explosive units and for the right acoustics isolation [1].

I.4.2. LIGHTWEIGHT AGGREGATES

Lightweight aggregates are numerous and among the important building materials due to their low volumetric density (less than 2000 kg/m³). Lightweight aggregates are considered to be a porous material. Their internal structure is a honeycomb shaped and from which they drive their lightness. This type of aggregate has a good thermal and sound insulation properties and good fire resistance due to the pores and voids in it. Their use in concrete helps to reduce the size of columns and beams and other bearing elements thereby reducing the weight of the structure. The production and the use of lightweight aggregates are not widely soread in Algeria partly because the researches made on their development are not sufficient enough. In Algeria there is only one synthetic lightweight aggregates factory situated in Bouinane (Wialay of Blida) based on expanded clay [2].

I.4.2.1. VOLCANIC AGGREGATE

a. Pumice

It is a rock of volcanic origin which occurs in many parts of the world. They are light in color or nearly white. They are light in weight enough yet sufficient strong to be used as light weight aggregate. The light weight of these rocks is due to escaping of gas from the molten lava when erupted from beneath the earth's crest. It is of fairly even texture of inter connected cells. Chemically it is inert and has about 75% silica content. Figure 11 shows a pumice aggregate.

Pumice is one of the oldest kinds of light weight aggregates which even have been used in Roman structures. It is mined, washed and used. To get the stronger aggregate, pumice may be heated to the beginning of fusion [1].

Figure I. 1: Pumice stone sample on the island of lipari, aeolian islands, ITAL [1]

b. Diatomite:

Diatomite is defined as a friable, sedimentary rock with a diatom content of at least 50%, it's a very light siliceous rock, very porous, friable and whose light color at the outcrop varies from light grey to blue-green or even white, depending on the alterations, the impurities contained and the degree of humidity. It is used in particular for the filtration of liquids and as a natural mineral charge [1]. Figure 1.2 shows a diatomite aggregate.

Figure I. 2: Diatomite [1]

c. Scoria:

Scoria, which is made from explosive volcanic eruptions, has been used for hundreds of years in the world as a construction material. Different researchers have tested the usage of scoria as a construction material in concrete production. Scoria is mainly used as a light-weight aggregate with silica fume and fly ash mineral admixture in the manufacturing of light-weight structural concrete wherein an exceptional performance was discovered with regards to the strength to unit weight ratio. Improvements in the mechanical strength of mortar had been additionally discovered while the use of volcanic scoria as sand in the manufacturing of Portland cement mortar [3]. Figure 1.3 shows a scoria aggregate.

Figure I. 3: Scoria

d. Pozzolane:

Pozzolane is a volcanic material, therefore natural usually red or black, with all intermediate shades, exceptionally gray, exist in considerable quantities in Algeria. If this product, which is a cheap product since it does not require any expensive energy other than that of grinding, could replace a significant part of the cement during concrete making, A substantial saving would be achieved [4]-[6]. Table 1.1 summarizes the physical characteristics of pozzolanic aggregates whereas table 1.2 summarizes the chemical its chemical composition. Figure 1.4 shows natural pozzolana piled in a site.

Table I. 1: Physical Characteristics Of Pozzolane [4]

Physical characteristics	Bulk density	Absolute density	SSB	Pozzolanicity	Absorption	Porosity	Moisture	Loss on ignition
Values	0.98	2.75	3560	85	58.70	57.10	2.50	5.60

Table I. 2: Chemical Characteristic Of The Pozzolane [5]

Component	SiO_2	Al_2O_2	CaO	Fe_2O_2	MgO	SO_3	Cl	LOI	Total
Content (%)	74.48	12.83	1.51	3.92	0.34	0	0	7.21	100.29

Figure I. 4: The Pozzolane [5]

I.4.2.2. ORGANIC AGGREGATES:

a. Rice husks:

Rice husks are characterized by very small pores under 0.1 mm. Rice husk ash (RHA) can be used as a fuel if it's burnt at high temperature and it becomes ash. Ash acquired is porous as fine aggregate and its grinding right into a fine power. RHA is a pozzolanic material includes 85% of silica content. Utilization of RHA as a supplementary cementitious material adds sustainability to concrete by reducing CO_2 emission of cement production. Absolute density of rice husk: 780 kg/m^3 and a total porosity close to 50% [7][8]. Figure 1.5 shows rice husk.

Figure I. 5: Rice husk [8].

b. Saw dust:

Sawdust (Figure 1.6) has been identified to be a perfect filler material to provide hollow concrete blocks and utilized as a light weight total in ground surface and in the assembling of precast products on an exceptionally limited scale. The shrinkage and water absorption are high when saw dust is sued [9]. Table 1.3 shows some physical properties of sawdust concrete.

Figure I. 6: Saw dust [9]

Table I. 3: Physical Properties Of Sawdust Concrete [9]

Mix ratio	Slump (mm)	Density (kg/m^3)	Water absorption (%)
1:1	40	1450	13
1:2	15	1280	15
1:2	5	1065	19

I.4.2.3. RECYCLED AGGREGATES:

a. Plastic:

The management of plastic waste is more than inevitable in order to reduce pollution that continues to grow from year to year. However, this requires implementation of waste treatment or recovery systems.

The use of waste plastics in the construction field can play an important role in the context economic of the country. Substitution of natural aggregates by plastics in a mortar or concrete allows to improve some of the essential properties (mechanical characteristics, thermal properties, durability, density, etc.) and to respond best to technical-economic problems as the conventional material [10].

b. Glass:

Being an artificial material, the chemical composition of glass is stable and well defined. This helps to prevent sudden chemical reactions and to change or treat the glass if necessary. The chemical aspect is therefore well controlled.

Water absorption in the glass is negligible or non-existent. This is an advantage for the concrete formulation because other natural materials such as gravel or sand absorb an initial amount of water depending on their nature and their origin. Thanks to this property of glass, the handling of concrete or the relationship between water and binder could be improved without the need to add plasticizers. This advantage promotes the rheological properties of fresh concrete.

Another advantage of glass is its abrasive resistance and hardness compared to that of natural aggregates. In addition, the compressive strength of the crushed glass is good and we can consider the mechanical nature of crushed glass as well suited for use as aggregates in concrete.

In addition, the source of recycled glass that increases by millions of tons each year worldwide (41 billion objects glass on average every year in the United States). Being a very durable and100% recyclable and infinitely, it is necessary to take advantage of this resource compared to the environment [1].

c. Rubber:

Rubber, by its nature, has quite different properties than natural aggregates. So the use of rubber in the construction sector helps to produce special concretes. Also the Mortars composed of these aggregates have an increasingly fluid behavior without the addition of water or additives. Rubber aggregate improves soil flexibility and water circulation for better drainage and faster drying [1].

I.4.2.4. ARTIFICIAL AGGREGATES

a. Clinker:

When baked clinker aggregates that is mainly composed of calcium silicate from industrial by-products (Figure 1.7). Clinker aggregates are innocuous in alkali silica reactivity test, and change in dimension by varied humidity is smaller, compared with common aggregates.

Clinker is a layer of clay around combusted coal sediment in order that it hardens as a brick. Clinker also can mean blob-formed ash material or porous mass resulting from coal combustion. Currently, the clinker from the rest of the combustion turns into industrial waste. The clinker could be very appropriate if it can be used as a substitute for concrete mixes [11]. Table 1.4 summarizes the physical properties of clinker aggregates.

Figure I. 7: Clinker aggregate [11].

Table I. 4: Characteristic Test Of Clinker Aggregate [11]

Characteristic test	Water content (%)	Sludge level (%)	Density (%)	Absorption (%)	Volume weight (kg/m^3)
	1.3	0	2.3	2.12	1.32

b. Perlite:

Perlite is a granular or powdery white-colored material (Figure 1.8). Siliceous sand of volcanic origin containing water is industrially expanded by heat treatment (1200°C). It is extensively used as loose-fill insulation, especially in masonry construction, due to its low toxicity. According to the Perlite Institute, «No test result or records indicates that perlite poses any fitness risk» Other insulators, including asbestos, vermiculite (which can also additionally include asbestos), and fiberglass are more hazardous; chemical inertness, that means it's going to not corrode piping, electric or communications conduits. Perlite has a pH of round 7, that's just like fresh water, pliability in the insulation of facades, roofs, ceilings, based on perlite, heat-insulating plasters, masonry mortars, or even adhesive compositions are produced [12].

Figure I. 8: Perlite [12]

c. Vermiculite

Vermiculite is a natural ore. Before processing, it is sorted, calibrated and sieved. Thermal treatment (natural gas exfoliation) at 900°C results in finished product (Figure 18). The rock consists of leaflets separated by molecules water. During thermal shock, water vapor separates the sheets to obtain grains in shape of finished accordion. The volume of vermiculite grains increases by 10 to 20 times. Stored air provides them with natural insulating properties. Table 1.5 summarizes the thermal conductivity of vermiculite according to its thickness. Vermiculite is available in 5 specially exfoliated grain sizes and processed for use in various fields of application [13].

Figure I. 9: Vermiculite [13]

Table I. 5: Thermal Conductivity Of Vermiculite [13]

Medium thermal conductivity λ=0.068W/Mk				
Thickness(cm)	5	10	15	20
R	0.7	1.5	2.2	2.9
K	1.4	0.7	0.4	0.3

d. Expanded clay:

Known as LECA (an acronym of light expanded clay aggregate) or LIAPOR (porous lias clay). Obtained from natural raw clay. It’s introduced wet into an oven and comes out after drying in the form of a nodule (an abnormal size of generally rounded shape) whose surface is smooth and slightly vitrified. Pellets are available in different sizes such as 4-8 mm. The dry density of expanded clay aggregates ranges between 300 and 500 kg/m³ and its internal tissue is honeycomb shaped. Expanded clay provides excellent insulation properties (used for sounds insulation) and is heat resistant. Due to its lightweight it's used in structures to reduce pressure and reduce the weight of the structures in general.

Expanded clay can also absorb a large amount of humidity and is considered incombustible because it does not contain organic materials. It’s not attacked by rodents and termites but if humidity is constantly present and fungi can grow on it. Expanded clay used either directly without binder or combined with a binder (cement, lime, resins ...) for insulation drainage and lightening as well as to obtain blocks, mortar, screeds, concrete, even refractories in a wide range of density and resistance. Expanded clay can be produced in granules or powder form in various sizes and in high strength structural formula for applications with higher structural or mechanical needs, and it can be delivered in big bags or in bulk. The natural origin of the product as well as an environmentally friendly production process allows expanded clay to be an ideal product for bio construction [14][15].

I.5. VARIOUS PROCESSES OF LIGHTWEIGHT AGGREGATES MANUFACTURE

Most lightweight aggregate manufacturing processes, with the exception of processes using blast furnace slag, have been limited to the use of sintered strand or a rotary kiln. In cases where the fresh pellets before baking are in a suitable shape, the sinter strand is preferred. When the shape of the fresh pellet is cohesive, and its shape can be maintained, the rotary kiln produces the most rounded particle with the most impermeable surface [16].

I.6.PRODUCTION METHOD USED FOR EXPANDED CLAY

Expanded clay aggregates produced in a rotary kiln consisting of a long steel cylinder of large diameter inclined approximately 5 ° from the horizontal. The furnace is lined inside the baking zone with refractory bricks which, during the rotation of the furnace, heat to the required temperature and "roast" the clay pellets so that the required degree of expansion occurs. The length and configuration of the furnace depends in part on the composition of the clay and the time it takes to "condition" the clay pellet in the preheated to reach a temperature of about 650 ° C to prevent it does not break until it becomes pyroplastic. The clay is excavated and, to eliminate natural variability, is usually deposited by stratification in a pile covered with a fertilizer spreader before being removed from the pile by scalping with a bucket conveyor. Clay is prepared by mixing thoroughly until a suitable consistency is obtained before granulation. Introduced into the oven. This can be in three segments, the upper end for drying and preheating, while at the lower end firing and then cooling takes place. As the prepared material advances through the kiln, the temperature of the clay pellets gradually increases until they actually expand. The expanded product is removed from the firing zone as soon as possible for cooling in order to freeze the particles to the required degree of expansion. Cooling takes place in a rotary cooler or fluidized bed heat exchanger. The finished products are sorted and, if necessary, crushed to grain sizes less than 16 mm. While the particle density may vary depending on the temperature range at which the expansion occurs, the average expansion temperature is around 1200 ±50°C. this varies for different clays. [16]

I.7.CHEMICAL AND MINERALOGICAL COMPOSITION OF LIGHTWEIGHT AGGREGATE:

Table I. 6: Chemical Composition Of Expanded Clay

	Sio2	Al2o3	Feo2	cao	mgo	Mn2o3	So3	feo	mno	K2o	Na2o	Tio2	S
Expanded clay	63%	17%	14%	1%	1%	0%	0%	0%	0%	2%	0%	1%	1%

Table I. 7: Mineralogical Composition Of Expanded Clay

	Mineralogical composition
Quartz	35%
Calcite	4%
Albite	6.5%
Sepiolite	5.5%
Kaolinite	15%
Illite	27%
Ferruginous minerals	6%

Table I. 8: Chemical Composition Of Pumice Diatomite And Fly Ash [1]

	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	MgO	K_2O	Na_2O	SO_3
Pumice	53-75	11-17	0.5-5	1-8	1	0.5-3	3-9	3-9	1
Diatomite	60.40	3.156	1.29	13.38	0.027	2.15	0.786	1.210	0%
Fly ash	49.5	30.2	9.5	4.6		2.4	1.5	1.5	0.9

Table I. 9: Chemical Composition Of Expanded Slag [1]

	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	MgO	K_2O	Na_2O	MnO	SO_3	P_2O_3
Expanded slag %	35.5	5.03	7.77	37.2	0.17	3.55	0.27	0.12	2.0	0%	0.09

I.8.PROPERTIES OF LIGHTWEIGHT AGGREGATES:

I.8.1. GEOMETRIC PROPERTIES:

I.8.1.1. PARTICLE SHAPE AND TEXTURE:

Depending on the source and the method of production lightweight aggregates exhibit considerable differences in particle shape and texture. Shapes maybe cubical, rounded, angular, or irregular while the textures may range from fine pore, relatively smooth skins to highly irregular surfaces with large exposed pores. Each particles consists of the typical features of lightweight aggregates which are a highly porous core containing a rather broad distribution of pore size and shape and a denser outer shell. [16]

I.8.1.2. PORE STRUCTURE OF LIGHTWEIGHT AGGREGATE:

Lightweight aggregates are porous and have the ability to suction, so it is necessary to look into the pore structure of the aggregates itself. There are two types of pores in the lightweight aggregates: open and closed pores. Open pores are the pores that are interconnected and take part in the permeation, whereas the closed pores are sealed and not interconnected. Thus, they do not take part in the permeation. The total porosity of a material is the sum of the closed and open pores, whereas the permeability will depend only upon the interconnected pores. The simple way to assess the interconnectivity of the pores is by measuring the water absorption property. [1]

I.8.2. PHYSICAL PROPERTIES:

I.8.2.1. UNIT WEIGHT:

Due to the cellular structure, the unit weight of the light aggregate is lower than that of normal weight aggregate with the same gradation and the same particle shape. The unit weight of the aggregate is essentially proportional to the specific gravity. The same specific gravity can have a significantly different unit weight due to a different percentage of voids in dry loose or dry_rodded volumes of aggregates of different particle shapes [16].

I.8.2.2. HYGROSCOPICITY:

It is the material's capacity to absorb water vapor, it depends on the temperature of the area, its humidity, the type, percentage and dimensions of the pores as well as the nature of the material. The more the pores increase, the more the hygroscopicity increase [16].

I.8.2.3. MOISTURE CONTENT:

The absorption of water by the lightweight aggregate particles is significant for concrete production. It is desirable to prevent such absorption during the concreting process. It is logical to soak the aggregate before mixing or to ask for delivery of very wet aggregates.

Another result of high water content in the lightweight aggregate of homogeneity in the cement paste of the concrete when compared to the vicinity of the surface of the particles and the bulk cement paste. When dry cement comes in contact with very aggregate particles, a cement paste layer of low water-to-cement ratio is produced on the surface. Results in irregularities in the concrete and creates a structure of higher permeability and low strength. If the stiffening of the consistency over time is due to the absorption of water, the absorption may be reduced by soaking the aggregate. There are a number of methods used:

- Immerse the aggregates in water, sometimes in hot water at the production site.
- Continuous sprinkling of stockpiled aggregate with water.
- Storing and agitating the aggregate in a lagoon filled with water.
- Pre-wet the aggregate in the mixer at the beginning of the mixing process and this method is the least effective.
- Vacuum-soaking which is the most effective but also the most expensive.

It should be noted that water contained in lightweight aggregates after the concrete has set plays a reserve role, and its migration to the mortar will at least partially compensate for the water lost by evaporation and hydration of the cement [18].

I.8.2.4. POROSITY OF LIGHTWEIGHT AGGREGATES:

Lightweight aggregates are characterized by a very high porosity between 25% and 75% of the apparent volume much greater than that of aggregates of normal density it is depending on the size of the aggregates. the porosity of a light aggregate can be determined by:

$$\mu = v / V \qquad \text{(Eq. 1.1)}$$

v: the volume of the pores
V: the total volume of the body

Usually, large pores are located at the core from the start of aggregate expansion, while small pores are found on the carapace, which is estimated to be between 500 and 1000 µm. Despite the differences in distribution and size, the pores are generally not connected to each other. The capillary distribution of two types of expanded clay aggregate and one type of expanded shale aggregate shows pore size variability within the same type of light aggregate (Figure 1.10). The open porosity of porous aggregates affects the fresh and hard condition of light concrete [1].

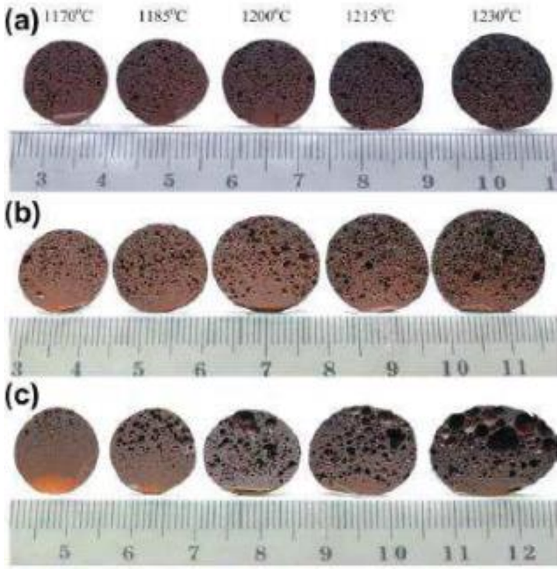

Figure I. 10: Porosity Of Lightweight Aggregates Of Expanded Clay (Liao And Huang 2011).

I.8.2.5. SLUMP AND AIR ENTRAINED OF THE LIGHTWEIGHT AGGREGATES:

The workability of freshly produced lightweight concrete requires special attention, as the aggregate tents separate with mixtures with high consistency and float to the surface. To counteract this tendency it is necessary to limit the maximum slump and to entrain air. Approximately (5~7) % air entrainment is generally required to reduce mixed water needs while maintaining the desired slump and reducing the tendency for segregation and bleeding. A slump of (51~76) mm means a relatively high work capacity. A slump of more than (75~102) mm can lead to segregation, with light aggregate particles floating upwards. The tendency for larger particles of lightweight aggregates can be difficult to place and work with due to the porosity and angularity of the aggregates. The place ability of concrete can be improved by adding air entraining agents [1].

I.8.2.6. PERMEABILITY:

Permeability is the ability of the soil to allow the flow of water through the material. The voids in between the solid particles in soil are interconnected, allowing water to flow pass through them. There are several factors affecting the soil void system such as particle size distribution, particle size, particle shape and texture, void ratio, and mineralogical composition. The smaller the particles, the smaller the voids, thus creating more resistance to the water flow and therefore making the value of permeability low. The void ratio also has major influence on the permeability since it is dependent on how the soil is placed or compacted. Lightweight aggregate can be classified as granular material which produces good drainage behavior. LWA has superb water-draining properties, and because it is much lighter than any alternative materials such as gravel. Typical value of coefficient of permeability or hydraulic conductivity, k for clean gravel material is found to be 1 to 100 cm/s, while for course sand is 0.01 to 1 cm/s. Constant head test in accordance to ASTM D 2434 was chosen to determine the coefficient of permeability of LECA. This is because LECA aggregate is similar to coarse or granular materials. The permeability, k value for LECA determined in this study is 2.53 cm/s based on maximum density of LECA (compacted). [18]

I.8.2.7. WATER ABSORPTION:

Due to their porous structure, light aggregates absorb more water than normal aggregates. The absorption rate of light aggregates depends on the size of the pores, their interconnectivity and distribution, especially for those exposed to the surface. Water internal absorbed in the particle is not immediately available for reaction chemical with cement and is not taken into account in the calculation of the ratio E/C.

