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Producing Lightweight Concrete Tiles by Using Expanded Clay Aggregates

A Thesis
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قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ ﴿32﴾

Abstract

The available traditional precast concrete tiles used for roofing are so heavy. This work was conducted to produce lightweight concrete (LWC) tiles incorporated with light expanded clay (LECA) which may represent a good alternative for traditional production. This study highlights the importance of density of LECA and the curing type on the fresh and oven-dry density, slump, compressive strength, fracture load, modulus of rupture, and thermal conductivity of concrete at various ages up to 28 days. In addition to reference mix made with natural coarse aggregate, two other mixes having LECA of two various densities namely, 320 and 700 kg/ m^3. Regardless of its type, the maximum size of coarse aggregate in all mixes was 10 mm. Samples of 72 concrete tiles (50*50*5 cm), 81 cubes (10*10*10 cm), and 27 small disks (40 mm diameter) were poured and subjected to different conditions of curing (continuous curing in water, 3 days curing in water, and air curing).

The results showed that the fresh density of concrete ranging from 2343 kg/m^3 to 1820 kg/m^3 and 1640 kg/m^3 when LECA of high density (HDLECA) and LECA of low density (LDLECA) were used, respectively. The LWC with HDLECA performed better compressive strength, fracture load, and modulus of rupture than LWC made with LDLECA though the two types of LWCs showed lower results as compared to natural weight concrete (NWC). The compressive strength decreased by up to (53%) when replacing the natural coarse aggregate with LDLECA, while it decreased by only (30%) when replacing the natural coarse aggregate with HDLECA. Furthermore, the higher density of concrete was the higher thermal conductivity of concrete.

The experimental results also showed that the best compressive strength, fracture load, and modulus of rupture were observed for water cured samples, followed by partially water-cured samples, and air-cured samples respectively. The weight of the concrete tiles was reduced by range (6.7-9 kg) when replacing the natural aggregates with the lightweight aggregates. The outcomes of the present work indicated that concrete tiles satisfying the requirements of Iraqi standard No. (1107 : 1988) can be produced by incorporating HDLECA thus leading to lighter weight and more thermal insulation than normal weight concrete tiles.

Certificate

I certify that the preparation of this thesis entitled " **Producing Lightweight Concrete Tiles by Using Expanded Clay Aggregates** *" was presented by "* **Hussein Ali Annon Esal** *", and made under my supervision at the department of civil engineering, college of engineering, University of Babylon, as partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Construction Materials).*

Supervisor

Signature:

Name: Asst. Prof. Dr. Ali Hassoon Nahhab

Date :   /   /

Acknowledgments

Dedication

I dedicate this thesis to the spirit of my father, who worked a lot in order to see me successful and superior, But he is certainly flying high in the sky, he hears and watching me, and to my family who helped me to complete this wonderful scientific achievement.

Hussein Ali Annon Esal

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AC	*air curing*
ACI	*American Concrete Institute*
ASTM	*American Society for Testing and Materials*
b	*Concrete tile width which equal to 500 mm.*
BS	*British Standard*
cm	*Centimeter*
°C	*Celsius temperature*
Dim.	*Diameter*
Eq.	*Equation*
et al.	*and others*
etc.	*to the end*
f_{cu}	*Ultimate compressive strength*
Fig	*Figure*
GPa	*Giga Pascal (equal to 1000×N/mm2 (MPa)*
h	*height of concrete tile which equal to 50 mm.*
HDLECA	*High density Lightweight Expanded Clay Aggregate*
hrs.	*hours*
HRWR	*High Range Water Reducing*
i.e.	*in other word*
IQS	*The Iraqi standards*
K	*Thermal Conductivity*
Kg	*kilogram*
kN	*Kilo Newton*
l	*The distance between the supports which equal to 400 mm*
L	*Litter*
LDLECA	*Low density Lightweight Expanded Clay Aggregate*
LECA	*Lightweight Expanded Clay Aggregate*
LWC	*lightweight concrete*
LWC-HD	*High density lightweight concrete*
LWC-LD	*Low density lightweight concrete*
m	*Meter*
max.	*Maximum*

MgSO4	magnesium sulfate
mm	Millimeter
MOR	Modulus of Rupture
MPa	Mega Pascal (MN/m2)
No.	Number
NWA	Natural weight coarse aggregate
NWC	Natural weight concrete
ºk	Temperature unit (Kelvin)
p	Fracture load
PWC	partial water curing
r	Disc radius
s	second
SAC	Sound absorption coefficient
SCC	Self-Compacting Concrete
SP	Super plasticizer
SRPC	Sulfate Resisting Portland Cement
SSD	Saturated Surface Dry
V	Voltage
w	Energy measurement unit (watt).
w/c	Water-Cement ratio
WC	water curing

Chapter One

CHAPTER ONE

Introduction

1.1   General

The manufacture and production of concrete tiles are one of the important industries in the past and in our time because of their important role in providing services to people, whether in cover walkways, floors of buildings, or other structures. Also in cover roofs and preserving them from the effects of moisture and other erosion factors such as freezing and thawing.

There are different sizes and shapes of concrete tiles such as square, rectangular, and polygon, they have different colors such as white, yellow, and red. The thickness of them varies according to the purpose of use as shown in plate (1.1). The tiles used in the roofs are characterized by being impermeable to water, preferably lightweight, and resistant to climatic conditions, while the tiles lining the walkways are characterized by their ability to bear large loads **(Kawther et al., 2020).**

Concrete tiles are usually produced with certain mixing ratios so that they can withstand external conditions such as temperature changes, humidity, the effects of salts .... etc.
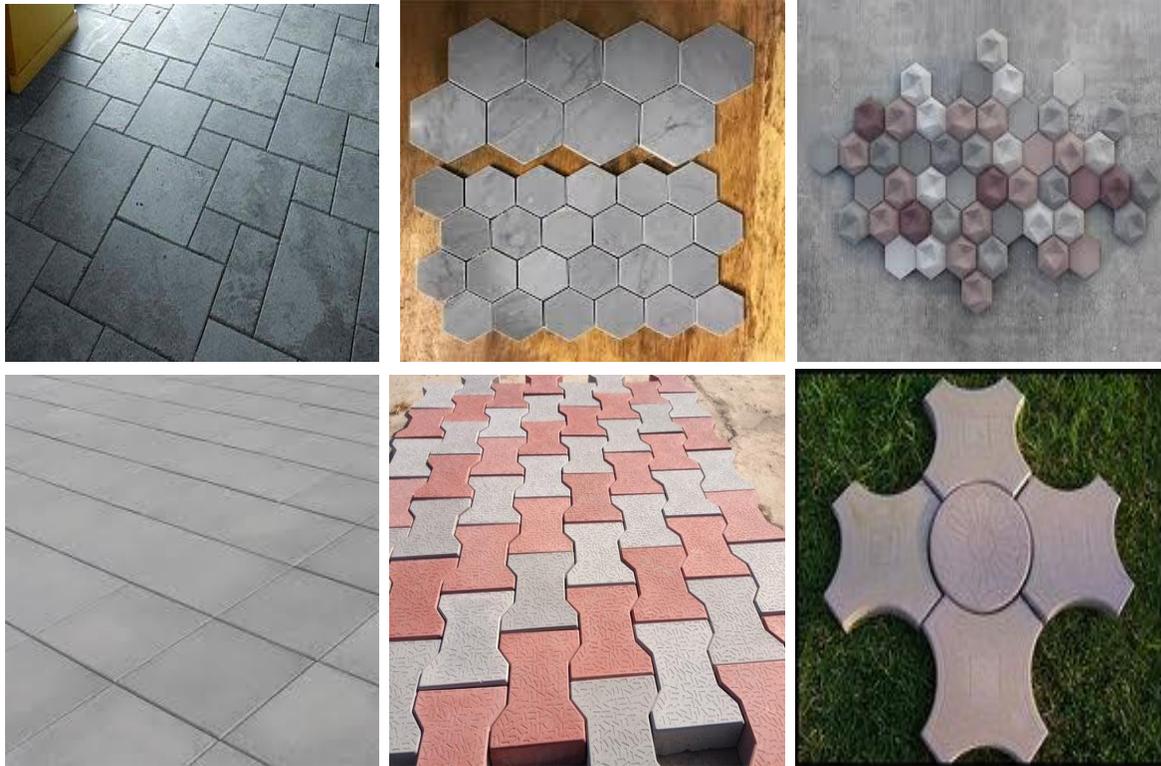
Plate (1.1) Some types of precast concrete tiles.

The strength and properties of concrete tiles depend on the properties, qualities, and quantities of the mixture materials that make up the concrete tiles. Improving the characteristics of the concrete tiles product by improving the properties of the concrete mixture is self-evident by doing increment in the cement content, using crushed coarse aggregate, limiting the maximum size of aggregate, reducing the water/cement ratio, the use of additives, good compact during work it (**Neville, 1996).**

Developed countries resort to building more heat-insulating buildings to reduce energy consumption in heating and cooling. Here, lightweight concrete in general and lightweight concrete tiles, in particular, can play an important role in the thermal insulation of buildings.

For the purpose of getting lightweight tiles, lightweight aggregate concrete (LWAC) can be used. LWC has an equilibrium density ranging from 1120 kg/m^3 to 1840 kg/m^3 and compressive strength of at least 17 MPa**,** LWC can be produced by different methods such as using lightweight aggregates instead of normal weight aggregate in concrete mixes, eliminating fine aggregate from the concrete mix, and creating big voids inside the concrete **(ACI.13R-03, 2003)**. Lightweight concrete tiles are distinguished from ordinary concrete tiles in that they are easy to apply and have higher thermal and sound insulation, but they have less breaking strength and less durability. There are two types of lightweight aggregates, the first is natural like pumice, scoria, and diatomite, the second type is artificial like rotary kiln expanded clay (LECA), shale, and slate, as well as expanded slag, **(Neville, 2010).**

Companies and factories have manufactured expanded clay because it is useful in many fields, such as agriculture and construction, in addition to the availability of its raw material, which makes it relatively cheap.

Plate (1.2) The factory of manufacturing of LECA, (https://www.leca.asia).

Expanded clay is made by drying and burning clay at high thermal temperatures in factories containing rotary kilns. It is characterized by having a low density, high porosity, high water absorption capacity, and good thermal and sound insulation (**Heiza et al., 2017**).

1.2 Applications of Tiles

- Lightweight concrete tiles are used for covering roofs, floors, pavement, External walkways, and all areas that require small dead loads.
- Lightweight concrete tiles can be used in places that need good thermal and sound insulation.

1.3 Significance of the Research

- The available precast concrete tiles used for roofing are usually heavy. So, the lightweight concrete tiles represent a good alternative for such production.
- It gives an initial idea to engineers and workers in determining the proportions of mixing materials needed to produce lightweight concrete tiles that conform to specifications.
- It highlights the importance of curing concrete with water after pouring to improve its properties, especially in hot weather.
- It is possible to benefit from this research in the production of lightweight and natural weight concrete tiles in precast factories.
- It helps researchers in the future to predict changes in the properties of concrete as a result of changing the type of coarse aggregate and changing curing conditions.

1.4 Objective and Methodology of the Research

According to the author knowledge, there is little previous research dealing with the incorporation of LECA in the manufacture of concrete tiles though there are many works dealing with the use of LECA in concrete. Furthermore, the available traditional precast concrete tiles used for roofing are so heavy. So this work can be considered as a begin to know the properties and specifications of the tiles produced with LECA which represent a good alternative for the traditional production. This study highlights the importance of density of LECA (320, 700 kg/m^3) and the curing type on the compressive strength, fracture load, and oven-dry density of lightweight concrete at 3, 7, and 28 days. The results were also compared with normal-weight concrete (without LECA). The samples were cured under three different curing regimes namely, water curing, partial water curing, and air curing.

1.5 Layout of Thesis

In this study, chapter one includes an introduction about concrete tiles and their importance and the use of lightweight concrete in its production, while chapter two includes previous studies on precast concrete tiles and lightweight concrete. In chapter three , the particulars of the used materials, mix proportion, and the tests carried out throughout the experimental work. Chapter four provides the results from the conducted experiments and their discussions. Finally, chapter five is concerned with the conclusion derived from this study and recommendations for further research in the future time.

Chapter Two

CHAPTER TWO

Literature Review

2.1 Introduction

In this chapter, some previous studies and research were mentioned about precast concrete tiles, the effect of curing on the properties of concrete, and the properties of lightweight concrete, in addition to the properties of expanded clay aggregate and its use in lightweight concrete.

2.2 Precast Concrete Tiles

Precast concrete tiles are known as one of the concrete formations that are used in paving walkways and surfaces, and it consists of a mixture of cement, aggregate, water, and pigment sometimes, where these materials are exposed after mixing to compaction or press or both. These tiles are produced with different dimensions and colors, (**Iraqi Code for Building Materials No.311/2017**). It is possible to improve the properties of precast concrete tiles through the use of meshes, whether they are made of polymer, iron, or other fibers, as these meshes will contribute to :

 a. Improving the durability of tiles.

b. Improving the general mechanical properties of tiles.

c. Increase the ability of tiles to absorb shock.

g. Reduce the rate of damage during transport or sudden impacts.

e. Reducing the number of capillary cracks expected to occur during casting and processing **(Shah and Key – 1972, Netlon Ltd. – 1988, Engel and Bakis – 2001).**

Rao et al., (1981) have concluded that type of the mesh, the number of layers used, and the shape and dimensions of the holes affect the behavior of the precast concrete tiles in terms of resistance, degree of cracking, course of cracks, width, and depth of cracks, and how the damage spreads. Ilda et al., (2009) made lightweight concrete tiles using expanded clay, after conducting experiments on them, they concluded that these lightweight tiles are highly efficient in thermal insulation, especially in the summer. Olusegun et al., (2011), produced concrete tiles with dimensions (1.4*15*15 cm) using granite and red clay as aggregate, they concluded that burning the sample led to the breaking of the molecular bonds in the burned concrete tiles, thus a weakening compressive strength and modulus of rupture. de Souza et al., (2015), conducted experiments on concrete tiles and ceramic tiles to find out which was less harmful to the environment when made. They found that concrete tiles have more impact on climate change and water consumption during production. Narain et al., (2016) made concrete tiles containing a highly coated phase change material (PCMs), they concluded that this material improves the thermal insulation of the tiles. On the other hand, it reduced the concrete's compressive strength from 50.42 MPa to 30.46 MPa and reduced the density from $2,627 kg/m^3$ to $1,947 \text{ kg/m}^3$ when Its volume was equal to 20% of the volume of concrete. They prefer to use it in lightweight buildings where the thermal conductivity is small. Suzuki & Manzello, (2017) conducted a test on three types of tiles (Profile Concrete Tile, Flat Concrete Tile, and Flat Terracotta Tile) where they exposed the tiles to the fire moving by a flowing air current at a speed of 6 m/s. They found that the tiles type Flat Terracotta Tile (Terracotta Tile made from locally available materials such as terracotta or slate) have more number of firebrands penetrated in unit area, followed by Flat Concrete Tile and Profile Concrete Tile, respectively.

Eugênio et al., (2021), used iron ore tailing in the production of concrete roof tiles , they concluded that replacing limestone powder with iron ore tailing reduced the porosity of the concrete roof tiles and increased the flexural strength, while the physical properties of the concrete roof tiles remained without appreciable change.