Light aggregates are characterized by very high porosity (between 25 and 75% of the apparent volume) (Figure 1.11). The size and distribution of the pores influence the strength of the aggregates, but mainly determines their absorption properties (absorption rate and total absorption).

Absorption capacity of an aggregate is estimated from the absorption coefficient at atmospheric pressure or vacuum. All methods for estimating the absorption coefficient of an aggregate are developed in the presence of water [17].

A. PYCNOMETER METHOD:

The pycnometer method is described in NF EN 1097-6

Pycnometers are containers with a known volume Available in several sizes standard nominal

The pycnometer will be provided with an appropriate calibration sheet. This sheet shows the volume true real pycnometer, as well as the reference temperature corresponding to this volume*

The pycnometer method consists of immersing a previously dried test sample in a pycnometer filled with water in order to measure the increase in mass of the sample due to the penetration of water into the pores accessible to water. [18]

$$W_{24=} [(M_{sss} - M_{sec}) / M_{sec}] \qquad \text{(Eq 1.2)}$$

Avec:

Msss: mass of saturated and surface dry aggregates in air

M : dry sample mass

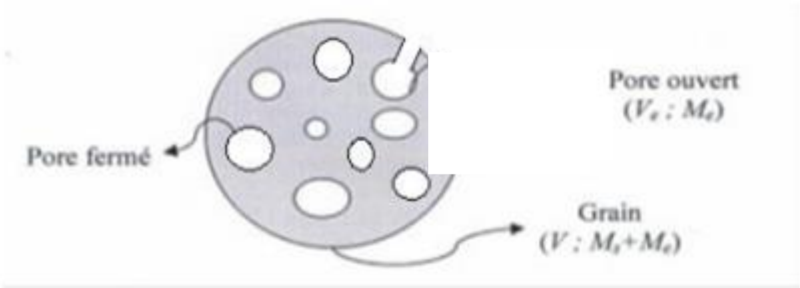

Figure I. 11: Porous Structure Diagram Of Lightweight Aggregates [18]

B. METHOD BASED ON VACUUM SATURATION:

The principle is to keep the pycnometer under vacuum during the absorption test in applying a constant pressure of 4 kPa for 10, 20 and 30 minutes, respectively. The results showed that the 10-minute vacuum absorption coefficient is equivalent to atmospheric pressure absorption coefficient according to the procedure described in the standard triggered.

Figure I. 12: Vacuum Water Absorption Measuring Apparatus (Mills Beale Et Al. 2009) [18]

Porous aggregates are difficult to reach the dry saturated state by the usual methods because of the friction developed between the grains. therefore, the light sands, recycled have difficulty measuring**.** (Kasemchaisiri and Tangtermsirikul 2007) proposed an approach to phase out free water by gravity in static or dynamic mode. [18]

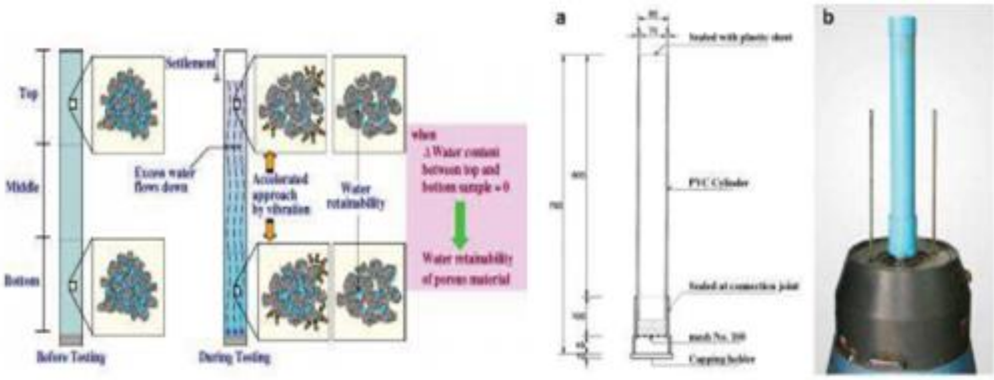

Figure I. 13: Absorption Test Device Based On Gravity Displacement Of Open Water (Kasemchaisiri And Tangtermsirikul 2007) [18]

The test consists of following the evolution of the mass difference between the partial sample top and bottom sample. The mass difference cancels out when free water is completely eliminated from both samples. This state is close to the dry saturated state on the surface estimate the moisture content of the unsaturated sample in the upper part by the expression:

$$W_1=\frac{B-A}{A}*100 \quad \text{(Eq 1.3)}$$

Wi: content of the sample;

B: mass of the unsaturated sample at the top;

A: mass of the sample in the upper part after constant mass drying in the oven 105 5°C.

I.8.2.8. BULK DENSITY:

Among the fundamental characteristics of light aggregates its bulk density. It refers to the dry light aggregate mass ratio randomly filling without compaction a container specified on the volume of the container. It can be determined by the procedure of the standard NF EN 1097-3.

Bulk density is involved in the choice of lightweight aggregate for a given type of lightweight concrete (insulating concrete or structural concrete). For the manufacture of insulating concretes oriented towards light aggregates of low bulk density and for the realization of structural concrete, light aggregate with a higher bulk density will be selected [16].

I.8.2.9. THE REAL DENSITY:

A dry mass of granular material related to the unit volume of solid material, including the volume of voids contained in the grain**.** It is less than or equal to 2000 kg/m^3. It expresses the ratio of the mass of a sample of dry light aggregates to the volume in water. It can be determined according to the norm NF EN 1097-6.

The density is a prominent parameter in the process of determining the proportions of granular constituents used in concrete. The relation between the apparent density and the absolute density [16]. that is used to estimate the real density of light aggregates is:

$$Mv_{real}=\frac{7}{4}\,Mv_{bulk} \qquad \text{(Eq 1.4)}$$

I.8.3. ELASTIC MODULUS OF LECA:

The average elastic modulus for common and structural LECA are 0.57 to 2.31 and 2.66 to 6.27 GPa respectively, and there is a linear relation between the elastic modulus and the particle density of lightweight expanded clay aggregates. Their elastic modulus exponentially decreases with the increase in particle size. The equation for the determination of the elastic modulus of LECA was introduced:

$$E_{GPa}=8.96\ p\ \text{ton/m}^3 - 3.78 \qquad \text{(Eq. 1.5)}$$

Where p in ton/m^3: is particle dry density of LECA

The elastic modulus values of LECA varies between 243 kPa to 6.80 GPa depending on the production process [16].

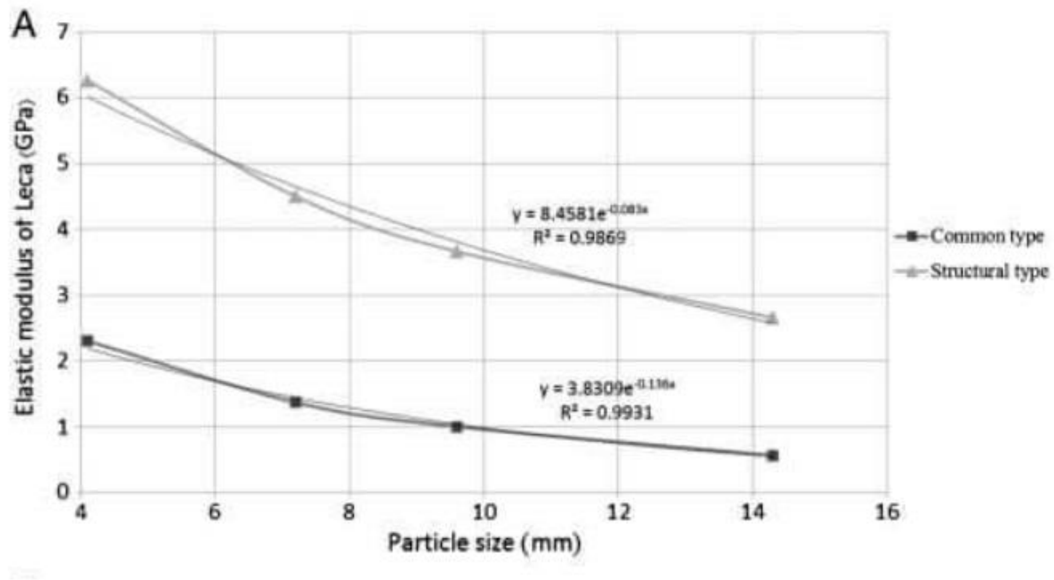

Figure I. 14: Elastic Modulus Of Lica

I.8.4. LIGHTWEIGHT AGGREGATE-CEMENT PASTE INTERFACE:

The interface is characterized by a mechanical interlocking with a chemical reaction in the form of pozzolanic reaction. The lightweight aggregates has a porous surface as a result of this, part of the binder will penetrate into the aggregate which will subsequently reduce the internal bleeding water zone. If the bleeding water carries with it more amounts of cement particles, a layer of laitance will be formed if this is at the top of a slab a porous and weak surface layer will result in a dusty surface. When the aggregates are porous or has a pozzolanic character as in the case of lightweight aggregates, the internal water area will decrease [1].

I.8.5. CHLORIDE AND SULPHATE CONTENT AND PH VALUE OF LECA:

LECA aggregate has a pH value of 9.5 which is shows that the material is alkali, while the measured of chloride and sulphate content are 6.5 mg/L and 95 mg/L respectively [1].

I.8.6. FIRE RESISTANCE:

It is well established that lightweight aggregate has better fire resistance than normal aggregates. It is the power of a material to resist the action of high temperatures without loss of load bearing capacity (resistance and deformation) all building materials are divided into non-combustible, low-combustible and combustible materials. Among the materials that do not burn (incombustible) we have expanded clay [1].

I.9.MORTAR ROLE AND COMPOSITION:

It is a mixture that contains aggregates often less than 4 mm in size and one or more binders (cement, gypsum ...) And possibly additives and admixtures, in addition water. The most important functions of mortar are:

- To bind materials together
- To provide a level or smooth finish
- To protect against weathering
- To improve thermal insulation
- To repair constructions.

In its plastic state the mortar must be readily workable to allow the mason to work at a satisfactory and economic rate, and be compatible with the unit being laid. In its hardened state the mortar must be strong enough to:

- bond the unit together and help them resist lateral forces.
- fully fill and seal the joints against rain penetration and erosion, but it should also be weak enough to allow minor movements to be accommodated in the joints rather than cracks developing in the masonry units.

The mortar must also be durable in the environment into which it is to be built with particular care being taken in exposed and aggressive conditions.

Mortar primarily consists of sand together with a binder and water, additions, admixtures and pigments are added to enhance performance characteristics or appearance.

Sand: gives volume, stability, resistance to wear or erosion and other desired physical properties to the finish structure typically we use commercial product called normalized sand it consists of fine, medium and coarse grained. The fine grained will arrange themselves to fill the gaps between the coarse grains it helps to reduce the volume variation, the released heat and also the price of the whole structure.

-**Binder:** has a very important role in forming the strength of the mortar both in fresh and hardened state, it sticks various particles together and forms the adhesive properties of the mortar to the substrate. Generally, one can use standardized cement (white or gray), special cement (aluminous, prompt, etc) masonry binder, and lime.

-**Water:** the mixing water should be clean and not contain any dissolved substances that have a harmful effect, potable water is satisfactory.

Admixtures: these include pozzolanic fine powders (ash, silica fume, etc), fiber of different types and dyes (natural or synthetic).

Additives: Chemical products that are used in the case of mortar and concrete they modify the properties of mortar and concrete in which they were added in a small proportion (about 5% by weight of cement) in general. The most used additives are plasticizers (water reducer), air entraining agents, modifiers of setting process (retarders, accelerators) and water repellents.

Pigments: The pigments in common use are inorganic iron oxides and ochres, giving browns, reds and yellow, chromium oxides and cobalt spinels giving stable green and blue, and carbon black [15].

I.10.TYPES OF MORTAR:

I.10.1. BASED ON APPLICATIONS:

I.10.1.1. BRICKLAYING OR STONE LAYING MORTAR:

The proportions of ingredients for bricklaying or stone laying mortar is decided based on kind of binding material used. The ratio of sand and cement depends on the intended use for example, load bearing structure such as foundations require higher sand to cement ratio than non-load bearing structures. Mortar shouldn't be too wet or too dry or the bricks won't set properly. A typical (load bearing) mortar joint should be (10 mm thick for both horizontal and vertical joints and (7 to 13mm) for other applications. Mortar for brickwork can be divided into two groups:

a. **Designed mortars:** The composition and manufacturing method is selected by the producer to achieve specified properties; designed mortars are classified by their compressive strength [19].

b. **Prescribed mortars:** Are made in predetermined proportions, the properties of which are assumed from the stated proportions of the constituents and are classified by designations.

The variations in the water suction rate of bricks can adversely affect bricklaying.

For good adhesion to brick, mortar must have good workability, poor workability will result in air spaces between mortar and bricks, preventing good bond formation, water ingress and durability issues. Bricks with a roughly textured bed face and medium suction rates will have a greater bond performance with the mortar than smooth textured low suction rate bricks.

Mortar that contain only Portland cement or CEM 1 (composite cement) and sand tend to be coarse and have poor workability. If additional water is added to improve workability this will have a negative effect on strength and drying shrinkage. The addition of lime will increase workability, reduce the water requirement improve strength and resistance to shrinkage within mortar beds [19].

I.10.2.2. FINISHING MORTAR:

Plastering is a process of rendering mortar into a surface lo bond the bricks and also to cover the same inside, outside and ceiling mortar. There are different grades and types of plaster mortars also ways of rendering the same are different.the plaster material should fulfill the following requirements:

- it should adhere to the back pound and should remain adhered during all seasons;
- it should be hard and durable;
- it should possess good workability;
- it should be possible to apply it during all weather conditions;
- it should be cost efficient;
- it should effectively reduce penetration of moisture.

The selection of type of plaster depends upon the following factors:

- availability of binding materials;

- durability requirements atmospheric conditions and variations in weather;
- location of surface (exposed surface or interior surface);
- methods of application: plaster mortar can be used as: gunniting, grout, spraying, rendering by toweling.

A. DEFECTS IN PLASTERING:

The fallowing defects may arise in plasterwork:

- **Blistering** of plastered surface: the formation of small patches of plaster that swell in the outer covered surface.

- **Crazing**: it is a network of small hexagonal slits with a size ranging from 5 mm to 75 mm occurs in mortars that contain a high amount of cement and sand that contains an excessive amount of dust.

- **Map cracking**: this Type is usually deeper and stretches up to 200 mm in size it occurs when high amounts of cement are added with excessive moisture loss early and also due to the use of poorly graded sand and highly absorbent bricks.

- **Plastic shrinkage cracking**: it occurs when excessive amount of water is lost from the plaster in the first hours after application and it is in the form of horizontal cracks that form in the corner and between the windows.

- **Drying shrinkage cracks**: it occurs when moisture is lost after the plaster hardened as it always shrinks and cracks due to the high amount of cement in the mix and poor quality sand that requires a lot of water and this type of cracks are stable.

- **Structural cracks**: these cracks arise in the wall not in the plaster, and appear in the plaster in the form of a straight vertical line, a horizontal line, or in steeped diagonal lines. This type of cracks occur as result of the differential movement of the foundation, the expansion of moisture and the thermal movement of the roof slab.

- **Deboning:** it can be observed as a hollow sound when the surface is tapped, and it occurs when the outer layer is exposed to air and it shrinks at à different rate than the plaster that is in contact with the wall and this occurs due to the application of a thick layer of plaster.

- **Greening**: occurs when the difference in the suction capacity between the walls of bricks and mortar, and thus the joints of the mortar appears clearly through the plaster.

- **Expansion**: this happens because of the gypsum based product in the mixture in wet conditions, where the sulfates in the gypsum react with the cement paste forming a compound of increased size which leads to disruption of the plaster.

- **efflorescence:** it occurs due to the presence of salts in the materials for the manufacture of gypsum, sand, cement and even water and it is in the form of white crystalline substance that appears on the surface affecting the adhesion of the paint to the surface of the wall .

- **flaking:** it is the removal of small portions of surface, mortar flaking is typically very shallow in depth and it occurs when the cement putty dries close to the surface before it has a chance to develop strength and form a strong bond with aggregate particles through the wetting process.
- **Rust stains**: occurs when plaster is applied on metal laths.
- **popping**: the formation of a conical holes in the surface of the plaster of varying sizes and occurs due to the presence of polluting particles in the mixture that interact with moisture [15].

I.10.2. BASED ON BINDING MATERIALS:

I.10.2.1. SURKHI MORTAR:

In this type of mortar, the binder is lime and the fine aggregate is surkhi (burnt brick). Surkhi Mortar is used for ordinary masonry work of all kinds, in foundation as superstructure but it cannot be used for plastering or pointing since surkhi cannot resist the weathering and humid conditions. Surkhi mortar present some advantages such as the reduction in hydration temperature, reduction of cracking, mores resistance to alkalis and salt solutions, less bleeding and more water proof.

However, when compared to ordinary mortar it is more subjected to shrinkage it has low compressive strength as c ompared to ordinary cement mortar cannot resist the long exposure of humidity [15].

I.10.2.2. GYPSUM MORTAR:

Gypsum is used as binding material in this type of mortar. And this type has some important weaknesses such as low compressive strength, high rate of water absorption and low setting time. Its main advantages are the prevention of flash setting of mortar during manufacturing and prevention of shrinkage cracks because gypsum reaction produces less heat as compared to cement reaction with water. In addition, gypsum mortar doesn't need any curing saving and gypsum mortar is fire resistant. Gypsum mortar is also resistant to insects and rodents [20] [21].

I.10.2.3. CEMENT MORTAR:

Cement is used as binding material in this type of mortar and sand is employed as aggregates, the proportion of cement and sand is decided based on the specified durability and working conditions. Cement mortars are very resistant they provide good strength and water resistance and their setting is faster. On the other hand, they are more subject to shrinkage. To increase the flexural strength and elasticity of the cement mortar it is possible to add a combination of silica fume (SF) and low calcium content fly ash (FA) and sometimes a little lime to make it more plastic [22] [23] [24].

I.10.2.4. GAUGED MORTAR:

Cement and lime are used as binding material in this type of mortar and Sand is used as fine aggregate which combines the plasticity of lime with the strength of Cement. Cement and hydrated lime mortars have been shown to have high levels of flexural bond strength is enhanced by the following properties of cement- lime mortars. This type of mortar presents higher flexural bond strength, higher bond and minimize the potential for water penetration into masonry walls. In addition, cracks could be autogenously healed by the reaction of hydrated lime with carbon dioxide in the atmosphere which produces limestone which helps to seal the crack and fill voids in the mortar.

I.10.2.5. LIME MORTAR:

In lime based mortar, the binder is largely a hydrated lime with more or less hydraulic properties. Lime mortar is more breathable than cement meaning that is less likely to trap moisture within the construction. Lime mortars are greasy and smooth the harden more slowly than cement mortars. Lime mortar is one of the oldest type of mortar, the Egyptian were the first to use lime mortar about 6000 years ago they use lime to plaster the pyramids of Giza. The European standard for building lime (BS EN 459.1) defines and classifies different types of building lime.

- lime with hydraulic properties including NHLS, FLS and HLS.
- air limes including CLS and dolomitic limes (DLS) (hydraulic lime has a behavior similar to cement).
- calcium air limes are the most used in the production of mortars [25] [26].

1.10.3. MORTAR BASED ON STRENGTH CLASSES (ASTM C 270):

There are many types of mortar according to their applications (Table 1. 9).