2.3 Curing of Concrete

Curing is primarily intended to keep the concrete moist by limiting moisture loss during the setting and hardening of concrete, as well as providing moisture from outside the concrete. We must point out the role of curing in improving the properties of concrete. Curing begins after the end of the fresh period of concrete, usually after 24 hours. Curing improves the properties of concrete, such as increasing resistance to compression, tensile and bending, and increasing concrete durability by reducing its permeability, It also reduces the effect of shrinkage and the appearance of cracks, as it increases the proportion of hydrated cement and fills the gaps, thus protecting concrete from the penetration of harmful chemical compounds such as chlorides. The improvement in the quality of the concrete is reflected positively in the improvement of the properties of the concrete tiles made of it, where its durability and resistance to breakage increases, and its water absorption rate decreases, all this is a result of attention to curing of concrete. Curing of concrete can be carried out by different methods such as:

- Immersion and Ponding: Ponding is a method of curing concrete on flat surfaces such as pavement structures and tiles.
- fogging or Sprinkling curing: Wet, humidity fabric coverings should be applied as soon as the concrete has hardened enough already to avoid surface damage. It can be used other curing methods during the waiting period such as fogging or the application of membrane forming finishing

aids. It's important to cover the entire surface with a damp fabric, including the concrete ends.

- Cotton Mats, Rugs, and Burlap: Cotton Mats, rugs, burlap, and other absorbent material coverings will keep water on the surface, whether horizontal or vertical. These materials must be devoid of harmful compounds like sugar or fertilizer that affect the concrete or induce degeneration. To eliminate soluble chemicals or make burlap more absorbent, burlap should be washed several times in water. Cotton mats and rugs retain moisture longer than burlap and are less likely to dry out. They are handled similarly to burlap, except that because of their greater mass, they must be applied to a freshly finished surface after the concrete has solidified to a greater degree than burlap.

- Sawdust and Sand: Sawdust and sand are especially useful where placed on the surface of the concrete as covering to protect the surface against scars and stains **(Goel et al., 2013).**

Plate (2.1) Type of concrete curing (a) Immersion in water, (b) Sprinkling curing, and (c) Using cotton in curing of concrete.

Jaegermann & Glucklich, (1969) referred to the effects of moisture transfer in concrete at early ages to reach a state of equilibrium and considered it one of the most important factors that cause early drying, which leads to shrinkage and plastic shrinkage cracking. **Rasheeduzzafar & Al-Saadoun, (1989)** confirmed that the curing period has an important role in protecting iron from damage in reinforced concrete.

Bentur & Goldman, (1989) studied the effect of curing on the physical properties of concrete, they concluded that poor curing affected the strength of concrete whether the concrete was ordinary or contained silica fume. **Wang et al., (1994)** studied the transfer of moisture inside the concrete and what it causes in terms of plastic shrinkage and cracks, and the extent of the effect of the delay in curing the concrete cover on the amount of moisture loss. They found that the delay in curing concrete with water led to the formation of concrete with similar properties to those of air-cured concrete only. The activity of membrane curing was highly dependent on the age of concrete during its application. **Khan & Ayers, (1995)** made six concrete mixtures, four of which contained different percentages of silica fume (5, 10, 15, and 20%) of the cement content, while the other contained fly ash at 15 percent. They found that the minimum curing period for fly ash concrete was six and a half days, while ordinary and silica fume concretes required three days, and three and three-quarter days, respectively. **Ibrahim et al., (2013)** used four methods for curing concrete in hot weather, which are wet burlap, acrylic curing compound, bitumen-based curing compound, and water-based curing compound. They found that the method of curing by bitumen-based curing compound was the best.

2.4 Light Weight Concrete (LWC)

There are different types of lightweight concrete according to the materials included in there composition. Lightweight concrete is characterized by being light in weight, low in thermal conductivity, low in density, easy to transport and lay, and with higher workability. The ancient Greeks used lightweight concrete in construction for the first time in past centuries, and since then, the use of lightweight concrete has spread widely to other countries such as the USA, UK, France, etc.,**(Chandra & Berntsson, 2002).** According to **ACI.213R-03 (2009),** structural lightweight aggregate concrete (LWAC) is described as concrete made from lightweight aggregates that have a compressive strength greater than 17 MPa and an air-dry density from 1120 to 1840 kg/m^3.

2.4.1 Classification of Lightweight Concrete

LWC characteristics rely on the kinds of LWA in the concrete such that lightweight structural aggregate can create more than 35MPa compressive strength, **Neville & Brooks, (2010); ACI 213R,(2003); Miled et al., (2004); Mohammed & Hamad, (2014).** As shown in Fig. (2.1), **ACI 213 Committee (2009)** classified lightweight concrete into three classes, based on strength and specific weight:

1) Low-density, low-strength LWC used for heat and sound insulation (400- 800) kg/m^3.

2) Moderate-strength LWC, used in the construction of building blocks and other applications that do not need high strength, (800-1400) kg/m^3.

3) Structural lightweight concretes (more than 1400 kg/m^3).

Samidi, (1997) classified LWC into two types depending on the implementation, one type is partly consolidated LWC and the second type is structural LWC. The partly consolidated LWC is primarily applicable in blocks,

panels,… etc. The main criteria for this kind of LWC is that it must have a low density to rich better heating insulation and low drying shrinkage to prevent cracks. **Neville & Brooks, (2010**) classified lightweight concrete according to its composition and manufacture into three types;

1- Lightweight concrete formed as a result of replacing the natural weight in whole or partial lightweight aggregates.

2- lightweight concrete formed due to creating bubbles and air voids in it, such as cellular, aerated, and foamed concrete.