1.10.3.1. TYPE M MORTAR:

It is the strongest of the four with a strength over 17.2 MPa. When the structure must withstand high gravity and/or lateral loads type M mortar should be used. Type M mortar contains the highest proportion of Portland cement and has relatively poor adhesion and sealing properties. This makes them unsuitable for many exposed applications [27] [28] [29].

1.10.3.2. TYPE N MORTAR:

Type N mortar mix has a medium strength with minimum 5.2 MPa it is considered to be a general purpose mix useful for above grade walls, exterior, and interior load bearing installations that are exposed to several weather and high heat also the perfect mix for soft stone masonry. This general-purpose mortar has good bonding capacities, and since the cement is not overburdened by Portland it cures more slowly and allows for better workability, it's more elastic than a high strength mortar, which helps to prevent cracking and spelling of adjacent masonry [27] [28] [29].

1.10.3.3. TYPE S MORTAR:

It has medium strength minimum 12.4 MPa and high tensile bond strength, and it works well and can withstand soil pressure, wind and seismic loads and is the ideal choice for below grade applications such as masonry foundations manholes, retaining walls, and sewers, as well as at grade projects like patios and walkways. Type S mortar has great durability that is why it is highly suitable for locations where the masonry is in contact with the ground [27] [28] [29].

I.10.3.4. TYPE O MORTAR:

Is a lime rich mortar and is considered a low strength mortar with a minimum strength of 2.5 MPa and is used for internal applications but its external use is limited due to its low structural capacity. It is also suitable for restyling and similar repair work on existing structures due to its consistency and ease of use. Type O mortar also allows for more flexing, which can help prevent cracks and spalls in masonry units [27] [28] [29].

Table I. 10: Classification Of Mortar Types According To Building Segment [27] [28] [29]

Building segment	Exterior, above grade	Load bearing	Non load bearing parapet wall	Exterior , at below grade	Interior load bearing	Non load bearing
Mortar type	N or S or M	N	N or S	S or M	N or S	N

1.10.4. TYPES OF MORTARS ACCORDING TO THEIR DENSITY:

I.10.4.1. LIGHTWEIGHT MORTAR:

If the mortar having bulk density of less than 15 kN/m³ then it is called as lightweight aggregate mortar (LWAM). Lightweight mortar is generally used in the sound proof and heat proof constructions.

The use of lightweight aggregate concrete and mortar can be traced to as early as 3000 BC, earlier lightweight aggregates (LWA) were of natural origin mostly volcanic pumice, scoria, tuff etc these have been used both as fine and coarse aggregates. The low density results in high thermal insulation of buildings and in some instances, the thickness of roofs and walls can be reduced where there is reduction in weight, a higher degree of thermal insulation will be achieved. The bond between the aggregates and matrix is stronger in the case of LWAM than in normal weight mortar. Cement paste penetrates inside the aggregates due to their porous nature, thus, there is very little or no interfacial transition zones between the aggregates and the matrix the weakest zone. LWAM is very durable and as an example is the ship Selma built with the LWAC and LWAM at the end of world war 1 in 1917 which is still in satisfactory [29].

I.10.4.2. HEAVY MORTAR:

If the halving of 15 kg/m³ or more then it is called heavyweight mortar generally heavy aggregates like quartzes are used in this type of mortars [29].

I.11.TYPES OF LIGHTWEIGHT MORTAR:

1.11.1. CAVERNOUS MORTAR:

It is a very porous light mortar due to the presence of voids due to absence or fine element. it is obtained from large aggregates (current or light) moistened and encased in a paste of cement or a mortar, and is placed in place by at least 50 cm splice layer and stitching. It is used as a mortar or concrete filling or to oppose capillary lifts [30].

1.11.2. LIGHTWEIGHT CELLULAR MORTAR:

It was first patented and utilized in year 1923 and a limited scale of fabrication was started a year later. The utilization of LCM in construction industry was very restricted until the late 1970s, when it was on track to be implemented in Holland for ground engineering applications and voids filling jobs. It has several advantages such as its exceptional thermal properties, low density, excellent fire resistance, shock resistance and frost resistance. The density of cellular mortar varies between 550, 650, 750, 850 and 950 kg/m^3; and a water/cement ratio = 0.45. Figure 1.14 shows that the thermal conductivity of all LCM is absolutely proportional with the LCM density, the thermal conductivity for LCM reduced from 0.30 to 0.24W/mK and further reduced to 0.19W/mK for corresponding densities of 950, 750 and 550 kg/m^3.

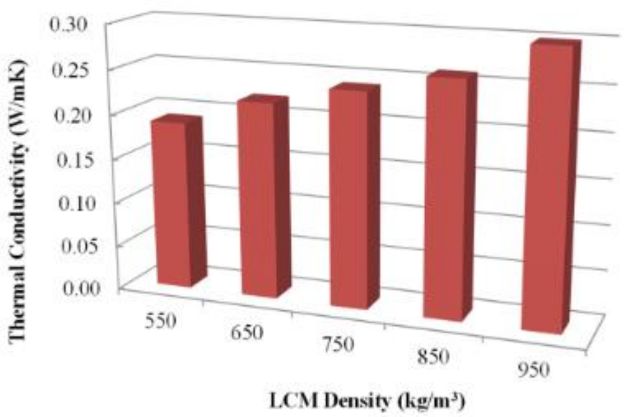

Figure I. 15: Thermal Conductivity Of Lcm Of Different Densities [31]

I.11.3. LIGHTWEIGHT AGGREGATE MORTAR:

1.11.3.1. LIGHTWEIGHT MORTAR MADE WITH VERMICULITE:

Vermiculite in a mortar reduces water demand and the compressive strength in vermiculite-based mortars is a little low compared to ordinary mortar and this is because of the porous structure of vermiculite water absorption in this mortar increases by adding vermiculite [32].

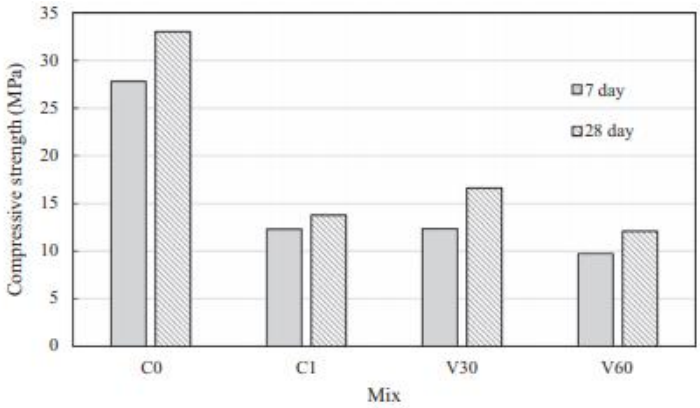

Figure I. 16: Compressive Strength Of Mortars At 7 And 28 Days [32].

1.11.3.2. LIGHTWEIGHT MORTAR MADE WITH WOODEN WASTE:

Wood production industries have a large amount of waste, wood dust are very fine particles, in the past wood ash has been used as a cement substitute (Figure 1.16). Wood waste mortar has good thermal and insulating properties wood waste helps reduce mortar's compressive and tensile strength [33].

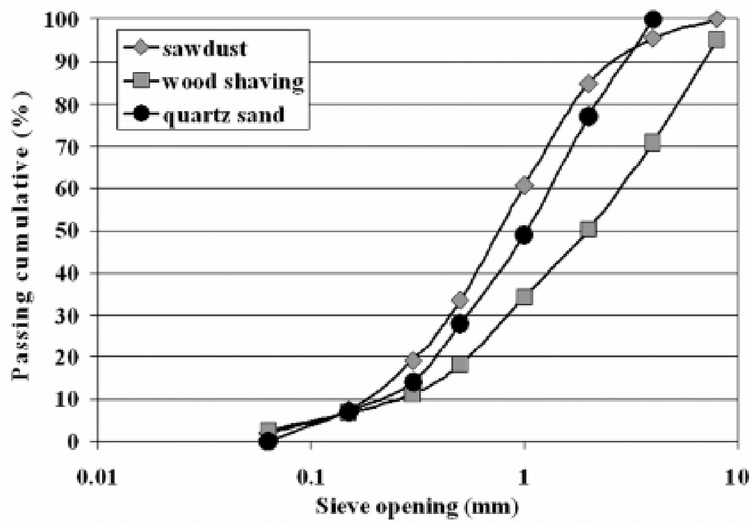

Figure I. 17: Grain Size Distributions Curves Of Sand And Wooden Waste [33].

I.11.3.3. LIGHTWEIGHT MORTAR MADE WITH DOOM PALM FIBER:

Date palm waste is a good product for the development of insulating materials the tensile and compressive and bending strength of doom palm fiber mortar decreased when the fiber content exceeded 0.5% concerning the density it decreased to 39% [34]. Tables 1.10 and 1.11 summarize the physical and mechanical properties respectively of date palm mortar.

Table I. 11: Geometrical Sizes And Physical Properties Of Doom Fibers [35]

Property	Min	Max
Diameter (mm)	0.1	0.8
Apparent density (kg/m^3)	512	1089
Specific density (kg/m^3)	1300	1450
Natural moisture content (%)	9.5	10.5
Water absorption saturation (%)	97	203

Table I. 12: Mechanical Properties Of Dom Fibers [36]

Property	Length (mm)		
	100	60	20
Tensile strength (MPa)	170 40	240 30	290 20
Enalgation (%)	16 3	12 2	11 2
Elastic modulus (GPa)	4.74 2	5 2	5.25 2

I.11.3.4. LIGHTWEIGHT MORTAR MADE WITH PERLITE:

Lightweight mortar with expanded perlite has a high covering capacity and also maneuverability concerning absorption perlite need more water perlite modifies the mechanical characteristics of the mortar by reducing its bending and compression (Figure 1.17) [37] [38] [39].

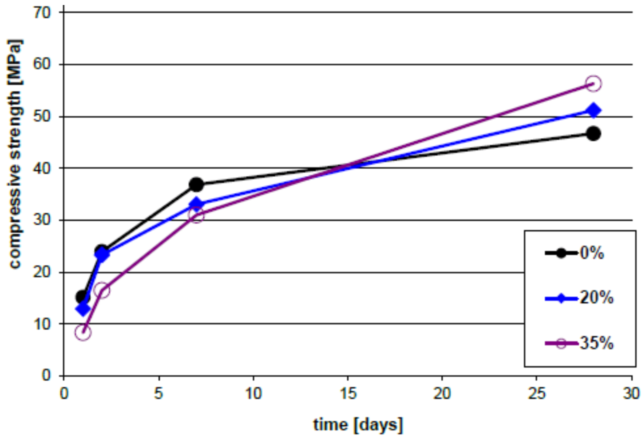

Figure I. 18: Effect Of Replacing Cement With Perlite Waste On The Development Of Resistance To Mortar Compression (Kotwica Et Al. 2016).

I.12.PROPERTIES OF LIGHTWEIGHT MORTARS:

I.12.1. Density:

The first consequence of using lightweight aggregates is 20% to 30% reduction in the density of the mortar. For comparison, the density of an expanded clay mortar is around 1600 kg/m³. For mortars with 10% silica fume, the complete replacement of natural sand by light sand decreases the density of the dry mortar by about 160 kg/m³ expanded shale, 230 kg/m³ pumice and 220 kg/m³ expanded clay [40].

I.12.2. Workability:

Slump value is a function of the self-weight of the mortar mass. This indicates that even though mortar having same slump, but by using LWA it may exhibit higher workability than the normal density aggregate mortar.

I.12.3. Adhesion:

Over the years a growing number of problems have been observed related to adhesion failure between mortar coatings and concrete bases. This problem has been aggravated by the use of concrete with increasingly high levels of resistance. Therefore the adhesive property must be considered in at least 3 stages including fresh, plastic and hardened state. Adhesive properties of fresh mortars pastes are considered in two points of view. Firstly, it must fulfill the requirement during the application process, including pumping, casting, smoothing etc... The adhesion strength must sufficient to stay on the support but it must also be limited in order to avoid excessive sticking to the working tool, or in order to avoid blockages during the pumping process.

I.12.4. Rheology:

It concerns the relationships between shear stress, shear strain and time, it deforms when exerted to a force, results in the change of the shape and dimensions of the material. A mortar made with aggregates with rough, angular and elongated particles requires more water than a mortar made with smooth, rounded and compact aggregate. From the point of view of rheology in the fresh state, the angular particles therefore require more cement to maintain the same W/L ratio. Likewise, mortars made with angular aggregates have a very discontinuous particle size and can be difficult to pump On the other hand, the paste /aggregates adhesion is often better in the case of rough and angular particles compared to smooth and rounded particles it is therefore important to take these aspects into account when selecting aggregates for a mortar [43] [44].

I.12.5. freeze/thaw behavior:

The freezing of water in mortar causes the ice to occupy more volume, which can cause cracking due to expansion pressure. The thawing of the ice allows more water to enter, which will cause further damage in the following time freeze period. The performance of lightweight mortar under freeze/thaw conditions depends mainly on the mix proportions, the type of aggregate, its moisture content and the level of air entrainment. For most types of aggregates, whether in the case of presoaking or air-dry condition, laboratory tests showed that non air entrained lightweight mortar is more durable in the conditions of freezing/thawing compared to non-air entrained normal weight mortar (particularly when natural fines are used). For air entrained mortar made with presoaked aggregates the performance of lightweight aggregates mortar is not significantly different from that of normal weight mortar, while air entrained mortar made with lightweight aggregate in the air-dry condition shows a significant improvement over similar normal weight mortar [45] [46].

I.12.6. permeability:

Porosity and permeability are not synonymous since size of pores and their continuity must be taken into consideration. Since porous lightweight aggregates are surrounded by a matrix which is less cracked, lightweight aggregate mortar is not necessarily more permeable than normal weight mortar owing to excellent aggregate matrix bond and increased hydration effects. Researchers have confirmed this behavior in measuring lower water permeability's and chloride for air cured lightweight aggregate mortar with normal weight mortar and much lower gas permeability's (Table 1.12) [47] [48].

Table I. 13: The Difference In Water And Oxygen Permeability Between Different Types Of Expanded Clay And Normal Weight Aggregate [48]

	Water permeability (/$10^{-12}m^2$)	Oxygen permeability (/$10^{-12}m^2$)
Leca	5	0.5
Lytog	5	0.4
Liapor	15	0.4
Granite	85	1.0

I.12.7. Carbonation:

Carbonation is the reaction between carbon dioxide in the atmosphere, moisture and the minerals present in the cement paste. This reaction reduces the alkalinity of the mortar and can lead to shrinkage, but more importantly, if it reaches any embedded metal such as reinforcement, it can promote the process of corrosion. Most lightweight aggregates are more porous and permeable than normal weight particles and this allows greater diffusion of gases such as carbon dioxide. The carbonation depth decreases with the increase of cement content and the use of dense fine particles [48].

I.12.8. Water absorption:

Expanded clay shows a higher water absorption compared to ordinary aggregate, and this is related to the porous structure of its grains. This results in lightweight aggregates mortar having higher absorptions than typical normal weight mortar on a mass basis, however as long as the aggregate particles in the lightweight aggregate mortar are surrounded by a high quality matrix, the difference is not as large as expected (Table 1.13) [48].

Table I. 14: Physical Properties Of Leca [48]

Reference study	Bulk density	Specific gravity	Saturated and surface dried particle density kg/m^3	Apparent particle density kg/m^3	Absorption
Rumsys; et al (217)	488	-	1002	804	25
Ardakani; A M.yazdani	257	0.481	-	-	26
Wu etal (2016)	663	-	-	1174	10
Siamak boudaghpour (2008)	400	-	-	-	17

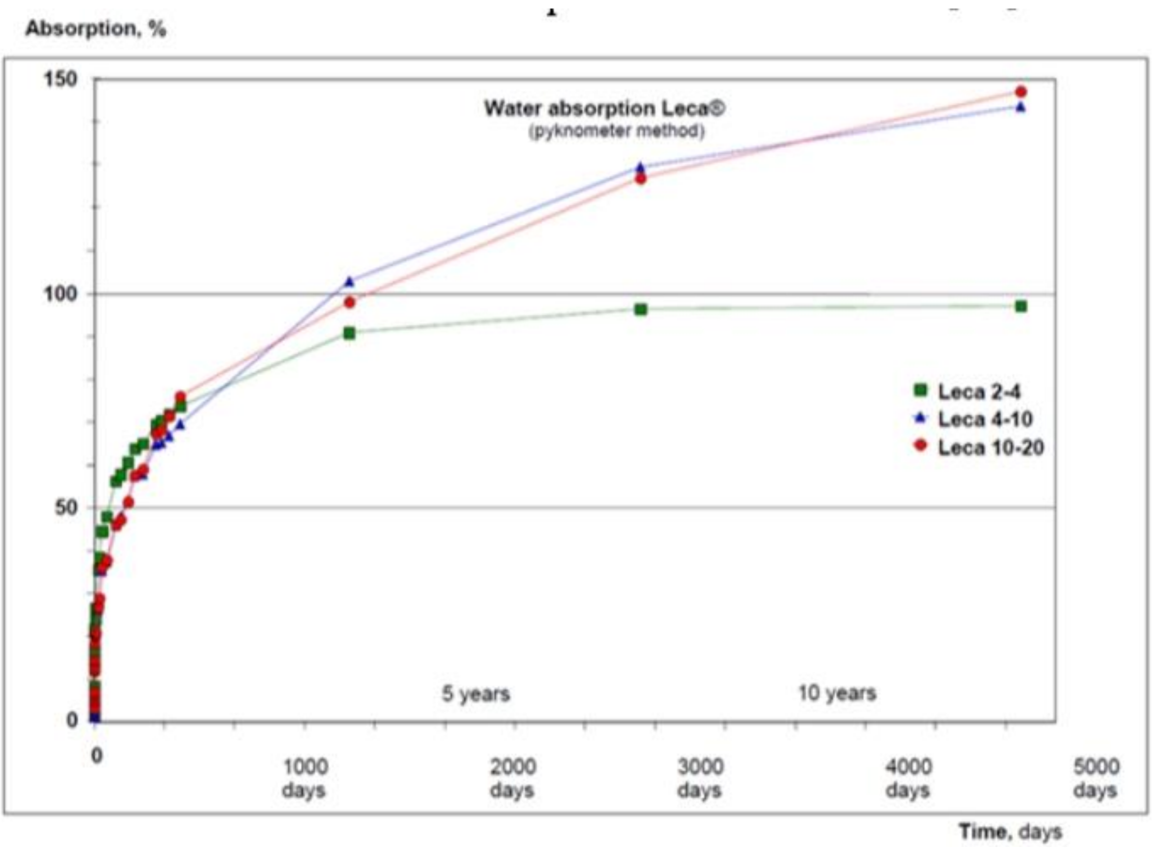

Figure I. 19: Water Absorption Of Different Fraction Of Expanded Clay

I.12.9. Abrasion resistance:

The resistance to abrasion of lightweight aggregate mortar increases with compressive strength, but when aggregate particles are exposed as a result of the abrasion of the matrix of lightweight aggregate mortar it deteriorates relatively quickly. However, the resistance can be improved by using surface treatments and combining the relatively fine and coarse particles [48].

I.12.10. Modulus of elasticity:

For any mortar its stiffness depends on the stiffness of the various constituents and their relative volumetric proportions in the mix. Lower stiffness of lightweight aggregate particles and higher cement contents result in larger deformations however, these effects are alleviated by lower density. Since the moduli of lightweight aggregate particles are generally lower than those of natural dense aggregates and the fact that most lightweight aggregate mortars contain higher cement contents it follows that the overall moduli of lightweight aggregate mortars will be lower than normal weight mortars. The lower E_value for lightweight mortars will give rise to increased deformations for structural elements under a given load although the effect will be reduced by lower dead loads of lightweight mortars elements themselves, however under dynamic conditions, such as impact or load fluctuation reduced stiffness can be beneficial. It should be noted that although the E_value is not directly related to strength and density, a useful empirical relationship which provides an approximate E_value For most purposes is:

$$E=D^2\sqrt{fcu} * 10^{-6}\ kn/mm^2 \qquad \text{(Eq. 1. 6)}$$

Where

D: is nominal density.

Fcu: cube strength

Generally, young's modulus of lightweight mortar is considered to be equal to ⅓ to ¾ of that of traditional mortar of the same strength.

I.12.11. Creep:

Generally lightweight aggregates mortar produces higher creep strain than ordinary mortar due to the lower E_value of the aggregates and the higher proportion of matrix. However, in larger structures, creep is rarely as large as expected in laboratory tests due to the differences in exposure conditions, processing reinforcement, restraint, stress level, size, shape, etc .

I.12.12. Shrinkage:

Shrinkage is generally greater for lightweight mortar than for natural weight mortar. However, laboratory data on shrinkage are pessimistic and not relevant to large-scale cases. When creep and shrinkage occur simultaneously shrinkage cracking is rare in lightweight mortar due to reduced restraint by creep, continuous water supply from total pores and better tensile capacity [49] [50].

I.12.13. Compressive strength:

With lightweight aggregates and a suitable mortar formulation, it is possible to obtain compressive strength comparable to those obtained with traditional mortar. The factors influencing strength include:

- strength and stiffness of aggregate particles: weaker particles require higher cement contents;
- water/cement ratio: this has the same effect on strength as ordinary mortar. However, the effective water/cement ratio is reduced due to water absorption.
- cement content: the strength increases as the cement increases. The cement content is on average 10% higher for lightweight aggregate than ordinary aggregates and hence it will give approximately 5% higher strength.
- age: similar strength age relationships as for traditional weight mortar. If mortar dries than hydration will cease but the situation is better for lightweight aggregate mortar than for normal weight mortar owing to the reserve of water available in aggregate pores. Thus lightweight aggregate mortar is more tolerant of poor curing than normal weight mortar.
- Density: Aggregates of different density will result in different mortar strength as well as densities.

The substitution of cement by silica fume from 0 to 5, 10, and 15% makes it possible to gradually improve the compressive strength, that at 7 days increases respectively from 35 to 40, 45, and 49 MPa, that at 28 days increases from 50 to 53, 58, and 61 MPa [51].

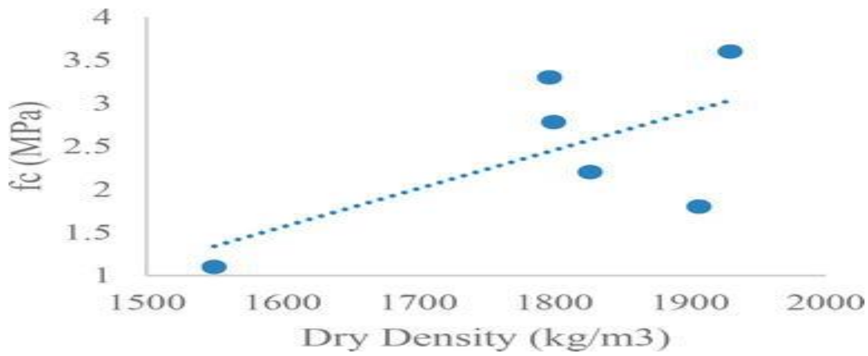

Figure I. 20: The Relationship Between Dry Density And Compressive Strength

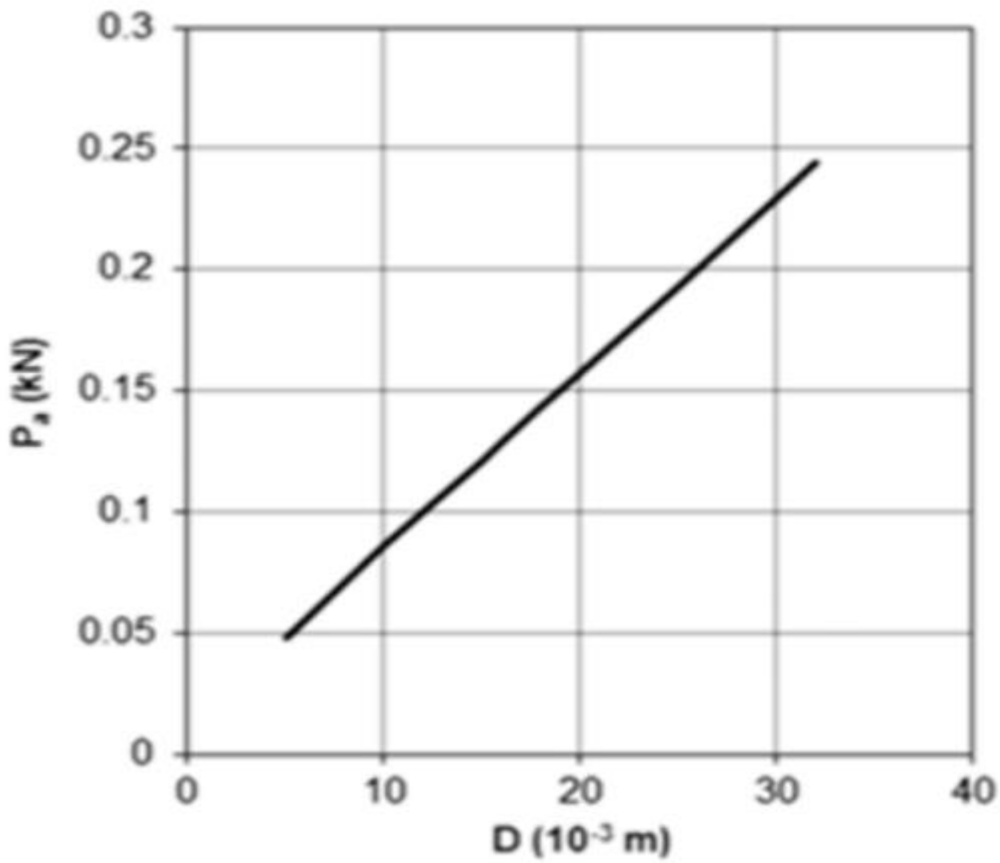

Figure I. 21: The Relationship Between Crushing Load And Particle Diameter

I.12.14. Tensile strength:

Like conventional mortars lightweight mortars have low tensile strength, since crack propagation can occur through aggregates. The factors influencing compressive strength also influence tensile strength. The principal differences between lightweight aggregate mortar and normal weight mortar are due to:

- fracture path: this travels through, rather than around, lightweight aggregate particles;

- total water content: is higher for lightweight aggregate mortar due to the absorption of lightweight aggregate. Thus, in drying situations greater moisture gradients can cause a significant reduction in tensile strength although this effect is somewhat alleviated by the effects of increased hydration;
- Tensile strengths by splitting of 3.3 to 4.2 MPa for mortars with a density of 1940 kg/m³, and from 3.5 to 5.6 MPa for densities of 1620 to 1885 kg/m³ [52].

In the case of mortar of lightweight mortar, the tensile strength must be corrected by a correction factor depending on the density according to the following equation:

$$ni = 0.4 + 0.6\left(\frac{p}{2200}\right) \qquad \text{(Eq. 1.7)}$$

ni=factor correction for tensile strength

p=density after oven drying of concrete kg/m

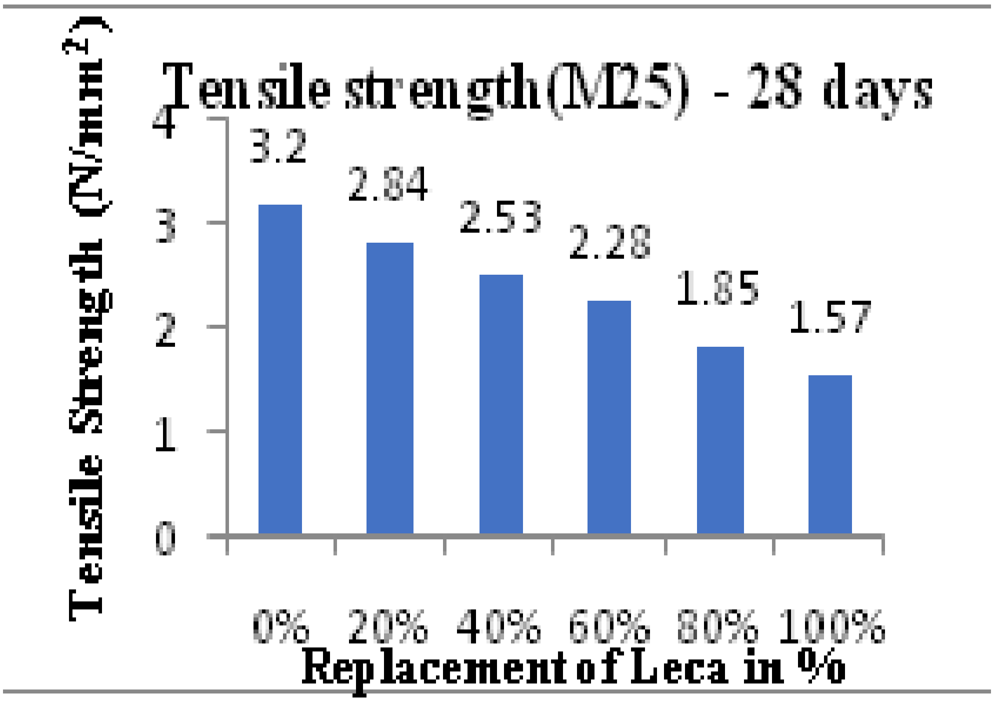

Figure I. 22: The Effect Of Expanded Clay Proportions On The Tensile Strength Of Concrete

I.12.15. Thermal expansion

The coefficients of expansion in lightweight mortars are lower than those of normal weight mortars; however, the range of coefficients for lightweight aggregate mortar is similar to that of natural weight mortar made from limestone aggregates.

I.12.16. Thermal conductivity

Thermal conductivity is an intrinsic quality of the material, which depends only on its constituents and its microstructure. The rate of heat transfer in lightweight aggregates is low compared to natural aggregates, due to its cellular structure. Lightweight aggregate mortars are characterized by lower specific heat and better insulation power than rigid aggregate mortars, thus during hardening and depending on the heat released by the hydration of the cement, light mortars can be subjected to a great increase in temperature than rigid aggregate mortars.

The thermal conductivity of the mortar is mainly related to the density of the mortar, the type of aggregate and the moisture content. The low density results in high thermal insulation of buildings and in some instances, the thickness of roofs and walls can be reduced where there is reduction in weight, a higher degree of thermal insulation will be achieved.

Another element making it possible to characterize the thermal properties of materials is specific heat C in (J/kg.K) this quantity characterized the quantity of heat necessary to rise the temperature of the unit of mass. The higher the specific heat, the more energy the material will need for its temperature to rise. It will therefore be less sensitive to temperature variations in the external environment. A high coefficient C reflects a high thermal inertia. It thus serves as a temperature regulator inside the structure [53]. Typical thermal properties of mortar made with expanded clay are given in table 1.14.

Table I. 15: Typical Properties Of Expanded Clay. [53]

	P (kg/m^3)	Porosity	C (J/kg.K)	λ (w m^{-1} k^{-1})
Mortar with expanded clay	1600	36%	900	0.46

I.12.17. FIRE RESISTANCE

Lightweight mortar is suitable for high fire rates better than normal weight mortar because it shows a slight decrease in strength at high temperature due to the inherent stability of lightweight aggregates, and provides more insulation due to their improved thermal conductivity. The thermal expansion of lightweight mortar is less, which leads to less spelling [30].

I.12.18. ACOUSTIC BEHAVIOR

Acoustic insulation aims to limit the transmission of these sounds through a material. This insulation is generally carried out by high density materials, because their inertia makes their movement more difficult by sound waves, and therefore they generate fewer waves transmitted by vibration. Thus to achieve the same insulation the thickness of lightweight mortar would need to be greater than normal weight mortar. However, as low permeability materials are good insulators, tests have shown that units made of lightweight mortar containing aggregates having a closely textured surface have better performance than expected by their mass. For example, the sound insulation of a 200 mm thick wall made with expanded clay aggregates was found to be the same (52 dB) as that for a wall made with normal weight aggregates of the same thickness [54].

I.13.LIGHTWEIGHT AGGREGATE SCREED

Roof screeding is non_structural concrete poured typically without any steel reinforcement. Roof screeding receives maximum exposure against temperature fluctuations, which often results in concrete cracks and access to rain water. The use of lightweight aggregates for screeding has many benefits such as durability reduction in weight, rot and moisture resistance, fire resistance, good heat and sound insulation and chemical and aggressive environments resistance [30].

-There are two main types of fluid screed: The former are fluid screeds formulated on a cement basis. Their main advantage is that they dry quickly and are excellent at punching stresses. The second are screeds formulated with anhydrite (binder powder based on calcium sulphate). They have the advantage of very low shrinkage, which makes it possible to produce large surfaces without joints. However, their characteristics require a longer drying time, ranging from 3 to 9 weeks depending on the site [30].

I.14.Conclusion:

In this chapter, we presented a summary of current knowledge on the various light aggregates and their chemical and mineralogical compositions, as well as the physical, thermal and mechanical properties of mortars and screeds based on lightweight aggregates. The literature review has shown that there are several types of lightweight aggregates. The Lightweight aggregate mortar and screed has advantages of low weight and low thermal conductivity. The results obtained demonstrate the achievement of values of elastic modulus lower by almost a third for light mortar mixtures by compared to the usual mortar mixtures. The low density and porosity of lightweight aggregate does not affect its permeability to water, gas and lightweight mortar and screed is durable if its composition is optimized.

CHAPTER II: MATERIALS USED AND TESTS

II.1. INTRODUCTION

This experimental study is based on the effects of expanded clay aggregates on the properties of mortar and fluid screed. The screeds were formulated using the excess paste method, as for the mortars we used a calculation program. The characterization of the materials is given first and then the tests carried out on mortar and screed in the fresh and hardened state are presented. Physical, chemical and mechanical tests were carried out at “ALGEXPAN” laboratory located in Bouainane (Blida) and at the construction development laboratory “Lafarge Rouiba”. The work is divided into three parts:

- Characterization of the materials used.
- Mortar and screeds compositions.
- Characterization of fresh and hardened state of mortars and screeds.

II.2.1. SOURCE OF LIGHTWEIGHT AGGREGATES

The lightweight aggregates were obtained from the ALGEXPAN factory. It is the only factory in Algeria and Africa to produce lightweight aggregates manufactured from expanded clay 100% Algerian, Blida province (Figure II.1). The factory is located on the heights and has a deposit of clay, the aggregates products present a harmony between resistance and lightness, and the aggregates are obtained by transformation of clay into porous and resistant stones using heat treatment without additives. The extraction of 1 m³ of raw material contributes to the production of 2 to 3 m³ of materials, their daily production amounts to 600 m³.

Figure II. 1: The Algexpan Factory

II.3.1. CEMENT:

The cement used in this study is from M’sila Lafarge cement plant. It is a Portland cement composed of CEM II/ B 42.5 N according to the standard NA 442. The physical and mechanical properties and chemical and mineralogical composition of the cement used are given n tables 1.1 to 1.4 respectively.

Table II. 1: physical characteristics of lafarge cement CPJ CEMII/B42.5.

characteristics	Normal consistency	Start of setting (mn)	End of setting (mn)	Specific mass (cm^2/g)	Fineness following the blain method (cm^2/g)	Specific surface(SSB) (cm^2/g)	Expansion 0.3-2.5 (Mn)	ρ abs (g/cm^3)	Shrinkage (µm/m)
CEMII/B	**25-28.50**	**140-195**	**195-290**	**3.10**	**3750-5250**	**3500**	**0.3-2.5**	3.05	**<1000**

Table II. 2: Mechanical characteristics of lafarge cement CPJ CEMII/B42.5.

Cement	Strength (MPa)	Age (days)	
		7J	**28J**
CPJ42.5N	Compressive	**≥10.0**	**42.4**
	Flexural	**7.5**	**9.1**

Table II. 3: Chemical composition of lafarge cements CPJ CEMII/B42.5.

CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Na_2O_3 (%)	K_2O (%)	SO_3 (%)	MgO (%)	CaO (%)	PAF (%)	Insoluble (%)
62.78	18.88	4.65	3.2	0.10	0.64	2.41	2.42	0.94	4.60	1.29

Table II. 4: Mineralogical composition of Lafarge cements CPJ CEMII/B42.5

C_3S (%)	C_2S (%)	C_3A (%)	C_4AF (%)	CaO (%)
55	21	8	10	01

Density of the cement was used by measuring the displacement of level of an inert liquid with regarded to the cement contained in a container when a given mass of cement is introduced therein by using the volumeter (chatelier) and the pycnometer methods.

We first weight the empty 50 ml pycnometer, then we weight the pycnometer filled with toluene, the desired quantity of cement (25g) is then introduced into the empty pycnometer, then we fill it with toluene until it overflows, finally we weight our pycnometer.

- The density of toluene:

$$\rho\, t = \frac{m3-m1}{V} \quad \text{(Eq. 2.1)}$$

- The mass m_t of toluene replaced by the mass m_4 of binder is:

$$M\, t = m3-(m5-m4) \quad \text{(Eq. 2.2)}$$

- The volume of binder replacing the liquid is:

$$Vc = mt/\rho t \quad \text{(Eq. 2.3)}$$

- And the volume mass of the binder will be:

$$\rho c = m4/Vc \quad \text{(Eq. 2.4)}$$

With:

m1: mass of empty pycnometer;

m3: mass of the pycnometer filled with toluene;

m4: mass of cement 25g;

m5: mass of the pycnometer containing a mass m4 of cement and supplemented with toluene;
V: the volume of the pycnometer 50 ml

II.3.2. MIXING WATER:

We used drinking water from the city of Rouiba in the preparation of our mortar and screed.

II.3.3. ADMIXTURES:

A superplasticizer type SIK A viscocrete tempo 12 was used for mortar.

When used in a premixed mortar, it gives it excellent isotropy and wet adhesion to all substrates traditional, up to thicknesses of 2cm per layer, reducing waste. In addition, it retains the initial workability for 45 minutes.

For screeds, a Pentagel I 100/NM and Pentagel RS 619 were used. It gives an excellent thixotropy and wet adhesion to all substrates traditional, up to thicknesses of 2 cm per layer, reducing waste. In addition, it retains the initial workability for 45 minutes.

a. Pentagel RS 619:

Pentagel RS 619 is the ideal additive to give cement based on gypsum based smooth finish mixtures the features necessary to make the laying on easier. It improve the water retention in the mixture and the facility of application even in this coats allowing an easy finishing the superposition of more coats without risking removing the previous ones or causing the irritating crimping behind the spatula. It allows application by machine as well, so reducing all operational times, it promotes the adhesion of the finish mixture to all traditional supports and after hardening it allows the application of all types of surface treatment.

II.3.4. SAND:

Sand is the constituent of the granular skeleton that has the greatest impact on mortar and screed. It plays an essential role in reducing volume variations, the heat released and concrete cost. It must be clean and do not contain harmful elements. We used four types of sand:

- Boughezoul sand: of particle size class 0/3 mm
- Correction sand (Boussaada): of particle size class 0/1 mm
- Expanded clay sand: Particle size class 0/3 mm (nodular)
- Expanded clay sand: Particle size class 0/3 mm (crushed)

II.3.4.1. SAND EQUIVALENT: (THE STANDARD NF P 18-598):

To assess the cleanliness of the sands used, the sand equivalent test was performed (Figure II.2). The test was carried out on the fractions (0/1, and 0 / 3mm) of the material to be studied. The sieving is done by wet process in order not to lose fine elements. The sample is washed, according to a standard process, and let it rest. After 20 minutes, Height h1: (clean sand + fine element), and Height h2 (clean sand only) are measured. We deduce the equivalent of sand which by convention is:

$$ES = H2/H1 * 100 \quad \text{(Eq. 2.5)}$$

The height h2 is measured visually or with the weighted foot assembly, we determine ESV (equivalent of visual sand) or ESP (equivalent of sand with the weighted foot assembly).

Table II. 5: The sand equivalent values indicate the nature and quality of the sand

Es(Visual)	Es(weighted foot assembly)	Nature and quality of sand
Es<65%	**Es<60%**	Clayey sand: risk of withdrawal or swelling to reject for quality concretes.
65%<Es<75%	**60%<Es<70%**	Slightly clay sand: of cleanliness permissible for quality concrete it is not particularly feared removal.
75%<Es<85%	**70%<Es<80%**	Clean sand has a small percentage of fine clays perfectly suitable for high quality concrete.
Es≥85%	**Es≥80%**	Very clean sand: almost total absence of fine.