3- Lightweight concrete is formed without fine aggregates and is called no-fines concrete. Plate (2.2) illustrate three types of LWC.
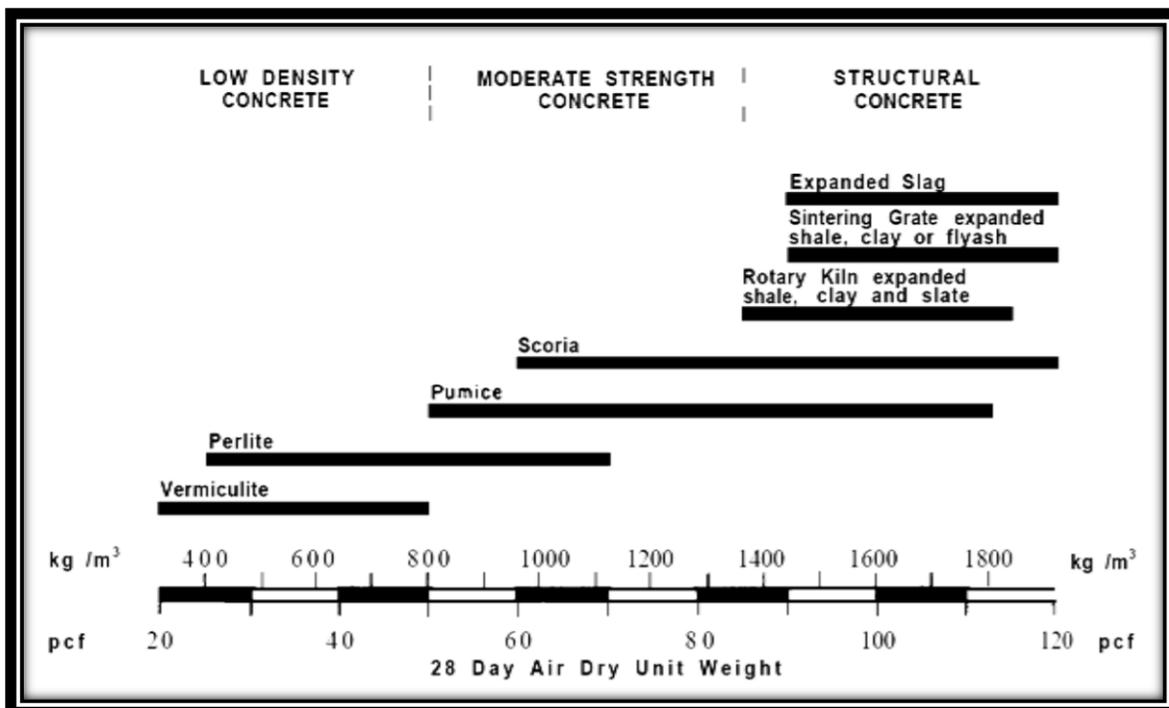
Fig. (2.1) Spectrum of lightweight aggregates concretes (ACI 213R-87).
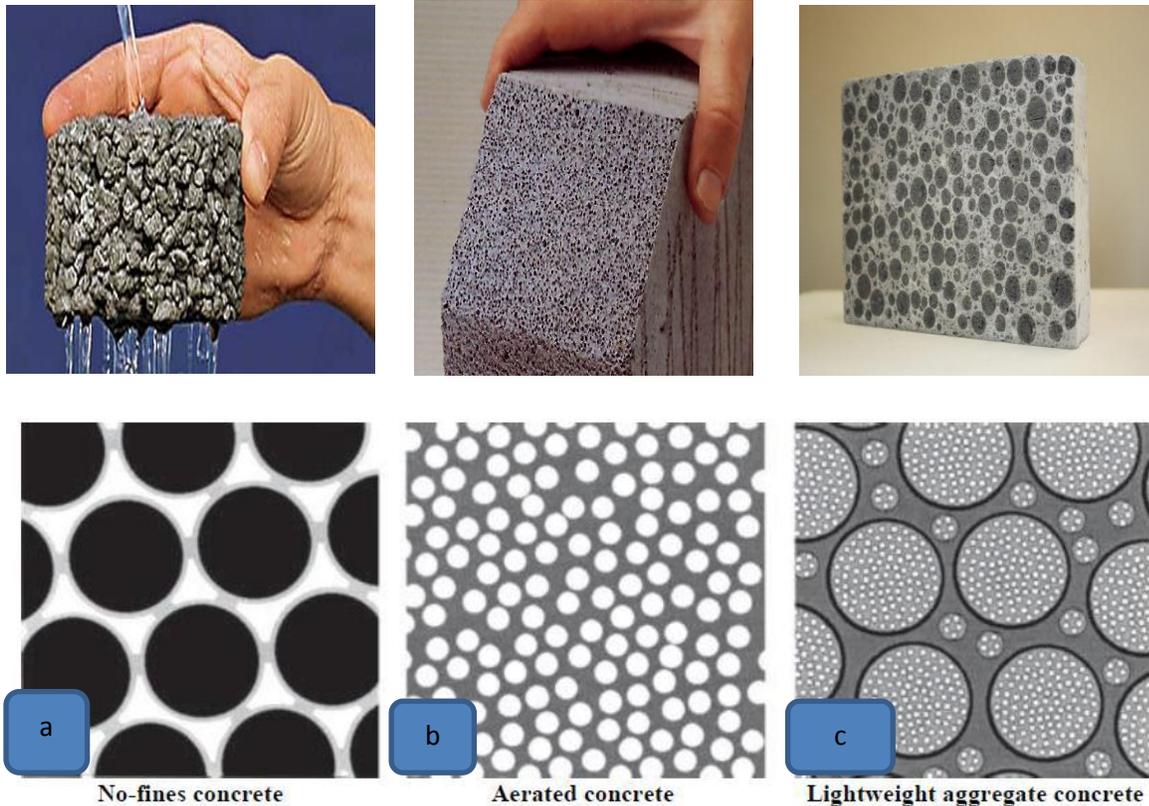
Plate (2.2) Some kinds of lightweight concrete, (a) No-fines concrete, (b) Aerated concrete, and (c) Lightweight aggregate concrete   (Slaby et al., 2008).

2.4.2 Lightweight Aggregate

2.4.2.1 Lightweight Expanded Clay Aggregate (LECA)

There are multiple sources of lightweight aggregates found as natural and artificial materials as shown in Fig (2.2). For the lightweight aggregate to be suitable for use in structures that consist of lightweight concrete containing microscopic pores, it must conform to the American Specifications**, (ASTM C330M-17a, 2017).** According to **Alexander, (1999) and Latosińska et al., (2021)**, LECA is primarily composed of silicon, aluminum, iron, and calcium oxides, as well as some alkalis and sodium and potassium oxides. When manufacturing LECA, Natural clay expands at 1000-1200 °C due to the action of gases emitted within the mass, resulting in expanded clay **(Cavaleri et al., 2003).**

The multiple separate air spaces inside LECA are the main reason for its being light in weight and that the bulk density of the LECA has a close relationship with the size of its particles, LECA has a bulk density of between 250 and 710 kg/m^3, **(Hall, 2010). Rashad, (2018),** mentioned many changes in the properties of concrete when it contains Lightweight Expanded Clay Aggregate such as decreasing its compression strength, tensile strength, flexure strength, density, weight, resistance to chloride reactions, resistance to freezing and thawing. On the other hand, its fire resistance, thermal and sound insulation, and water absorption will increase. **De Gennaro et al., (2005),** expressed an optimistic view of the growth and development of the lightweight aggregate industry because it is economical and has good performance when used in the construction field. Moreover, it has a high sound and thermal insulation because it contains gaps and pores inside. Furthermore, low-density products reduce self-weight, foundation size, and construction costs**, (Alduaij et al., 1999).**

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                    Lightweight Aggregate

        Natural Lightweight              Artificial Lightweight
            Aggregate                          Aggregate


        • Rice husk                      • Coke breeze
        • Sawdust                        • Foamed slag
        • Volcanic cinders               • Bloated clay
        • Scoria                         • Artificial cinders
        • Diatomite                      • Expanded shales
        • Pumice                           and slate
                                         • Sintered fly ash
                                         • Thermocole beads
                                         • Expanded perlite
                                         • Exfoliated
                                           vermiculite
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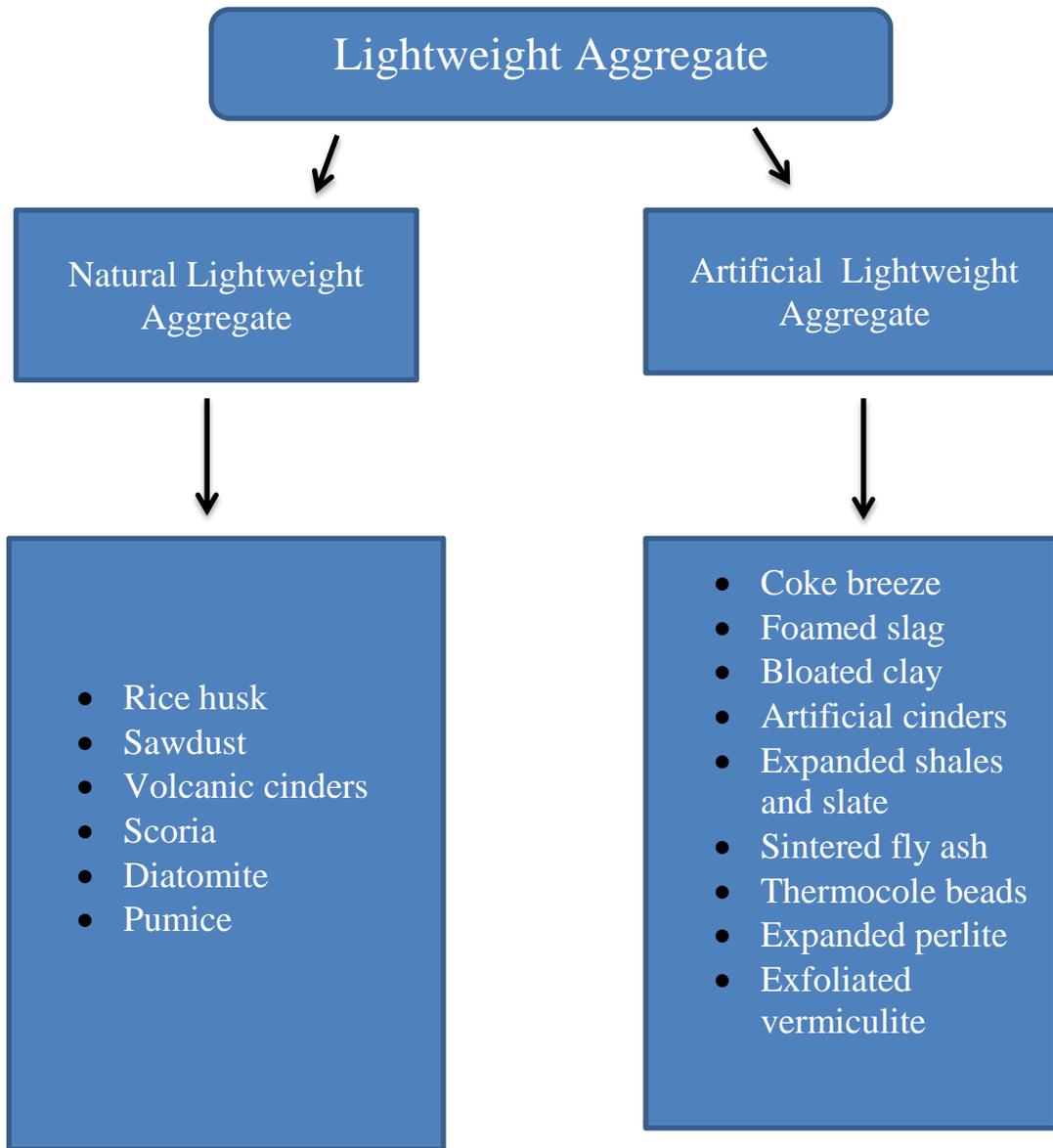
Fig. (2.2) Natural and artificial lightweight aggregate (Shetty, 2005).