Figure II. 2: Test Equipment "Sand Equivalent

II.3.4.2.THE REAL DENSITY (EN NF 1097 _ 6):

The real density ρa which is the mass per unit volume of the material that constitutes the aggregate, without taking into account the voids that may exist in or between the grains. The real density was measured according to standard EN NF 1097-6, part 1 which defines the real density of light aggregates with the exception of the 0/3 mm fraction which is defined in part 2 as for ordinary aggregates. Figures (II.3 to II.5) show the test method.

Figure II. 3: An Oven

The real density of the sand used in this work was carried out according to the following:

- Weigh the mass of saturated and superficially dry aggregates in air M1.
- Weigh the mass of the pycnometer containing the M2 saturated aggregates.
- Weigh the mass of a pycnometer filled with water only M3.
- Weigh the mass of the oven-dried test sample M4.

Figure II. 4: Real Density Test

Figure II. 5: Sand Pycnometer (0/3)

Figure II. 6: A Pycnometer

- The real density (part 1):

$$\rho_{abs} = \rho_w * \frac{Mu}{M4-(M2-M3)} \qquad \text{(Eq. 2.6)}$$

- The real density after oven drying:

$$\rho_{réal} : \rho_w * \frac{M4}{M4-(M2-M3)} \qquad \text{(Eq. 2.7)}$$

- The water absorption coefficient:

$$W_{A24} = \frac{100*(M1-M4)}{M4} \qquad \text{(Eq. 2.8)}$$

- The saturation density:

$$\rho_{ssd} = \frac{M1}{M1-(M2-M3)} * 1000 \qquad \text{(Eq. 2.9)}$$

-with:

ρ_w: density of water;

M_2: the mass of the pycnometer + water + sand;

M3: the mass of the pycnometer filled with water;
M4: the mass of the pycnometer filled with water

The real density for fraction (0/3 mm):

- The real density after oven drying:

$$\rho_{abs}=\frac{(M2-M1)*\rho w}{Mp+(Vp*\rho w)+Mw-Mf} \quad \text{(Eq. 2.10)}$$

- **Water absorption coefficient:**

$$W_f=\frac{Mw-(M2-M1)*100}{(M2-M1)} \quad \text{(Eq. 2.11)}$$

M1: density of empty pycnometer.
M2: density of pycnometer + dry aggregates.
Vp: volume of pycnometer.
ρw: density of water.
Mp: mass of the superficial sample.
Mw: surface dry mass of the sample.

The bulk density was measured according to NF EN 1097-3.

After sampling, a quantity of sample is poured into the cylinder adequate from a height of 1.5 cm; trim the excess with a ruler, place the cylinder delicately on a scale (to avoid all settling of aggregates). The mass of the cylinder was pre-calibrated. M is the mass of the sample and then the wet density is calculated. The test was carried out 3 times to obtain the average density. Finally, 1000g of each sample is weighed and passed in the oven to mass constant in order to be able to determine the water content and subsequently the density related. Figure II.6) shows the test underway.

Figure II. 7: Bulk Density Test

$$\rho(humid)=\frac{M}{V} \quad \text{(Eq. 2.12)}$$

With:

M: the mass of the sample (g).

V: the volume of the cylindrical container according to the fraction of aggregates.

$$\rho_{app} = \rho_{moy} - \frac{\rho moy * humidity}{100} \qquad \text{(Eq. 2.13)}$$

II.3.4.4. PARTICLE SIZE ANALYSIS (EN NF 933-1 AND EN NF 933-2) :

The particle size analysis was determined by using sieves with square mesh in order to obtain a representation of the distribution of the mass of the particles in the dry state depending on their size. The material studied is placed at the top of the sieves and the grain classifications are obtained by vibrating the sieve column (Figure II.7).

Figure II. 8: A Series Of Sieve

The test procedure is as follows:

- We first weigh empty sieves;
- Then we arrange them in an increasing way;
- After that we weigh a mass of 2000 g of each fraction, after putting the sieves in the sieve shaker, the mass of the sample is introduced into it;
- Lastly, we put the sieve shaker on for 20min for conventional aggregates and 10min for light aggregates;
- After sieving, we weigh our sieves with their refusal.
- Mf= Σ RC / 100

The fineness modulus was determined according to NF P18-540.

- For 1.8 <Mf <2.2: sand should be used if you are particularly looking for ease implementation to the likely detriment of resistance.
- For 2.2 <Mf <2.8: sand should be used if workability is desired. Satisfactory and good resistance with limited risks of segregation.
- For 2.8 <Mf 3.2: sand should be used if you are looking for high resistance to the detriment of workability and with risks of segregation.
- For Mf> 3.2: the sand must be rejected.

Methylene blue test (Figure II.8) was used to quantify the cleanliness of aggregates. The test consists of determining the quantity of clay particles present in the sample. For this, methylene blue is used, a substance preferably adsorbed by clays. The test consists of measuring the quantity of methylene blue fixed per 100 g of the granular fraction of soil analyzed. We call the blue value of the aggregate the number:

$$VB = V / Ms. \qquad \text{(Eq. 2.14)}$$

Where

V: is the volume of the methylene blue solution injected at the test portion.

M_S: is the dry mass of the sample

The test was performed according to the following:

- Sieve the sample to be studied through a 5 mm sieve.
- Take a mass of 120 gr and calculate the water content W of the test sample.
- Deduce the wet mass of the sample by: [Wet mass] = [Dry mass] x (1 + [Water content])
- Pour a sample of 30 g of dry soil into the beaker and add with distilled water up to the mark. Stir the mixture continuously using the paddle mixer.
- Add 5 cm^3 of methylene blue to the Beaker and take a drop of the mixture and place it on filter paper.
- If the central spot is surrounded by a turquoise blue halo, the test is positive. In this case the test is terminated, the clay particles are then saturated with methylene blue. The test is repeated identically, five times at one-minute intervals to confirm it.
- If the stain is surrounded by a colorless wet halo, the test is negative. In this case, methylene blue is added in portions of 5 cm^3 until the test is positive. The test is repeated identically, five times at one-minute intervals to confirm it.

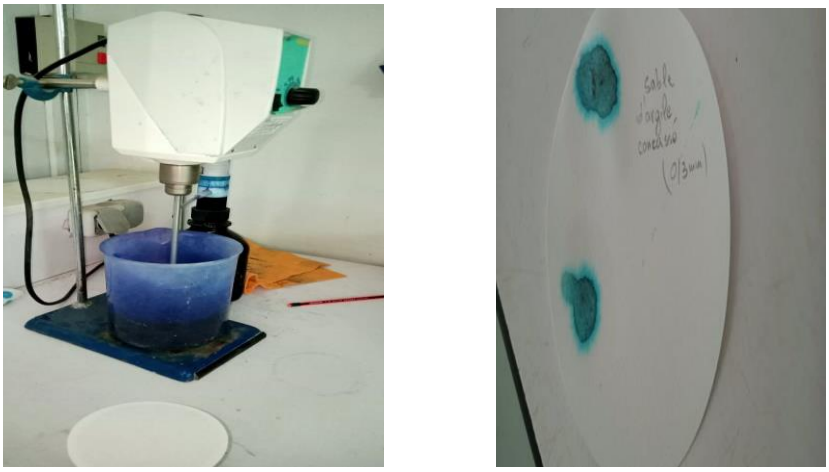

Figure II. 9: Methylene Blue Test

Calculate the blue ground value (VBS) by applying the following formula:

$$VBS = B/Ms * C*100 \quad \text{(Eq. 2.15)}$$

B: mass of blue introduced into the beaker (in gr)

Ms = dry mass of the test sample (in gr).

C: proportion of 0/5 mm subjected to the test in the 0/50 fraction of the dry material.

II.3.4.7. RESULTS ON THE SANDS USED:

The following tables represent the results of the various tests on the sands used. Table II.6 and figure II.9 present the grading test results and the grading curve of the sand 0/3. table II.7 summarizes the physical characteristics.

Table II. 6: Grading test of ordinary sand 0/3 (BOUGHEZOUL).

(BOUGHEZOUL) sand 0/3mm				
- The absolute density of the sample: 2.5g/cm^3 -The apparent density of the sample: 2.36g/cm^3 -The mass of the sample: M=1458g				
Opening sieves (mm)	Mass of refusal (g) Ri	Cumulative refusal mass (g) Rn	Percentage of cumulative refusals (Rn/M)*100	Percentage of cumulative sieves100-[(Rn/M)*100]
5	72	72	4.93	50.95
4	20	92	6.31	93.69
3.15	14	106	7.27	92.73
2	28	134	9.19	90.81
1.6	14	148	10.15	89.85
1	48	196	13.44	86.56
0.5	210	406	27.84	72.16
0.315	536	942	64.60	35.4
0.25	424	1148	81.20	18.8
0.125	246	1430	98.07	1.93
0.063	22	1452	99.58	0.42
Bottom	0	1452	99.58	0.24
MF : 2.29 (a preferred sand)				

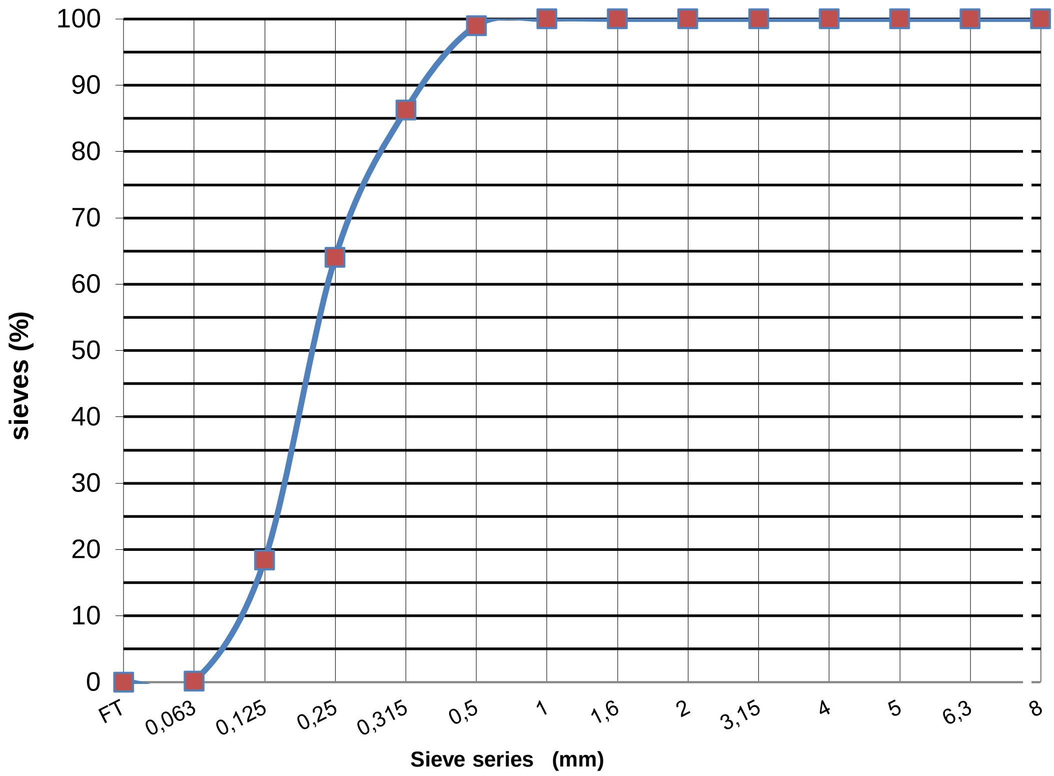

Figure II. 10: Grading Curve Of (Boughezoul) Sand 0/3

Table II. 7: Physical characteristics of ordinary (boughezoul) sand 0/3

physical characteristics	Results	Units
Bulk density	2360	Kg/m^3
absolute density	2500	Kg/m^3
Real density	2300	Kg/m^3
Water absorption coefficient	0.59	%
Methylene bleu value	1.92	
EPS weight foot assembly	46<60	%
Wet density	2290	Kg/m^3
Humidity	3	%

The particle size analysis of sand 0/1 is given in table II.8 and figure II.10 whereas the physical characteristics are given in table II.9.

Table II. 8: Grading test of ordinary sand 0/1(boussaada).

Opening sieves	Cumulative refusal mass (g)	Percentage of cumulative refusals (Rn/M)*100	Percentage of cumulative sieves100-[(Rn/M)*100]
8	0	0.00	100
6.3	0	0.00	100
5	0	0.00	100
4	0	0.00	100
3.15	0	0.00	100
2	0	0.00	100
1.6	0	0.00	100
1	2	0.17	99.82
0.5	11.8	1.05	98.95
0.315	80	7.14	92.86
0.25	185	16.51	83.48
0.125	957	85.45	14.55
0.063	1075	95.98	4.02
Bottom	1078	96.25	3.75

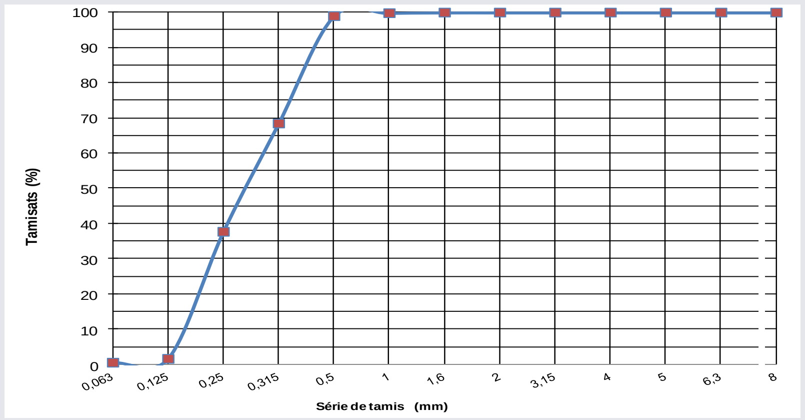

Figure II. 11: Grading Curve Of (Bousaada) Sand 0/1

Table II. 9: Physical characteristics of ordinary sand 0/1 (bousaada)

Physical characteristics	Results	Unit
Bulk density	2650	Kg/m^3
absolute density	2670	Kg/m^3
Real density	2650	Kg/m^3
EPS weight foat assembly	60<63.98<70	%
Water absorption coefficient	0.20	%
Methylene bleu value	2	
Wet density	_	
Humidity	0	%

Note: From the results we obtained, we notice that Boughezoul sand has a very high fines percentage, so it needs to be corrected; for this we used Boussaada sand.

The particle size of lightweight fine aggregates (0/3) type nodular are given in table II.10 and figure II.11 and the physical characteristics are given in Table 2.11.

Table II. 10: Grading test of expanded clay sand 0/3 (nodular)

Expanded clay sand 0/3 (NODULAR)				
- The absolute density of the sample : 1.94 g/cm^3; The apparent density of the sample :0.78 g/cm^3 - The mass of the sample :M=2000 g				
Opening sieves (mm)	Mass of refusal (g) Ri	Cumulative refusal mass (g) Rn	Percentage of cumulative refusals (Rn/M)*100	Percentage of cumulative sieves 100-[(Rn/M)*100]
5	4.84	4.84	0.24	99.76
4	2.82	7.66	0.38	99.62
3.15	4.65	12.31	0.61	99.39
2.5	15.62	27.93	1.39	98.61
1.6	657.98	685.91	34.29	65.71
1.25	371.11	1057.02	52.85	47.15
0.63	545.76	1602.78	80.13	19.87
0.315	226.19	1828.97	91.44	8.56
0.16	102.27	1931.16	96.55	3.72
0.08	34.52	1965.68	98.28	1.72
Bottom	27.07	1992.75	99.63	0.37
Mf :3.22(the sand is slightly coarse)				

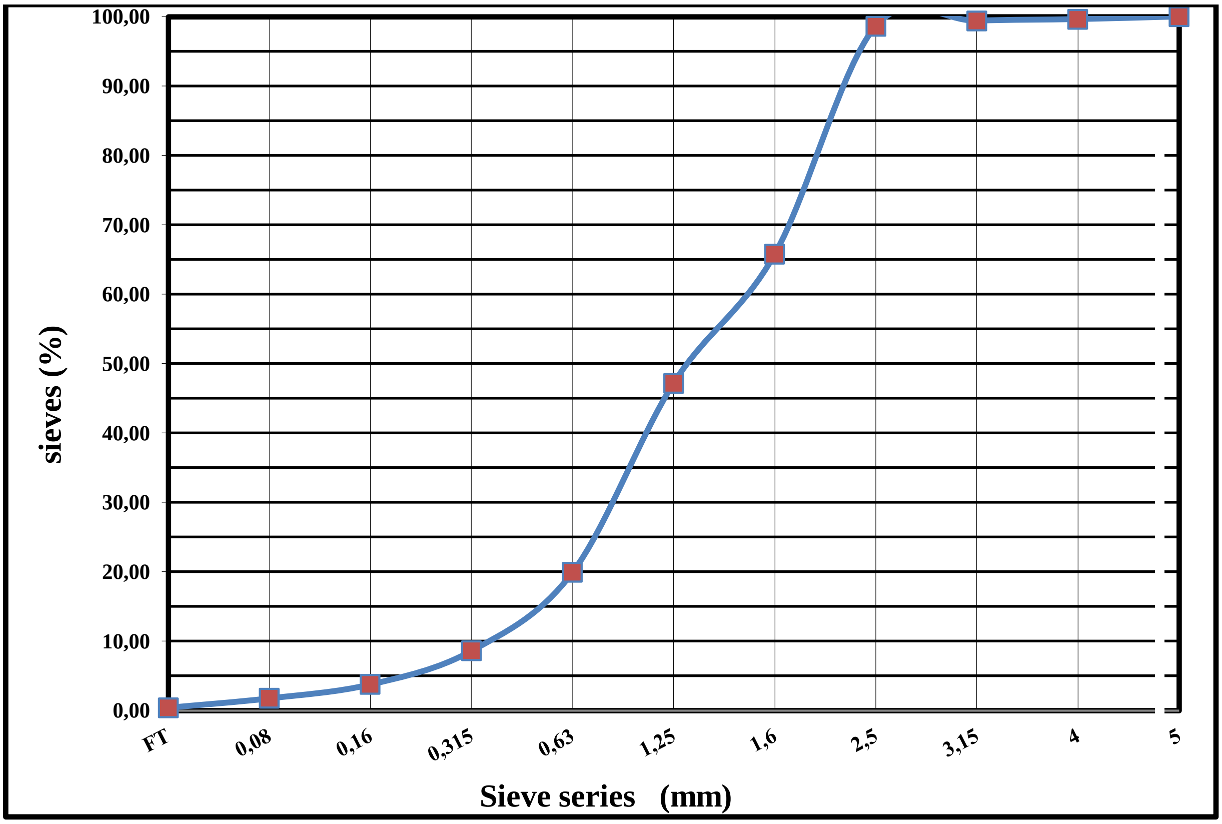

Figure II. 12: Grading Curve For Sand 0/3

Table II. 11: Physical characteristics of lightweight sand 0/3 (nodular)

Physical characteristics	Results	Units
Bulk density	787.00	Kg/m^3
Absolute density	1942.00	Kg/m^3
Real density	1762.00	Kg/m^3
Absorption coefficient	5.26	%
Methylene blue value	0.19	
EPS weight foot assembly	91.41>80	%
Wet density	874.93	Kg/m^3
Humidity	3.73	%

The characteristics of crushed sand (0/3) are given in tables II.12 and II.13 and figure II.12.

Table II. 12: Grading test of lightweight sand 0/3 (crushed).