2.4.3 Fresh and Hardened Properties of LWC

Many factors affect fresh and hardened properties of LWC such as temperature, relative humidity, sunlight, and wind speed, **(Weather et al., 1986).**

2.4.3.1 Fresh Properties of LWC

To some extent, there is some similarity between LWC and NWC in their fresh properties. However, lightweight concrete requires less effort when mixing and pouring compared to normal weight concrete, and some research has confirmed that the workability of lightweight concrete is higher than that of ordinary concrete despite the similarity in the slump magnitude. **Agrawal & Sharma, (2010),** mentioned that the slump test is a near test that gives an impression and information about the workability of concrete. It is also a simple and easy test to apply in the site or laboratory. Workability refers to a variety of characteristics of freshly mixed concrete that are difficult to quantify such as cohesiveness and consistency **(Marar, 2011).** A mixing procedure can differ in mixing time, mixing speed, air pressure in the mixing pan, addition time of the superplasticizer, temperature, etc. **(Dils et al., 2012). Youm et al., (2016),** made concrete mixtures using three types of aggregates (Argex Lightweight, Stalite Lightweight, and Normal-weight), three ratios of w/b (28.1,25.9, and 24.22), and three ratios of silica fume (0%,3.5%, and 7%). They noticed that the highest slump flow was 230 mm in the mixture containing Argex Lightweight and (0%) silica fume, and adding superplasticizer was required at 7% inclusion of silica fume. They indicated the need to add dosage of plasticizer when using silica fume at (7%) due to the decrease in the magnitude of slump flow.

OTHMAN et al., (2020) confirmed that the water absorbed by the expanded clay particles affected the consistency of the concrete mixture, such that the amount of slump increased from 100 mm to 150 mm when the percentage of LECA was increased from 30% to 100%.

2.4.3.2 Strength of LWC

The properties of LWC are more influenced by the characteristics of cement paste. There are some characteristics of aggregate that may affect concrete properties such as particle shape, relative density, surface texture, dry weight, the strength of lightweight aggregates, corrosion resistance, the total volume of voids, max. size, moisture content, absorption water, and MOE of lightweight aggregate particles (**ACI 213R-03,(2003) and Anwar H. (2012).**

2.4.3.2.1 Compressive Strength

Kolias & Georgiou, (2005) concluded that under certain curing conditions and for a certain age, the degree of compaction and the ratio of water to cement are the most important factors that control the compressive strength of concrete. The predominant influencer on the maximum value of compressive strength is the coarse aggregate. However, for some specific lightweight aggregates, the compressive strength could be quite high, approaching that of some normal-weight aggregates. Decreasing the maximum coarse aggregate size for most lightweight aggregates, particularly the weaker and more friable ones could increase this ceiling of strength. As a result, the concentration of stress around the aggregate is decreased and the concrete matrix would be more homogenous (**ACI 213R-03);** (**Anwar Hossain, 2012).**

Sajedi & Shafigh, (2012) made eleven concrete mixtures using expanded clay (LECA) as aggregates. They found that air-curing concrete showed 18% lower compressive strength than water-cured ones. Furthermore, the compressive strength of LWC was primarily based on the density, which was governed mainly by the content of cement.

Failure occurrence is being through the aggregate because of the softness of the lightweight aggregate compared to the surrounded mortar. However, the stress in the mortar is reduced by increasing the aggregate stiffness. Fig. (2.3) shows the normal and lightweight concrete behavior under the force of compression. The brittleness of lightweight concrete is more than that of normal-weight concrete **(Gerritse, 1981).**
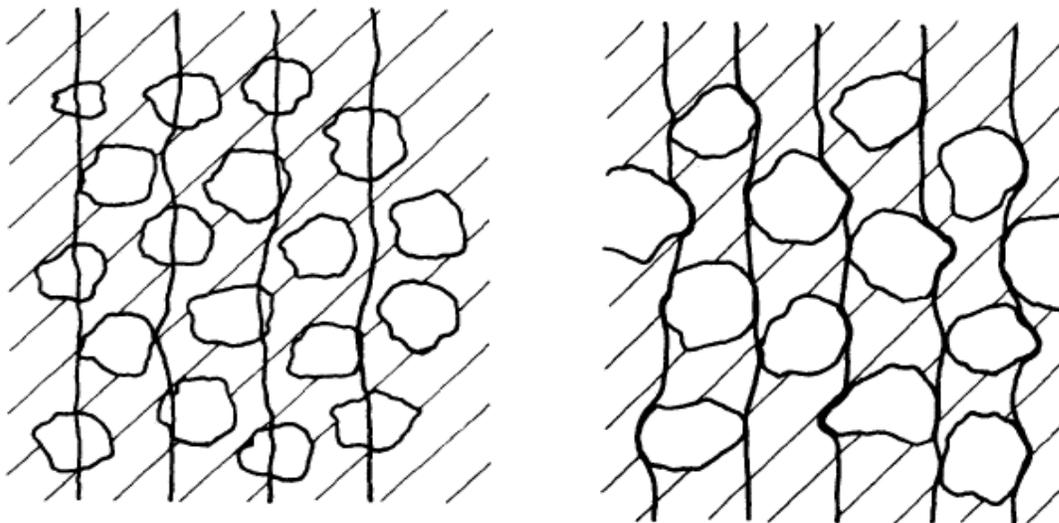
A-Failure paths in LWC.   **B-Failure paths in NWC.**

Fig. (2.3) Failure of concrete under compression (Gerritse, 1981).

Dilli et al., (2015) conducted experiments on lightweight concrete and ordinary concrete. They concluded that increasing the compressive strength led to an increase in the modulus of elasticity of concrete, they were also noted that the modulus of elasticity was affected by the strength and type of aggregate.

Rajprakash & Krishnamoorthi (2017) observed that the compressive strength of up to 29 and 25 MPa at 20% and 40 % respectively of substituted normal aggregate with lightweight expanded clay aggregate (LECA) can be reached when cured for,28, days, and, compressive, strength, can also be improved if cured for 60 days or more**. Ismail et al., (2018)** studied the behavior of LWC containing nano-silica. Many dosages of nano-silica were made to blend various concrete mixtures (0.75 %, 1.5 %, and 2 %). At 7, 28, and 90 days, 0.75% of nano-silica was the optimal addition percentage to obtain the maximum compressive strength. Moreover, the microstructure of nano-silica concrete mixtures was more homogeneous, with a lesser amount of voids. LECA was found to be the best lightweight aggregate in this study due to its density and strength. **Nehhaba & Nahhab (2020)** made experiments on the two types of concretes namely, concrete having LECA and self-compacting concrete having LECA. They concluded that the inclusion of sulfate resisting Portland cement led to an improvement in the elastic properties and strengths irrespective of the concrete type.