Expanded clay sand 0/3 (CRUSHED)				
- The absolute density of the sample: 1.71g/cm^3, The apparent density of the sample:0.66g/cm^3 - The mass of the sample: M=2000g				
Opening sieves (mm)	Mass of refusal (g) Ri	Cumulative refusal mass (g) Rn	Percentage of cumulative refusals (Rn/M)*100	Percentage of cumulative sieves 100-[(Rn/M)*100]
5	3.63	3.63	0.18	99.82
4	2.5	6.13	0.30	99.7
3.15	7.55	13.68	0.68	99.32
2.5	51.46	65.14	3.25	96.75
1.6	418.95	484.09	24.20	75.8
1.25	237.55	721.64	36.08	63.92
0.63	460.07	1181.71	59.08	40.92
0.135	266.97	1448.68	72.40	27.6
0.16	174.43	1623.11	81.15	18.85
0.08	125.7	1748.81	87.44	12.56
bottom	241.08	1989.89	99.49	0.51
Mf : 2.52(we are in the presence of preferential sand)				

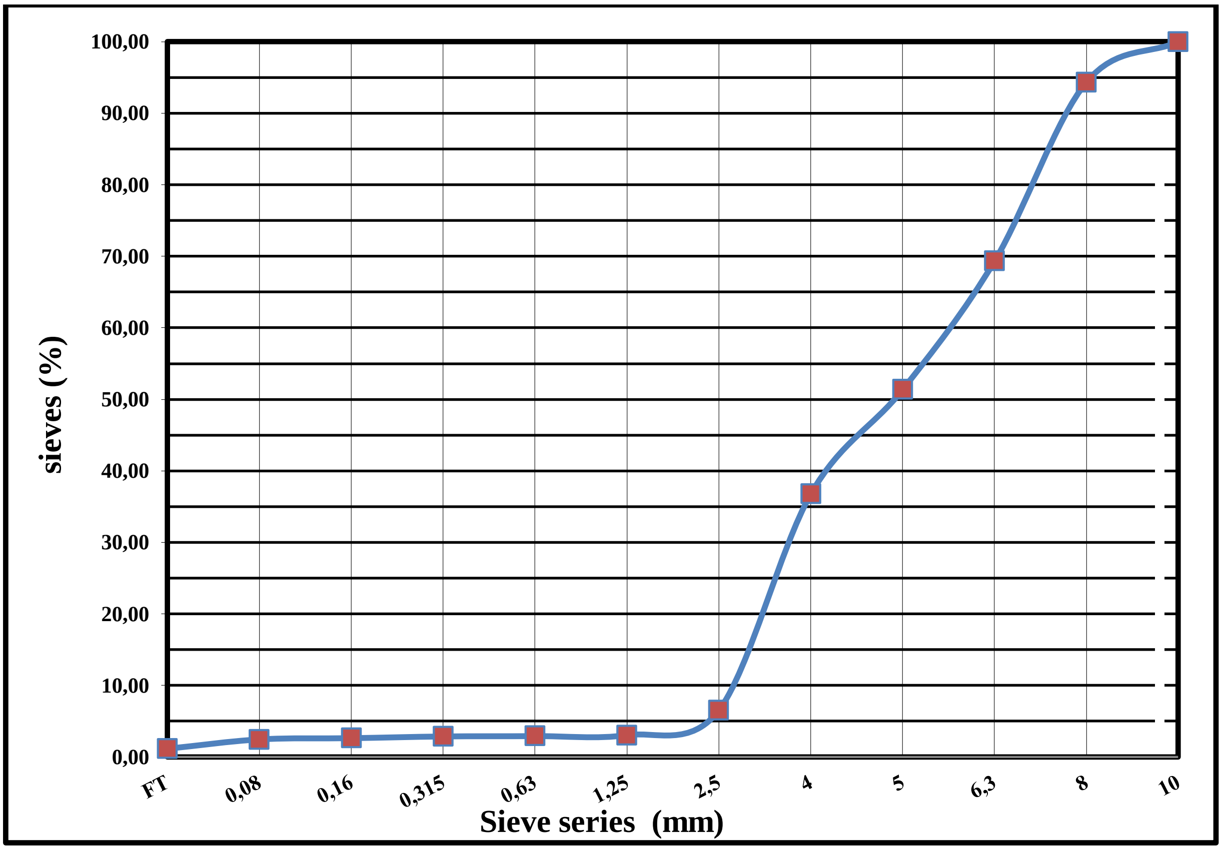

Figure II. 13: Grading Curve For Expanded Clay Sand 0/3 (Crushed)

Table II. 13: Physical characteristics of lightweight sand 0/3 (crushed).

Physical characteristics	Results	Units
Bulk density	669.00	Kg/m^3
Absolute density	1720	Kg/m^3
Real density	1548	Kg/m^3
Water absorption coefficient	7.23	%
Methylene blue value	0.19	
EPS weight foat assembly	93.93<80	%
Wet density	708.8	Kg/m^3
Humidity	5.48	%

II.3.5.1. ORDINARY AGGREGATES

We used one fraction (3/8) of gravel in our study. The fraction is crushed gravel of class (3/8) from the wilaya of Setif.

The grading test results are given in table II.14 and the grading curve is given in figure II.13. The physical characteristics are given in table II.15.

Table II. 14: Grading test of ordinary aggregate 3/8.

Ordinary aggregates 3/8mm				
- The absolute density of the sample:2.57g/cm^3; The apparent density of the sample: 2.83g/cm^3. - The mass of the sample:M=2000g				
Opening sieves (mm)	Mass of refusal (g) Ri	Cumulative refusal mass (g) Rn	Percentage of cumulative refusals (Rn/M)*100	Percentage of cumulative sieves 100-[(Rn/M)*100)
10	0.4	0.4	0.02	99.98
8	2.31	2.71	0.13	99.87
6.3	399.05	401.76	20.08	79.92
5	681.39	1083.15	54.15	45.85
4	491.97	1575.12	78.75	21.25
2.5	397.18	1972.3	98.61	1.39
1.25	10.16	1982.46	99.12	0.88
0.63	2.27	1984.73	99.23	0.77
0.315	1.94	1986.67	99.33	0.67
0.16	1.96	1988.63	99.43	0.57
0.08	1.88	1990.51	99.52	0.48
Bottom	3.9	1994.41	99.72	0.28

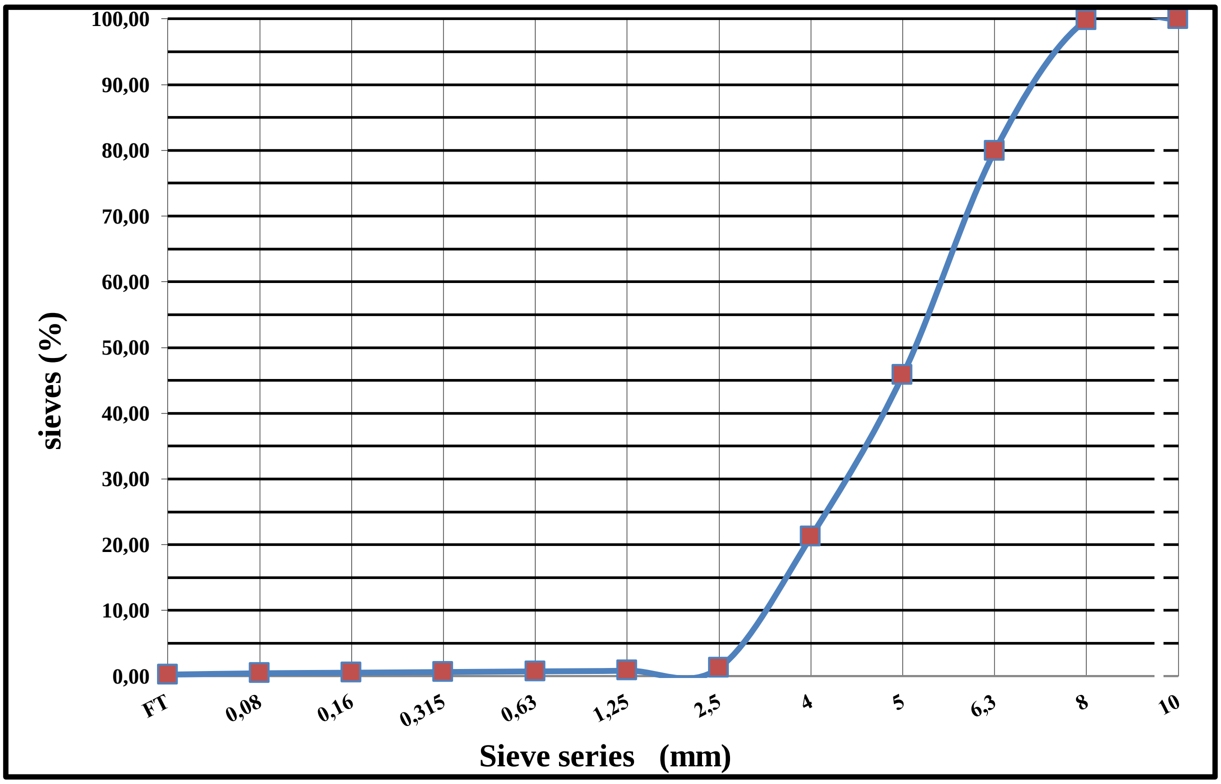

Figure II. 14: Grading Curve Of Ordinary Aggregate 3/8

Table II. 15: Physical characteristics of ordinary aggregate 3/8

Physical characteristics	Results	Units
Bulk density	2830	Kg/m^3
absolute density	2570	Kg/m^3
Water absorption coefficient	0.19	%
Humidity	0	%

II.3.5.2. LIGHTWEIGHT AGGREGATES

We used two fractions of the expanded clay in our study. The first fraction: is class (3/8) nodular gravel. The second fraction: is a crushed lightweight gravel of class (3/8)

Table II. 16: Grading test of expanded clay aggregates 3/8 (nodular).

Expanded clay aggregates 3/8mm (NODULAR)				
- The absolute density of the sample : 1.20g/ cm^3, The apparent density of the sample :0.70g/cm^3, The mass of the sample :M=1605g				
Opening sieves (mm)	Mass of refusal (g) Ri	Cumulative refusal mass (g) Rn	Percentage of cumulative refusal (Rn/M)*100	Percentage of cumulative sieves 100-[(Rn/M)*100]
10	33.21	33.21	2.06	97.94
8	233.49	266.7	16.61	83.39
6.3	526.27	792.96	49.40	50.6
5	326.27	1119.23	69.73	30.27
4	156.88	1276.11	79.50	20.5
2.5	259.56	1535.67	95.68	4.32
1.25	20.47	1556.14	96.95	3.05
0.63	29.05	1585.19	98.76	1.24
0.315	8.71	1593.9	99.30	0.7
0.16	4.24	1598.14	99.57	0.43
0.08	1.94	1600.08	99.69	0.31
Bottom	2.94	1603.02	99.87	0.13

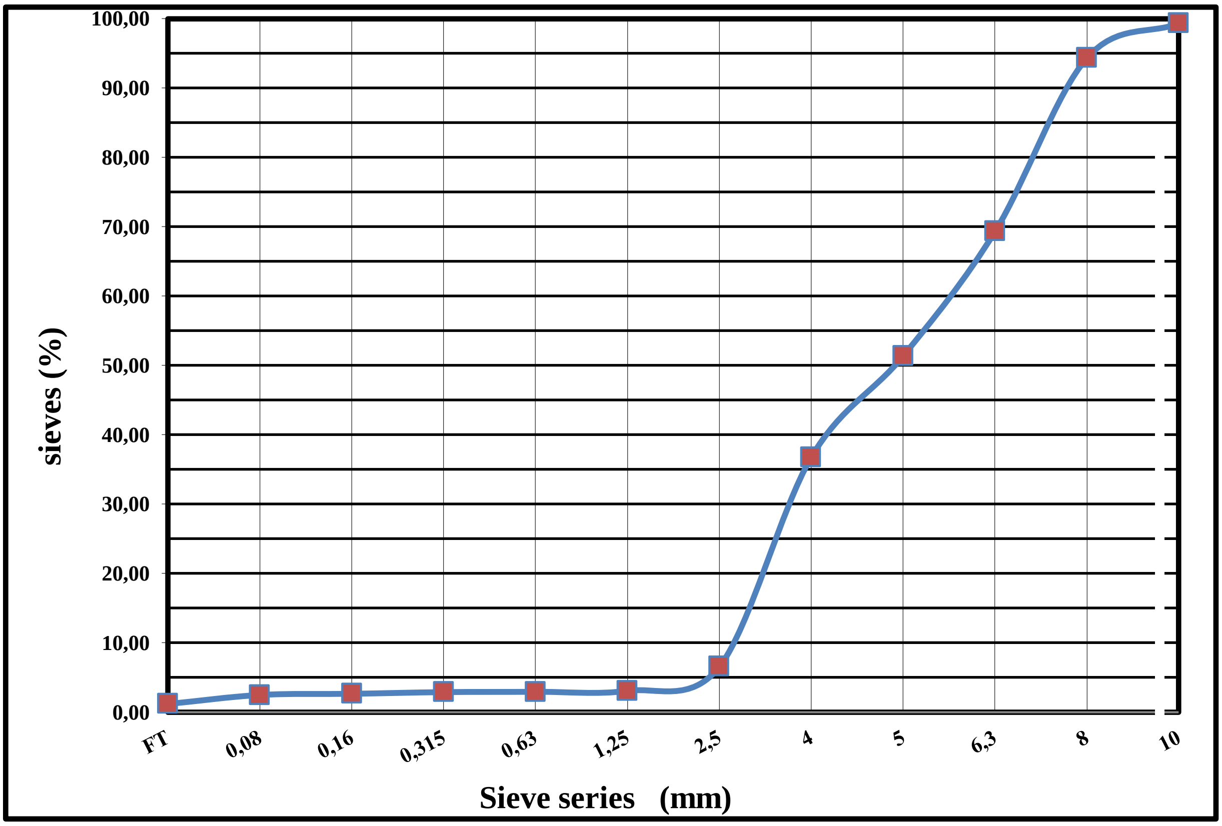

Figure II. 15: Grading Curve Of Expanded Clay Aggregate 3/8 (Nodular)

Table II. 17: Physical characteristics of expanded clay aggregate 3/8 (nodular).

Physical characteristics	Results	Units
Bulk density	701.00	Kg/m^3
absolute density	1209.00	Kg/m^3
Water absorption coefficient	8.12	%
Humidity	10	%

The characteristics of the 3/8 fraction of lightweight aggregates are given in tables 2.18 and 2.19 and figure 2.15.

Table II. 18: grading test of expanded clay aggregates 3/8 (crushed).

Expanded clay aggregate 3/8 (CRUSHED)				
- The absolute density of the sample**: 1.20g/ cm^3,** The apparent density of the sample**: 0.57g/ cm^3,** The mass of the sample**: M=2000g**				
Opening sieves (mm)	Mass of refusal (g) Ri	Cumulative refusal mass (g) Rn	Percentage of cumulative refusals (Rn/M)*100	Percentage of cumulative sieves100-[(Rn/M)*100]
10	1.31	1.31	0.65	99.35
8	111.39	112.7	5.63	94.37
6.3	500.23	612.93	30.64	69.36
5	359.14	972.07	48.60	51.4
4	291.93	1264	63.2	36.8
2.5	604.42	1868.42	93.42	6.58
1.25	69.82	1938.24	96.91	3.09
0.63	2.95	1941.19	97.05	2.95
0.315	0.95	1942.14	97.10	2.9
0.16	4.8	1946.94	97.34	2.66
0.08	3.42	1950.336	97.51	2.49
Bottom	25.86	1976.22	98.81	1.19

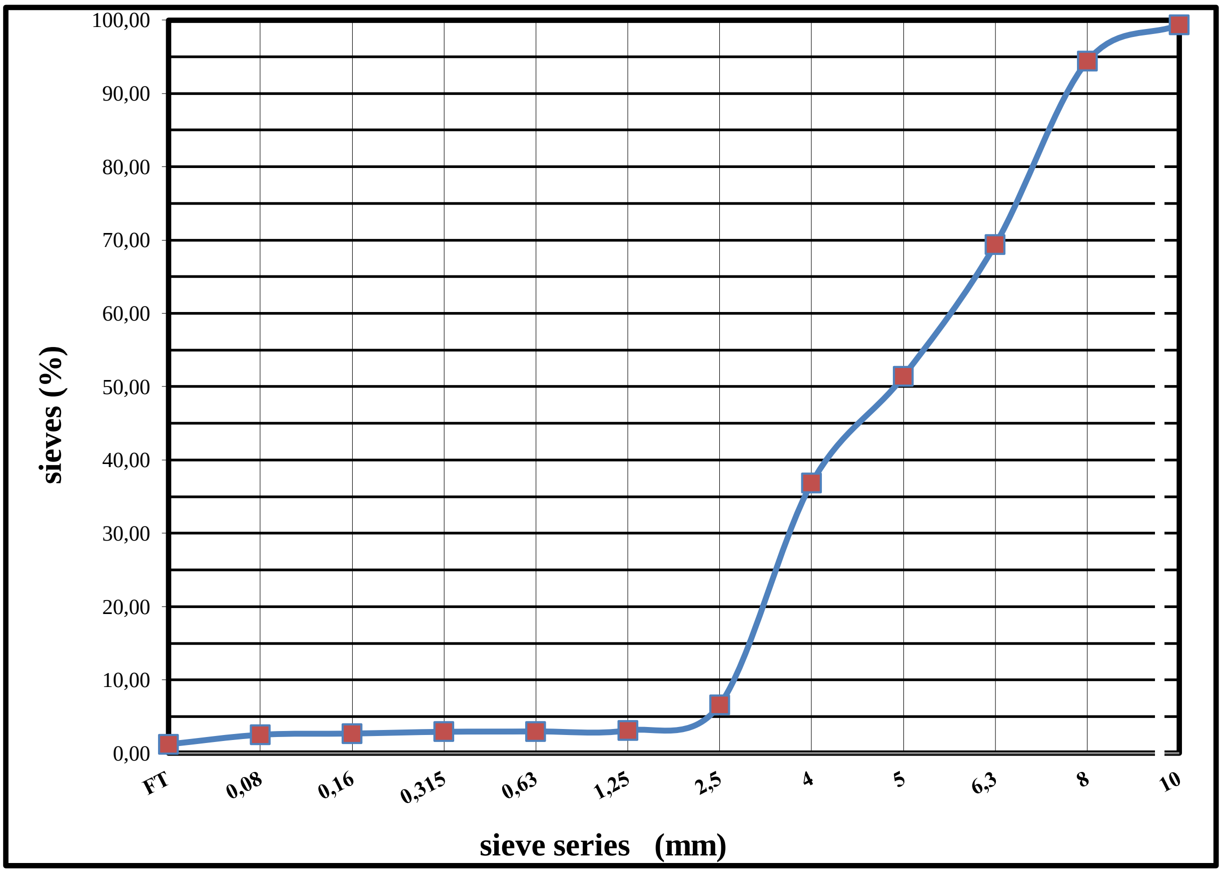

Figure II. 16: Grading Curve Of Expanded Clay Aggregate 3/8 (Crushed)

Table II. 19: Physical characteristics of lightweight aggregate 3/8 (crushed)

Physical characteristics	Results	Units
Bulk density	568.00	Kg/m^3
Absolute density	1150	Kg/m^3
Water absorption coefficient	14.2	%
Humidity	4.7	%

II.4. FORMULATION

II.4.1. MORTAR COMPOSITION :

Mortars are formulated using a software program (beton lab)

The following formulations given in table II.20 were adopted.

Table II.20: Formulation of mortars of different combinations.

	cement	sand (boughezoul)	sand 0/1 (boussaada)	lightweight sand	adjuvant	water
m.l (ac) adj (100nm)	30%	_	_	70%	0.16%	17.5%
m.l (an) adj (100 nm)	25%	_	45%	30%	0.18%	17.5%
m.o adj (rs 619)	25%	75%	_	_	012%	17.5%

II.4.2. SCREED COMPOSITION:

The Screeds are formulated According to the excess paste method and calculations are obtained using AGILIA SOLC-LAFARGE software. The Excess Paste Theory which is essential to understanding the mechanism of workability of fresh concrete was proposed by Kennedy in 1940. This theory explains the fact that in order to achieve workability it is necessary to have not only enough cement paste to cover the surface of the aggregates, so as to minimize the friction between them, but also an additional excess to give it a better fluidity. Figure (II.16) shows the void produced between the aggregates in contact. By adding cement paste, these tight aggregates are separated by a layer of cement paste around them.

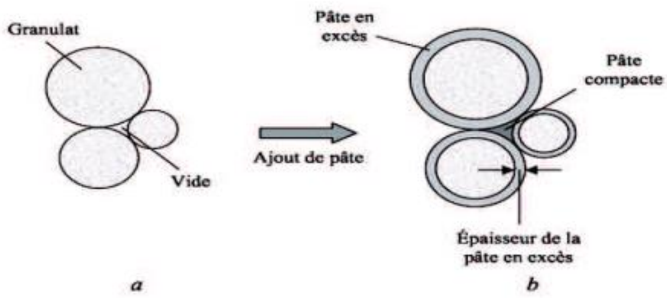

Figure II. 17: Example Of The Theory Of Excess Paste.

Ke = Cm/Pm *(Pulp Volume / Sand Volume) …… (Eq. 2.16)

Volume of paste = $V_{cement} + V_{wate}r + V_{sp} + V_{air}$ …. (Eq. 2.17)

wher Ke: it is a coefficient of spacing of the paste ;
Cm: compactness of the mixture;
Pm: Porosity of the mixture;
The following formulation (Table 2.21) were adapted.

Table II. 21: Formulation Of Screeds Of Different Combinations

	s.o adj (sika tempo 12)	**s.l (an/an) adj (sika tempo 12)**	**s.l (ac/ac) adj (sika tempo 12)**	**s.l (ac/an) adj (sika tempo 12)**	**s.l (an/ac) adj (sika tempo 12)**
Ciment dosage Kg/m^3	350	430	450	450	450
Ordinary sand (0/1) (Boussaada) dosage	_	153	162.5	150	150
Ordinary sand (0/3) (boughezoul) dosage	669.97	_	_	_	_
Expanded clay sand (0/3) nodular dosage	_	427	_	_	540
Expanded clay sand (0/3) crushed dosage	_	_	604	435	_
Ordinary aggregate (3/8) dosage	912.99	_	_	_	_

Expanded clay aggregate (3/8) nodular dosage	_	307	_	305	_
Expanded clay aggregate (3/8) crushed dosage	_	_	212	_	277
Adjuvant dosage	3.3	2.8	4.3	4.3	2.8
Water dosage Kg/m^3	175	240	270	270	277
w/c ratio	0.7	0.55	0.6	0.6	0.61

II.4.3. FESH STATE TESTS:

a. Spreading test at the choc table:

The spreading test at the impact table is a test carried out on fluid fresh concrete or mortar intended to be implemented by vibration according to NF EN 12350-52. For this test a shock table and a cone are used. The test is conducted by wetting the table with water; the cone is placed in the center of the table and filled with fresh mortar in two times. Each layer is tapped ten times. The cone is removed after 30 seconds of waiting, the mortar spreads out on the table; the table is raised to a height of 40 mm and then dropped fifteen times. The mortar spreads even more. The largest diameter and its perpendicular diameter are measured.

b. Density:

The density of a fresh mortar is determined by the quotient of its mass by the volume it occupies or introduced and compacted, in a prescribed manner in a measuring container of a given capacity (Figure II.17), it is expressed in (kg / m^3) (EN 1015-6).

Figure II. 18: Density In The Fresh State.

c. The occluded air:

The occluded air was measured using a 1 liter aerometer (Figure II.17). First, the lower chamber of the appliance is filled with mortar, then the upper chamber is fixed and water injected water with a wash bottle in the first tap. The second is then opened and when the water starts to come out both valves are closed and pressure is applied by actuating the integrated manual pump until the gauge needle of the device indicates the reference value 0%. The valve that separates the volumes of the two chambers (upper and lower) is opened, the mixture is then compressed and the percentage of oculus is directly indicated by the gauge needle.

Figure II. 19: Aerometer

d. mini cone (for screed):

For the determination of the spreading, the spreading cone is used (Figure II.18). This cone is placed on a spreading plate with a clean and moistened surface and of sufficient surface area, then it is filled with mortar. The cone is then lifted and the outgoing mortar forms a slump flow which expands under its own energy. The spread value corresponds to the average diameter of the slump flow.

Figure II. 20: Spreading Test.

e. Measurement of the heat of hydration of mortar by semi-adiabatic calorimetry

The method used is the Langavant method which consists of introducing a fresh mortar specimen into an isolated Dewar flask and monitoring the temperature changes within the specimen during the first early days. After a certain time, the heat of hydration of the mortar content in the sample is equal to the sum of the heat accumulated in the flask and the heat emitted to the environment during the test period. The temperature of the mortar is compared with the temperature of an inert sample placed in a reference calorimeter flask. The amount of heat achieved by the cement mortar is mainly dependent on the nature thereof, and may reach values between 10 ° C and 50 ° C. The amount of heat is expressed in joules per gram of cement.

II.4.4. HARDENED STATE TESTS:

II.4.4.1.PREPARATION AND CURING OF THE SPECIMENS:

The metal moulds are of a prismatic section shape (40 x 40 x 160 mm) (Figure II.19). The mortar is introduced into the three cells of the metal mould, the mortar does not require vibration on the impact table since it is a lightweight mortar, after which the excess mortar is removed by leveling. The surface of the specimens is then smoothed. After demoulding the prismatic specimens (40x40x160 mm), they are stored in a basin filled with water at 20 °C.

Figure II. 21: Prismatic Specimens Mould (40x40x 160 Mm)

II.4.4.3.MECHANICAL TESTS:

For the determination of the flexural strength, the concentrated load method at mid span using the standard flexing device is used.

The half-prisms obtained in the bending test shall be tested in compression on the side molding faces under a section of 40 mm x 40 mm.

a. Tensile strength by bending:

Place the prism in the flexural strength machine with a side casting on the bearing rollers and its longitudinal axis perpendicular to them (Figures II.19 and II.20). Apply the load vertically through the loading roller on the opposite side of the prism and increase until broken.

The bending strength R_f in (N/mm^2) is calculated using the formula:

$$Rf = \frac{1.5Ff}{b^3} * l \qquad \text{(Eq. 2.18)}$$

R_f: is the strength in flexion, in Newton per square millimeter or in MPa.
b: is the side of the square section of the prism, in millimeters.
Ff: is the charge applied in the middle of the prism at the rupture, in Newton.
l: is the distance between the supports, in millimeters.

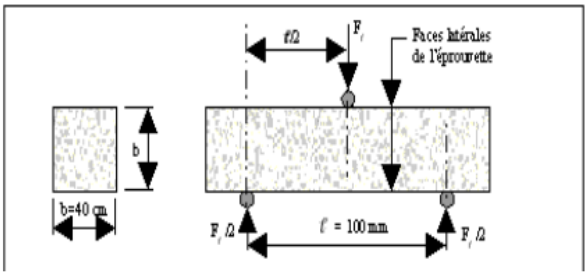

Figure II. 22: Device For Bending Strength Test

Figure II. 23: Tensile Strength By Bending Test

b. The compressive strength:

Center each half prism laterally to the trays of the machine to within 0.5 mm and longitudinally so that the end of the prism or cantilever in relation to the trays of about 10 mm (Figures II.21 and II.22). Increase the load with a providence speed throughout the application of load to failure (compensate for the decrease in load speed approaching the rupture). The compressive strength in (N/mm^2) is calculated using the formula following:

$$Rc = \frac{Fc}{b^2} \qquad \text{(Eq. 2.19)}$$

where RC: Compression strength in (MPa); FC: Breaking load in (N); b: side of the specimens is equal to 40 mm

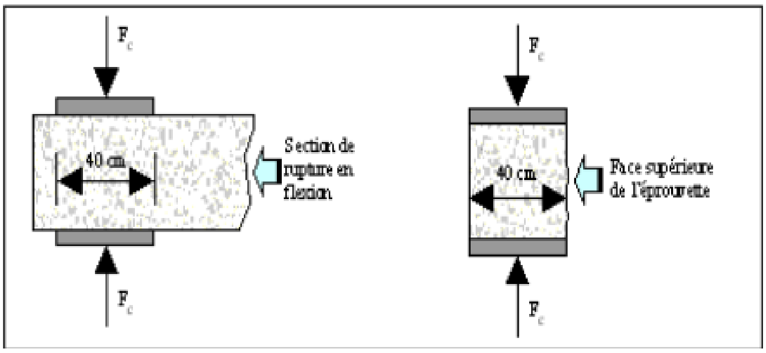

Figure II. 24: Compression Rupture Device

Figure II. 25: Tests Of Compressive Strength

c. Capillary absorption:

This test measures the rate of water absorption by capillary suction of unsaturated mortar specimens, which is in contact with water without hydraulic pressure. Before the sorptivity measurements, the test pieces will be pre-conditioned in the oven at about 105°C until a constant mass. The sorptivity test determines the rate of absorption by capillary ascent of specimens (40x40x160 mm) placed in the tray so that water only touches 5 mm from the specimens; the rest of the specimens is covered by a layer of resin on all other sides.

The increase in the mass of the test piece is then measured by the following formula:

$$C = 0.1(M2-M1)\ kg/(m^2.min^{0.5}) \qquad \text{(Eq. 2.20)}$$

With: M_1=the mass of the test piece after 10 min of absorption and M_2: the mass of the test piece after 85 min of absorption.

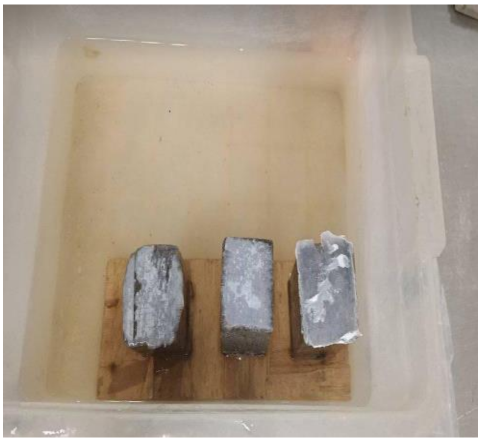 

Figure II. 26: Capillary Absorption Test

d. Heat of hydration

The purpose of the test is to continuously measure the hydration heat obtained is expressed in joules per gram of cement. It applies to all hydraulic binders whatever their chemical composition, with the expectation of quick cements.

II.5. CONCLUSION:

The physical tests, the chemical and the mineralogical analyzes carried out give a general idea on the main characteristics of the materials used for the formulation of the mortars which will be studied in the following chapter from the mechanical point of view knowing these characteristics significantly helps us to comment on the results of experimental tests.

CHAPITRE III: RESULTS AND DISCUSSIONS

III.1. INTRODUCTION:

In this chapter we present the results of the various tests carried out on the mortar. The fresh state properties are discussed first. Then, the results at the hardened state concern the compression and bending strengths as well as of capillary absorption coefficient (Sorptivity) and shrinkage.

III.2. WORKABILITY (SPREAD) OF FRESH MORTAR AND SCREED:

The characteristics of fresh mortars are presented in table 3.1 and figure 3.1 and those of screed are presented in table 3.2 and figure 3.2.

Table III. 1: Spread Of Mortar Mixes

Mortar mix	Spread (cm)
M.O with admixture	18.5
M.L (AN/AN) with admixture	19
M.L (AC/AC) with admixture	18.2

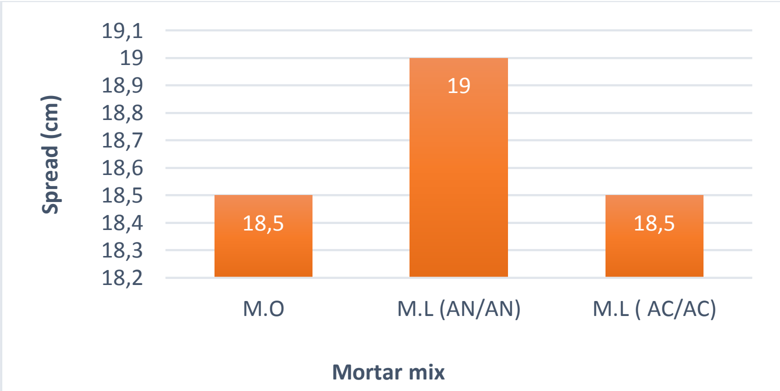

Figure III. 1: Spread of mortar mixes

We have fixed a spread of 160 mm to 180 mm for all mortar mixtures as a target, this is an indication of a good water demand of the mortars.

We set the same percentage of water in all the mixtures (17.5%) and we noticed that the greatest spread occurs in lightweight mortar made with nodular aggregates (AN) because they have a small absorption capacity due to the bark that surrounds the pellets, in contrast to the lightweight mortar made with crushed aggregates which has a higher absorption capacity due to the porous structure of this type of aggregates.

Table III. 2: Spread Of Screed Mixes

Screed mix	Spread (cm)
S.O with admixture	17
S.L (AN/AN) with admixture	20.5
S.L (AC/AC) with admixture	20.5
S.L (AN/AC) with admixture	23
S.L (AC/AN) with admixture	19

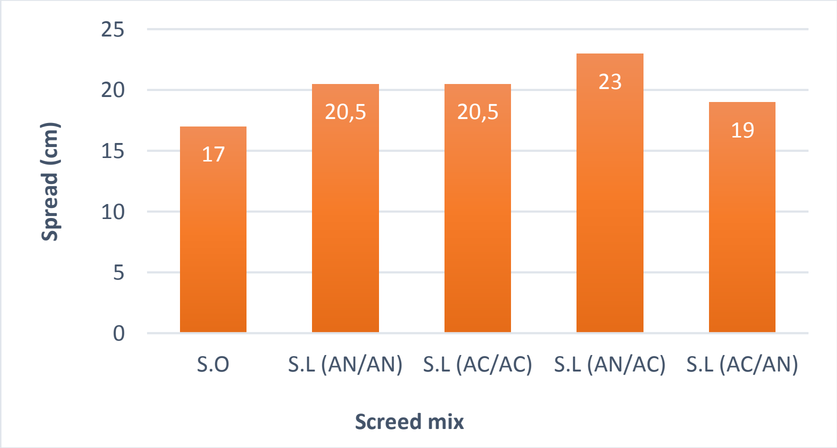

Figure III. 2: Spread of screed mixes

We have fixed a sprawl of 200 mm to 250mm for all screeds' mixtures as target, this is an indication of the good water demand of the mortar in 1m^3.

For the lightweight screed (AC/AC) we added an amount of 270 ml of water as for the lightweight screed (AN/AN) we added a smaller amount of water estimated at 240 ml. The obtained results confirm the high absorption capacity of the crushed aggregates (AC) as they need a greater amount of water due to their cellular structure, unlike nodular aggregates (AN) which do not need a large amount of water due to the bark that surrounds the pellets.

The same thing of the mixtures S.L (AN/AC) with 227 ml of water.

And S.L (AC/AN) with 270 ml of water the presence of crushed aggregates accompanied by an increase in the amount of water to reach the desired sprawl. As for the ordinary screed mixture, the small amount of water (175 ml) resulted in less spread compared with the other mixtures.

III.2.2. DENSITY:

The results of density of mortar are given in table 3.3 and figure 3.3 whereas the resulst of density of screed are given in table 3.4 and figure 3.4.

The density of the mortars is directly linked to the nature of the aggregates; it decreases with the decrease in their density. Expanded clay aggregates of different types (crushed or nodular) provide lightness to mortars.

The density of screeds is directly linked to the nature of the aggregates; it decreases with the decrease in their density.

Expanded clay aggregates of different types (crushed or nodular) provide lightness to screeds according to the results obtained we concluded that lightweight screed made with crushed aggregates has the lowest density because crushed aggregates (AC) has a lower density due to their exposed cellular structure that does not have a bark for nodular lightweight aggregates that their external structure surrounded by a bark.

The ordinary screed has the highest density and this is mainly due to the higher density of the aggregates used.

Table III. 3: Density Of Mortar Formulations

Mortar formulation	Density
M.O with admixture	1.68
M.L (AN/AN) with admixture	1.47
M.L (AC/AC) with admixture	1.02

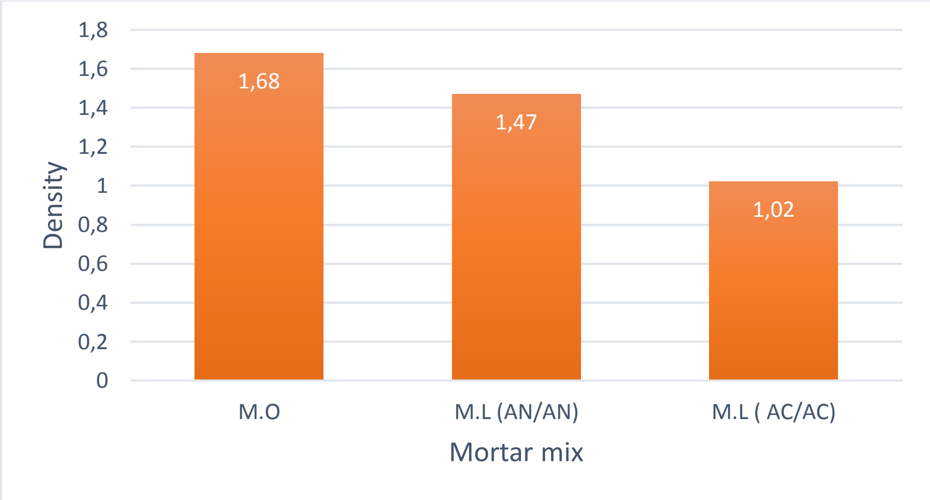

Figure III. 3: Density of mortar mixes

Table III. 4: Density Of Screed Mixes

Screed mix	Density
S.O with admixture	2.26
S.L (AN/AN) with admixture	1.70
S.L (AC/AC) with admixture	1.50
S.L (AN/AC) with admixture	1.61
S.L (AC/AN) with admixture	1.63

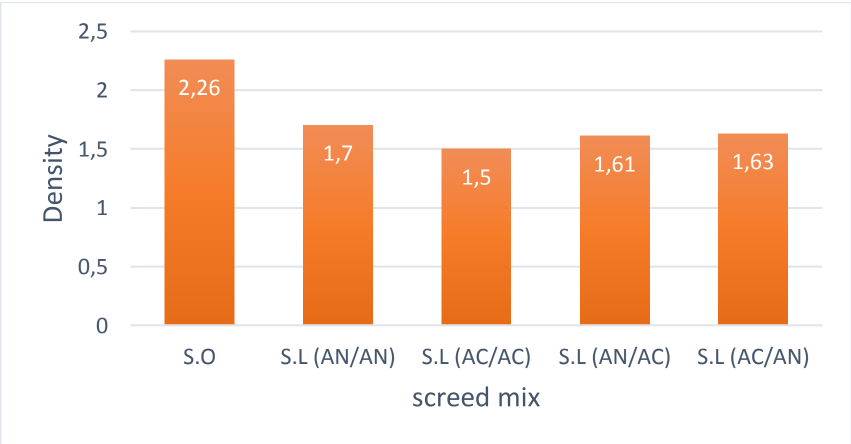

Figure III. 4: Density of screed mixes.

III.2.3. OCCLUDED AIR:

The quantity of air in the various mixes of mortar and screed are given in tables 3.5 and 3.6 and figure 3.5 and 3.6 respectively.

We have set the air content in the screeds at 5%, which was verified for all mixtures.