2.4.3.2.2 Flexure Strength

The flexural strength of LWC is affected by the characteristics of the LWA such as the shape of the particles, the maximum size of the particles, the amount of aggregates in the mixture, etc. As in ordinary concrete, the flexural strength increases as its compressive strength increases. **Mahdy, (2016)** found that the flexural and compressive strength increased when they treated lightweight aggregate by silica fume at different dosages. He used structural lightweight concrete with a density between 1650 and 1850 kg/m^3. A 10% of silica fume was more economical to treat LECA.

After conducting practical experiments on replacing natural-weight aggregates with light-weight aggregates, **(Rajprakash & Krishnamoorthi, 2017)** found a decrease in flexural and tensile strength when the proportion of coarse natural-weight aggregates was replaced with light-weighted aggregates.

2.4.3.2.3 Permeability and Water Absorption of LWC

It is known that the increase in the economic life of concrete depends mainly on its durability. The researchers mentioned many factors that affect permeability and rate of absorption in lightweight concrete and natural weight concrete. Studies and experiments have proven that lightweight concrete is more water-absorbent because it contains capillary pores and many gaps, as well as low its specific weight. In general, the factors affecting the water absorption rate of concrete are the type of aggregate, its quantity in the mixture, its ability to absorb the water, its shape, and its maximum size. The other factors are the temperature, the amount of cement paste, the quantity and type of cement, and the ratio of water to cement. Here, we will refer to some researchers in this field, such as **(Chia & Zhang, 2002)** found that normal concrete has higher water permeability than lightweight concrete, though the resistance to chloride penetration is similar for two types of concrete. After 28 days of exposure, it was seen that the water penetration resistance of LWC was higher than that of normal concrete .

Kolias & Georgiou,(2005) studied four ratios of w/c (0.3, 0.4, 0.5, and 0.6), and each ratio contains four water contents(140, 180, 220, and 260 L/m^3) and concluded that the water absorption increased with increased values of w/c ratios, because of increase of paste porosity. Also, they discovered that the moisture contents of the concrete samples at the time of examination have a significant impact on transport characteristics and capillary absorption for concrete as shown in Fig. (2.4). **Bastos et al., (2005)** discovered that increasing LECA content from (55% to 90%) as coarse aggregate caused a greater percentage of water absorption of concrete blocks. **Sandström et al., (2012)** mentioned that the water absorption of concrete is affected by several factors, such as the temperature of the surrounding environment when examining samples, the cycles of ice and thawing, and the ratio of water to cement. **Kumar Mehta & Monteiro, (2014)** found the rising permeability of concrete led to the large hole between molecules that increases their interactions and decimate its stabilities. Furthermore, the durability of concrete is primarily determined by the ability of liquids to penetrate the microstructure of the concrete, which is referred to as permeability,**(Zhang & Zong, 2014).**

Real et al., (2015) discovered that adding LECA to mortars increased the capillary absorption coefficient. As the amount of LECA in the mixture rose, the coefficient of capillary absorption increased by 27.9%, 28.85%, and 34.62% when the volume of LECA increased to 250, 300, and 400 L/m^3, respectively. Water absorption and absorption rates can vary widely in lightweight concrete manufactured using expanded clay and other lightweight aggregates such as expanded shale, pumice, slate, perlite, **(Lotfy et al., 2015). Muñoz-Ruiperez et al., (2016)** noticed an increase in the water absorption percentage of concrete when they replaced the normal weight sand aggregates with a blending of LECA.

Vargas et al., (2018), looked into the impact of two lightweight aggregates (LWA) (perlite and expanded clay) on the external sulfate resistance on concrete caused by magnesium sulfate (MgSO4). There was a resemblance in the reaction to chemical attack by magnesium sulfate mechanism between LWC and NWC, especially if the attack occurs primarily on the C-S-H, but the lightweight aggregate type could enhance this reaction.
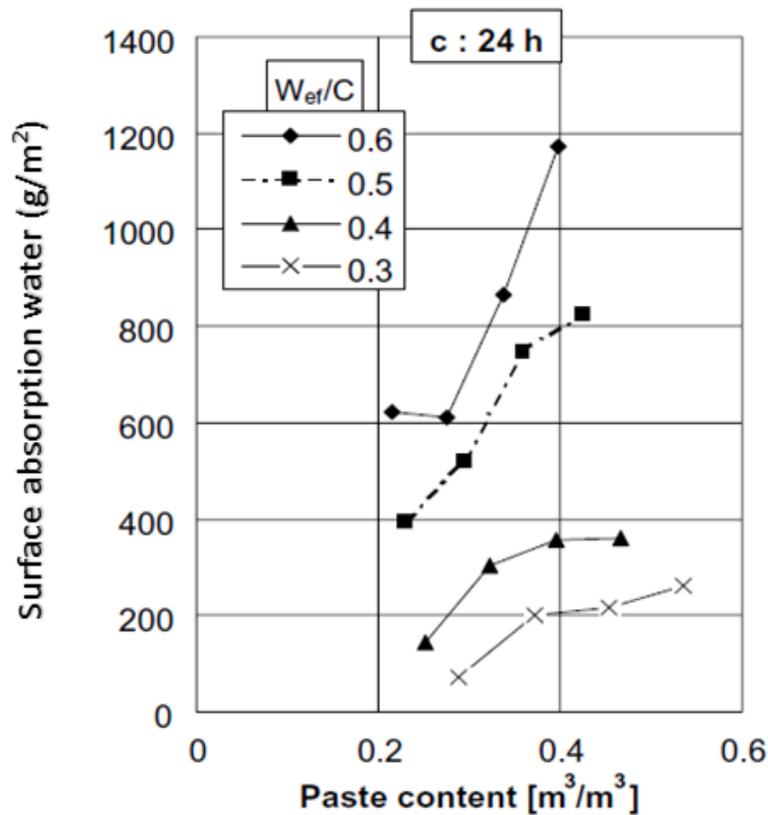
Fig. (2.4) Surface absorption water and paste content.

2.4.3.2.4 Density of LWC

It is known that the density of concrete expresses the extent of its strength, hardness, thermal and sound insulation, the quantity and density of aggregate is one of the factors affecting the density of concrete. **Mehta & Monteiro, (2006)** confirmed that it is possible to produce concrete with has density (1120 kg/m^3) by using lightweight aggregates instead of natural weight aggregates. According to **(Mačiulaitis et al., 2009),** the replacing of NWA with LECA size (0 -10mm) can produce concrete with a density of 1526 kg/m^3. Lightweight concrete has a dry density (1935 – 1995) kg/m^3, its compressive strength can reach (22.5 – 43) MPa in addition to well workability **(Shannag, 2011).**

At the age of 28 days, **Lakshmi et al., (2017)** discovered that the unit weight of concrete decreased by (9.71%, 10.38%, 15.13%, and 19%) when they partially replaced natural coarse aggregates with lightweight coarse aggregates by a percentage of (45, 50, 60, and 70) respectively. **Nahhab & Ketab, (2020)** made experiments using three maximum sizes of LECA (10,14, and 20 mm). They partially and completely replaced the natural coarse aggregates with lightweight aggregates, they concluded that increasing the maximum size of aggregate led to a decrease in the oven-dry density.

2.4.4 Thermal Insulation and Sound Isolation of LWC

The property of thermal insulation for the material was mentioned by **Snow, (1982),** as a property material or composite of materials that, when used properly, slow the rate of heat transport by conduction, convection, and radiation because of its high thermal resistance, it slows heat passage in or out of a structure.