Table III. 5: Occluded Air Of Mortarmixes

Mortar mix	Occluded air (%)
M.O with admixture	18
M.L (AN/AN) with admixture	24.5
M.L (AC/AC) with admixture	26.5

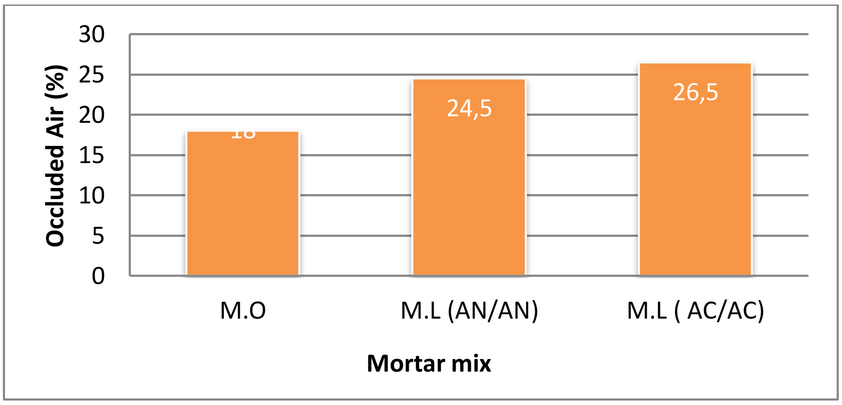

Figure III. 5: Occluded air of mortar mixes

Table III. 6: Occluded Air Of Screed Mixes

Screed mix	Occluded Air (%)
S.O with admixture	5
S.L (AN/AN) with admixture	3.1
S.L (AC/AC) with admixture	6.9
S.L (AN/AC) with admixture	4.5
S.L (AC/AN) with admixture	3.7

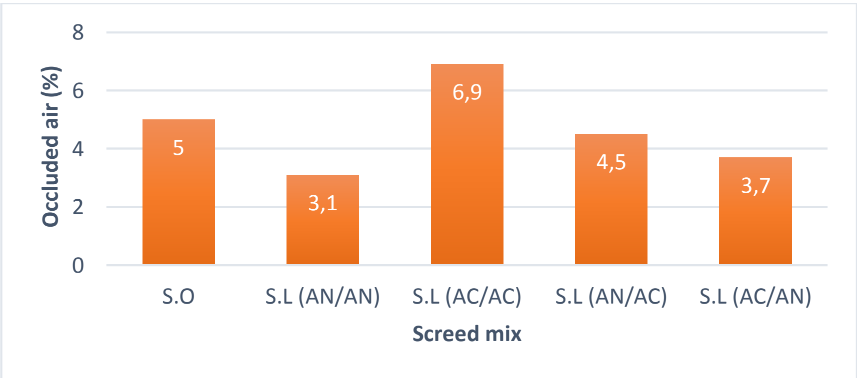

Figure III. 6: Screed of screed mixes

III.3.1. TENSILE STRENGTH BY BENDING:

The bending tensile strength results for mortar are summarized in table 3.7 and figure 3.7 whereas those for screed mixes are given in table 2.9 and figure 2.8. The bending tensile strength increases with age as expected due to higher hydration of cement. The highest bending strength is that of mix ML AN/AN where the increase between 7 days and 28 days is almost double as compared to about 30% for MO mix. The lowest bending strength is for mix ML AC/AC where there was no increase between 7 and 28 days.

The tendency observed for screed mixes is slightly different. The highest bending strength was for ordinary aggregates mixes. The gain in strength after 7 days is not important for all screed mixes. There was even slight reduction for some mixes. This might be due to the bond between aggregates and the mortar which is different for each type.

Table III. 7: Tensile Strength By Bending Of Mortar

	Tensile strength by bending(MPa)		
	7 days	14 days	28 days
M.O with admixture	2.26	3.05	2.99
M.L AN/AN with admixture	2.35	2.54	4.09
M.L AC/AC with admixture	1.3	2.43	1.3

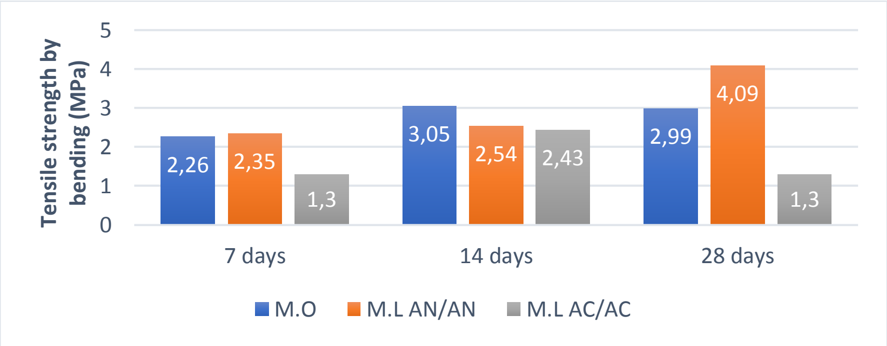

Figure III. 7: Tensile strength by bending of mortar mixes

Table III. 8: Tensile Strength By Bending Of Screed Mixes

	Tensile strength by bending (MPa)		
	7 days	14 days	28 days
S.O with admixture	7.22	7.64	8.97
S.L AN/AN with admixture	5.83	7.04	6.12
S.L AC/AC with admixture	6.41	7.85	4.98
S.L AN/AC with admixture	5.21	5.86	5.77
S.L AC/AN with admixture	5.46	6.27	5.12

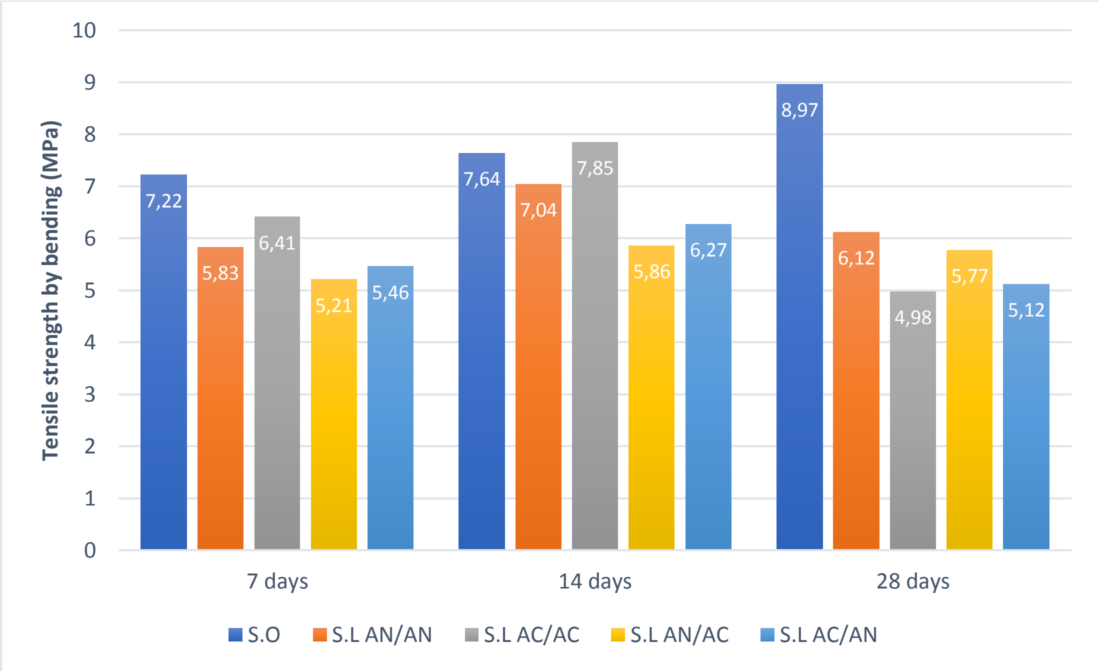

Figure III. 8: Tensile strength by bending of screed mixes

III.3.2. COMPRESSIVE STRENGTH

The compressive strength results for mortar and screed mixes are given in table 3.9 and figure 3.9 and table 3.10 and figure 3.10, respectively.

The tendency of compressive strength of mortar is comparable to that of bending strength though the increase in strength with time is more noticeable. The highest compressive strength is for mix with ordinary aggregates followed by AN/AN mix.

The development of compressive strength of screed is also similar to that observed in bending for screed mixes. the highest compressive strength is for screed with ordinary aggregates (49 MPa) followed by the mix AN/AN with 46.9 MPa at 28 days of age. The mix gave the lowest compressive strength of 16 MPa is mix AC/AC which is about 36% of mix AN/AN.

Table III. 9: Compressive Strength Of Mortar Mixes

	Compressive strength (MPa)		
	7 days	14 days	28 days
M.O (with admixture)	6.91	7.52	8.11
M.L AN/AN (with admixture)	3.96	4.19	5.35
M.L AC/AC (with admixture)	1.47	2.9	2.54

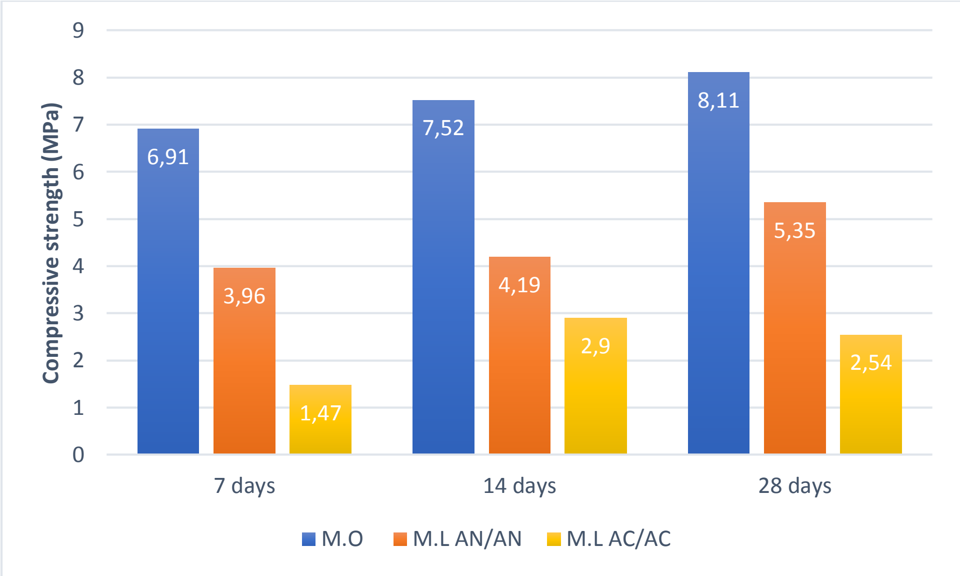

Figure III. 9: Compressive strength of mortar mixes.

Table III. 10: Compressive Strength Of Screed Mixes

	Compressive strength (MPa)		
	7 days	14 days	28 days
S.O (with admixture)	31.60	37.03	49.02
S.L AN/AN (with admixture))	43.44	29.52	46.91
S.L AC/AC (with admixture))	18.00	18.49	16.63
S.LAN/AC (with admixture)	30.42	38.08	39.92
S.L AC/AN (with admixture))	29.63	34.32	43.60

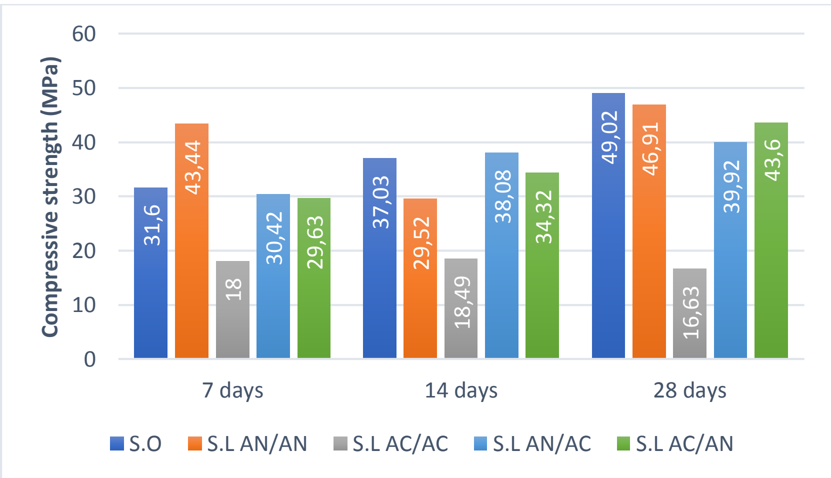

Figure III. 10: Compressive strength of screed mixes

III.3.3. CAPILLARY ABSORPTION

The total capillary absorption results are presented in table 3.11 and figure 3.11 for mortar specimens. and those for screed specimens are presented in table 3.12 and figure 3.12.

water capillary absorption is lower for all mixes in mortar and screed with lightweight aggregates as compared to ordinary aggregates.

In the case of AN/AN lightweight aggregate, the high temperature provides hardness to the crust, and this explains the low absorption of this types.

For AC/AC the AC crust has a high porosity due to its cellular structure despite the good anchoring of the aggregates with the cement paste.

AC/AN or AN/AC presented the same rate of capillary absorption which confirm the previous findings.

Table III. 11: Capillary Absorption Of Mortar Mixes

Mortar	**Capillary absorption (kg/m^3.min$^{0.5}$)**
M.O with admixture	0.26
M.L (AN) with admixture	0.12
M.L (AC) with admixture	0.175

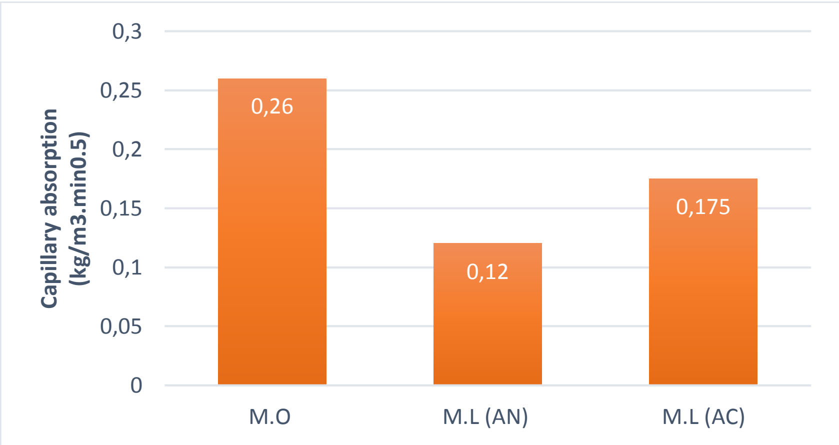

Figure III. 11: Capillary Absorption Of Mortar Mixes

Table III. 12: Capillary Absorption Of Screed Formulations

Screeds	**Capillary absorption (kg/m^3.min$^{0.5}$)**
S.O with admixture	0.3
S.L AN/AN with admixture	0.085
S.L AC/AC with admixture	0.25
S.L AN/AC with admixture	0.19
S.L AC/AN with admixture	0.19

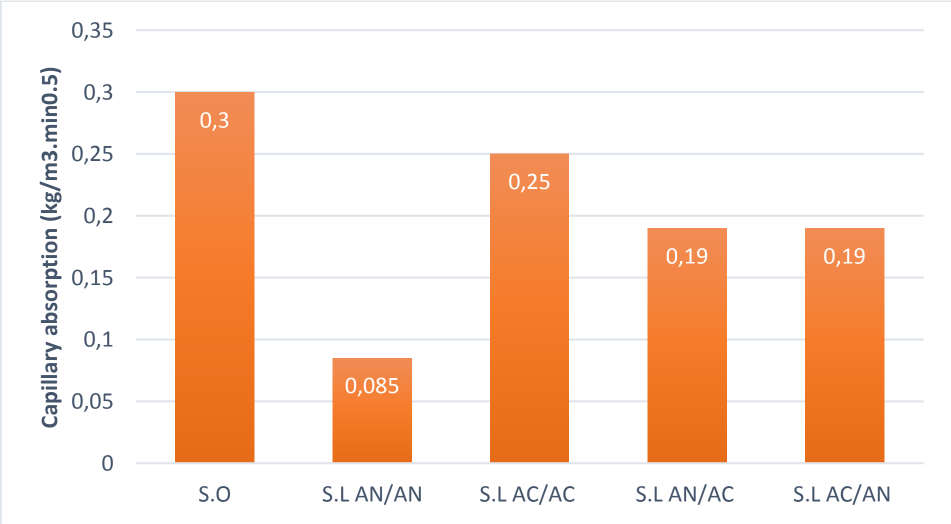

Figure III. 12: Capillary Absorption Of Screed Mixes

III.3.4. Heat of hydration:

The heat of hydration of ordinary mortar and the two mortars with lightweight aggregates are given in figures 3.13 to 3.15.

It can be clearly seen that the heat of hydration for lightweight mortar is lower than that of ordinary mortar even at the early time (less than 10 hours) although the cement content is comparable. This could be due to the insulating properties of the lightweight mortar which do not allow heat within the body of the specimen to be transferred easily. This can lead to a higher rise of temperature due to hydration in lightweight elements.

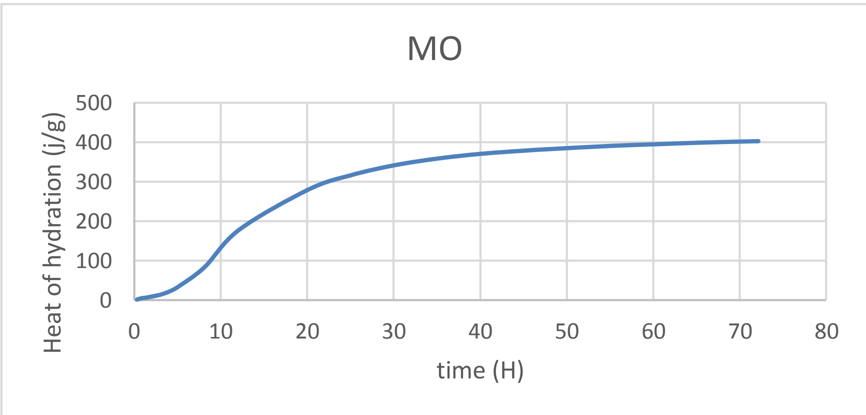

Figure III. 13: Heat Of Hydration Of Ordinary Mortar

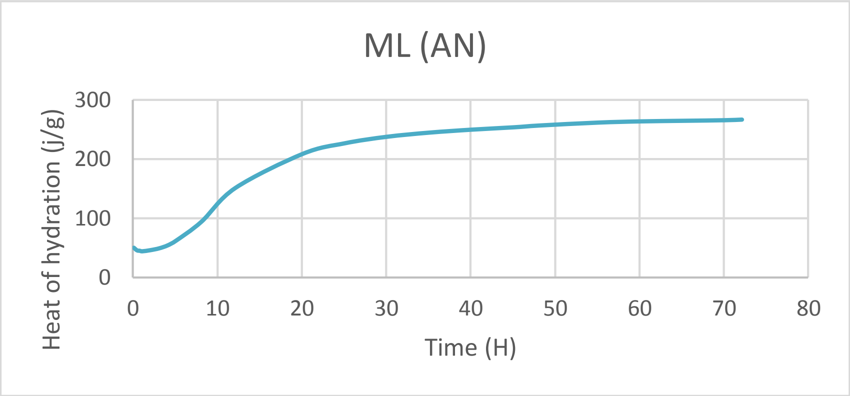

Figure III. 14: Heat of hydration of lightweight mortar type an

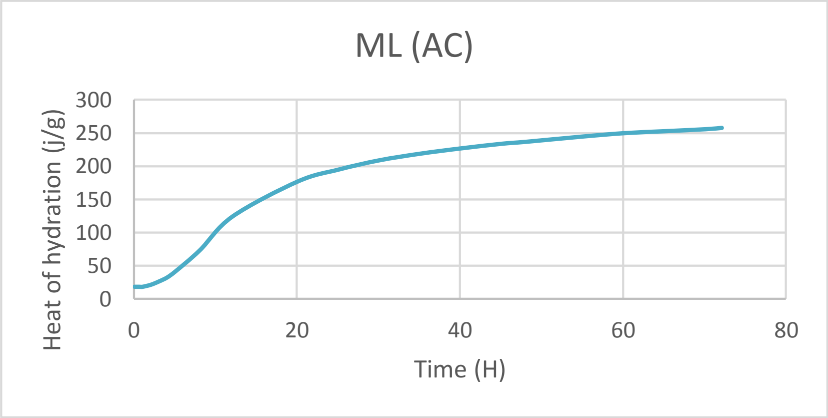

Figure III. 15: Heat Of Hydration Of Lightweight Mortar Type Ac

III.4. CONCLUSION

The experimental results showed that the use of lightweight aggregates in mortar and screed reduces the mechanical properties and it can be clearly seen that mortars made with expanded clay has a high insulating properties, water capillary absorption is lower for all mixes in mortar and screed with lightweight aggregates as compared to ordinary aggregates.

Detailed conclusions are given in the following chapter.

GENERAL CONCLUSION:

The purpose of this thesis was to study the particularity of lightweight mortar and screed based on expanded clay aggregates compared to ordinary mortar and screed, but also to present the expanded clay material to the Algerian market, because the use of this remains quite limited.

A bibliographic approach was carried out, and as a result, the characteristics of the lightweight aggregates are directly imparted to the mortar, thus the fresh density of lightweight mortar is around 1600 kg/m^3 the development and formulation of the various mortar and screed formulations gave rice to the following findings and conclusions: the density depends on the type of constituents used for the formulation.

The density of mortars and screeds is inversely proportional to the void rate of the lightweight aggregates introduced into the formulation.

The mortars and screed designed did not keep the same mechanical properties compared to ordinary mortars and screeds.

The maximum strength of lightweight mortar obtained is 8.11 Mpa and for lightweight screed is 49.02 Mpa .

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