According to **Sousa et al., (2004)**, masonry units that included LECA as part of aggregates (0.53 m^3 normal weight sand combined with 0.14 m^3 LECA with a size of 2–4 mm and 0.73 m^3 LECA with a size of 3–8 mm) showed great sound and thermal insulation. With the addition of LECA, the thermal conductivity decreased to 0.5 W/m K. **Cui & Shi, (2012)** studied the thermal properties of different types of concrete containing (expanded clay, perlite, and vermiculite) as a lightweight aggregate for use in thermal insulation above the roofs. They concluded that lightweight concrete with a density of (700-900) kg/m^3 was very suitable for thermal insulation, while concrete contained perlite as aggregate was suitable for roofs requiring low dead loads, and expanded clay concrete can be used in the roofs as structural concrete having good thermal insulation. As shown in Fig.(2.5).
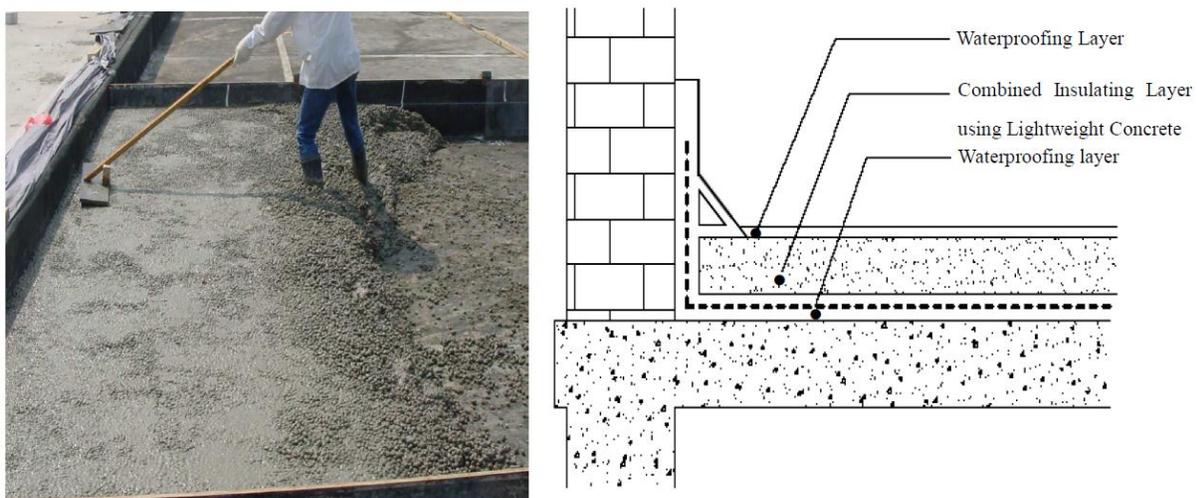
Fig. (2.5) Using LWC on the roofs, (Cui & Shi, 2012).

Melo et al., (2016) conducted experiments on self-compacting lightweight concrete and concluded that increasing the volume of clay expanded in the mixtures led to an improvement in the thermal and acoustic insulation of concrete. **Ahmad & Chen, (2019)** made concrete mixtures consisting of different proportions of LECA and foam, they noticed that increasing the proportion of foam and decreasing the proportion of LECA in the same mixture led to an improvement in the thermal insulation of lightweight concrete. Also, they noticed a direct relationship between dry density and thermal conductivity. **Manaf et al., (2021)** made lightweight concrete mixes using High-Density Polyethylene (HDPE) plastic waste, they concluded that increasing the ratio of HDPE led to an increase in Sound absorption coefficient (SAC).

2.4.5 Concluding Remarks

There are many studies dealing with ordinary and reinforced concrete tiles, and there are also a lot of research dealing with lightweight concrete, but we rarely find research related to the production of lightweight tiles and studying their mechanical and thermal properties.

In addition, this study adopted the Iraqi specifications in conducting tests of precast concrete tiles and gave importance to the effect of thermal insulation of concrete tiles to rationalize energy consumption.

Chapter Three

CHAPTER THREE

The Practical Experiments and Tests

3.1 Introduction

Chapter three deals with materials preparation, mixing, casting, and production of specimens of concrete cubes, tiles, and small discs by using lightweight expanded clay aggregate (LECA) of various densities (320,700 kg/m^3) as well as ordinary coarse aggregates. The produced samples were subjected to different types of curing regimes with different periods, as follows:

The first type (curing regime I): in which the specimens were immersed in water for three days, seven days, and twenty-eight days.

The second type (curing regime II): in which the specimens were immersed in water for three days only and left in the air up to testing age.

The third type (curing regime III): in which the specimens were left in the laboratory so that they were exposed to the air for three days, seven days, and twenty-eight days.

The normal and lightweight concretes have been subjected to various tests in both fresh and hardened states. In the fresh state, the slump and fresh density have been measured. In the hardened state, the concrete tiles have been tested for flexures such as fracture load, and modulus of rupture was determined. Cubes have been tested for compressive strength and oven dry density while concrete discs have been tested for thermal conductivity. Fig. (3.1-a) and Fig. (3.1-b) shows flow chart for the experiments.
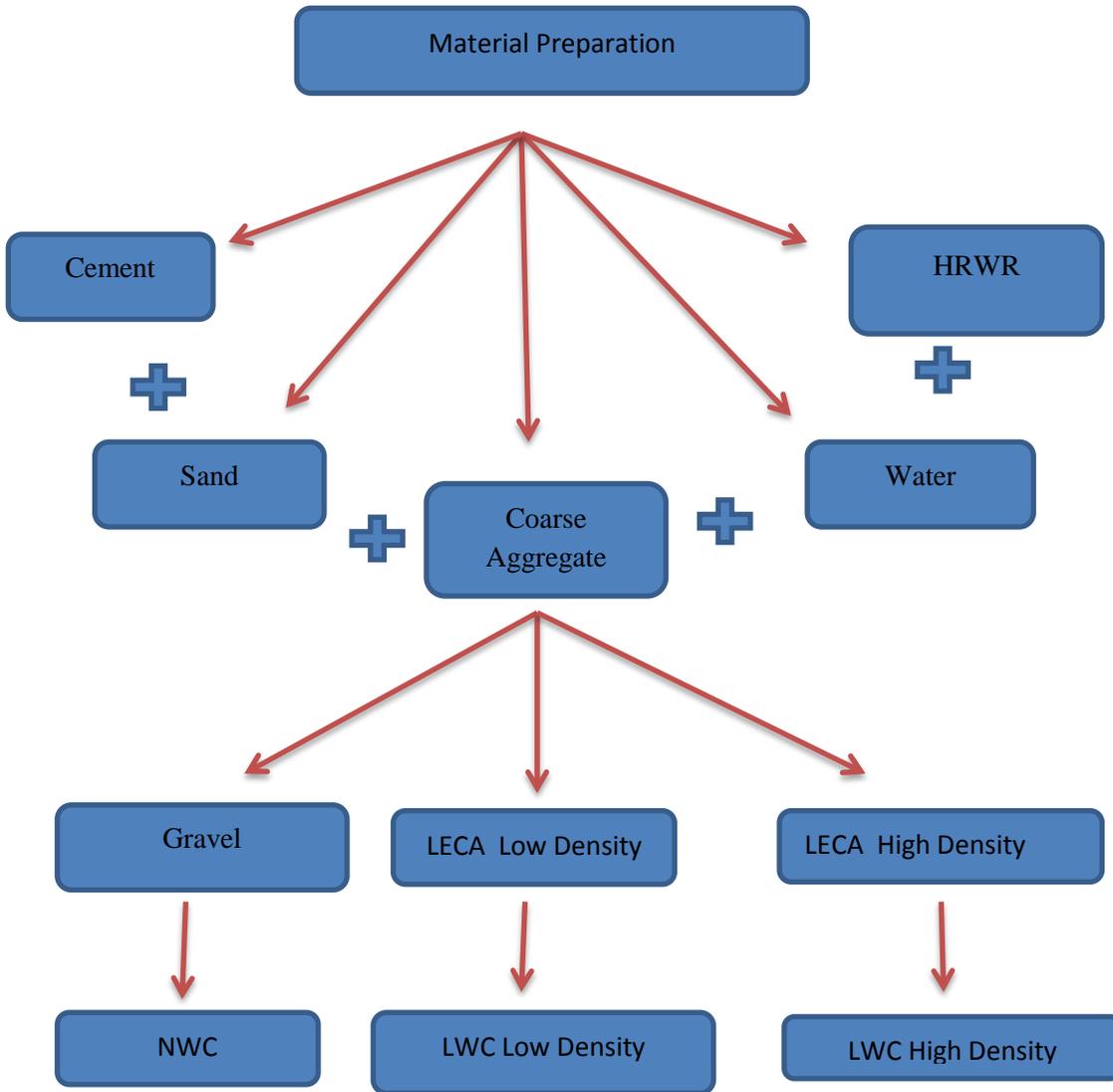
Fig. (3.1-a) Flow chart for experimental work program.

Mixing Construction Materials

Vibration

Slump Test

Fresh Density Measurement

Curing

in water to 3day

in water

in air

Cube(10*10*10)cm

Tile (50*50*5)cm

Disk (40mm Dim.)

Compressive Strength Test

Oven dry Test

Dimensions and Shapes Test

Tiles-Modulus of Rupture Test

Water Absorption Test

Thermal Conductivity Test
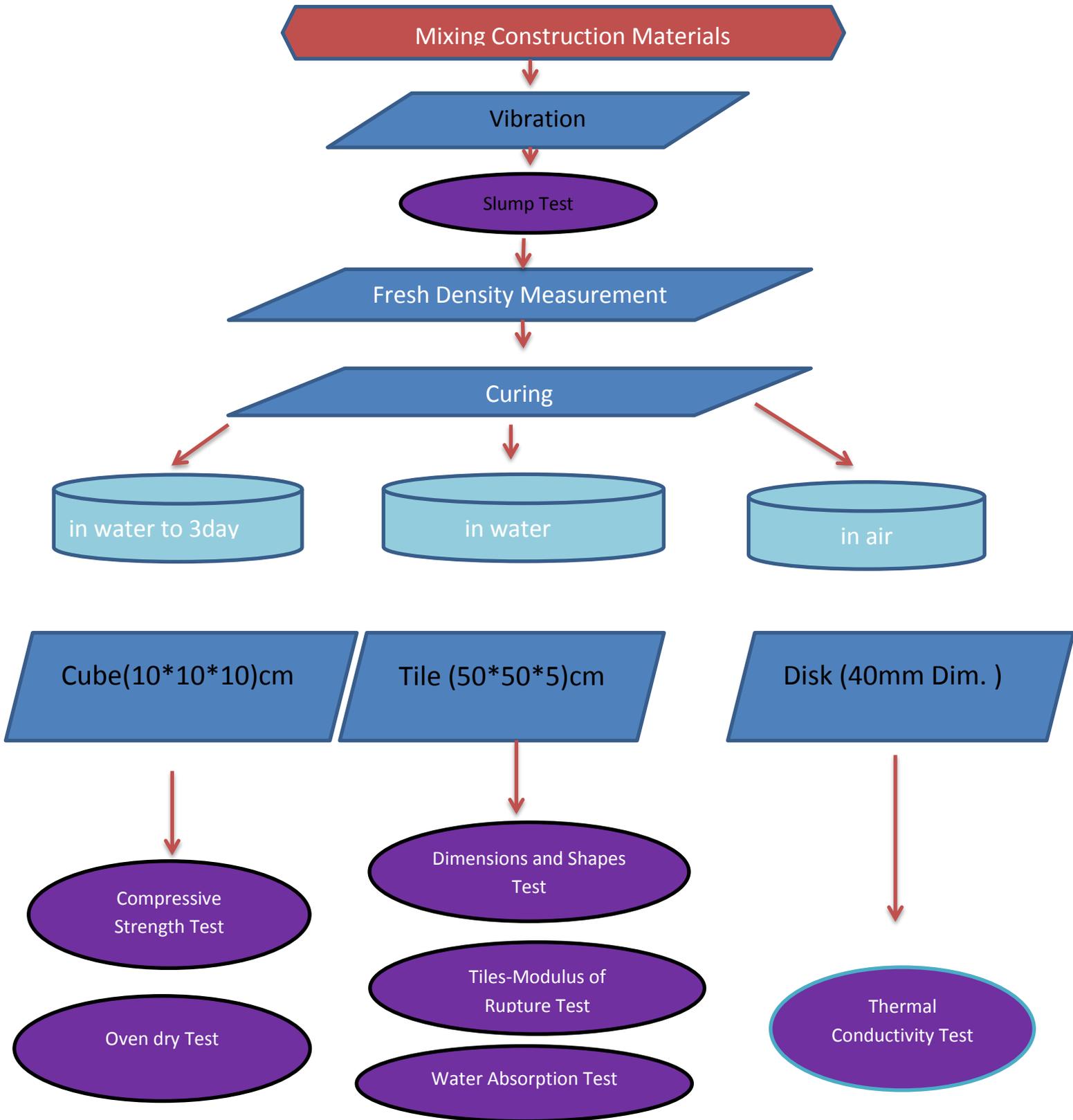
Fig. (3.1-b) Flow chart for experimental work program.

3.2 Materials

3.2.1 Sulfate Resisting Portland Cement (SRPC)

As shown in Plate (3.1), sulfate-resistant Portland cement used in this study is called (AL JESR) and is symbolized by the American Standard Specifications **(ASTM C 150, 2009)** as (**Type V**). The cement was having physical and chemical properties shown in Tables (3.1) and (3.2). It complied with Iraqi Standard **(IQS No. 5/ 1984).**

Plate (3.1) Sulfate resisting Portland cement used.

Table (3.1) Chemical characteristics of SRPC*.

Chemical Composition	Results	IQS No. 5/ 1984
CaO %	62.10	---
SiO_2 %	20.30	---
Al_2O_3 %	4.07	---
Fe_2O_3 %	5.17	---
MgO %	1.75	≤5.0 %
SO_3 %	2.33	≤2.5 %
L. O. I.	3.61	≤4.0 %
Insoluble Residue	0.55	≤1.5 %
L. S. F.	0.95	(0.66-1.02)
C_3S %	63.73	---
C_2S %	10.27	---
C_3A %	2.04	≤3.5%
C_4AF %	15.74	---

* The test was carried out in the lab. of construction materials at the University of Babylon.

Table (3.2) Physical characteristics of SRPC*.

Physical Properties	Test Result	IQS No. 5/ 1984
Fineness, Blaine, m^2/kg	335	≥ 250
Setting: initial (hour :min)	2:23	≥ 00:45
Final (hour :min)	3: 10	≤ 10:00 hrs
Soundness Using Autoclave Method	0.18	≤ 0.8 %
Compressive Strength in age 3 days (MPa)	18.04	≥15.00
Compressive Strength in age 7 days (MPa)	25.55	≥ 23.00

* The test was carried out in the lab. of construction materials at the University of Babylon.

3.2.2 Fine Aggregate

The fine aggregate (sand) was brought from an area in Karbala called (AL-Akhaidhir). Sieve analysis of sand is shown in Plate (3.2) while its physical and chemical properties are given in Tables (3.3) and (3.4). Both the figure and table indicated that the sand is satisfactory according to the Requirements of Iraqi Standard (IQS) No.45/ 1984, as shown in Plate (3.2).

Table (3.3) Sieve analysis of sand*.

Sieve Size (mm)	Cumulative passing %	Limits of IQS No.45/1984 /zone (2)
10	100	100
4.75	91	90 - 100
2.36	80	75 - 100
1.18	69	55 - 90
0.6	54	35 - 59
0.3	25	8 - 30
0.15	8	0 - 10

* The test was carried out in the lab. of construction materials at the University of Babylon.

Table (3.4) Physical and chemical properties of sand*.

Physical properties	Test result	Limits of IQS No.45/1984
Specific gravity	2.65	
Absorption %	0.93	
Fineness modulus	2.67	
Sulfate content %	0.35	≤ 0.5%
Fines particles passing from sieve 75 micron %	3	5%

* The test was carried out in the laboratory of construction materials at the University of Babylon.
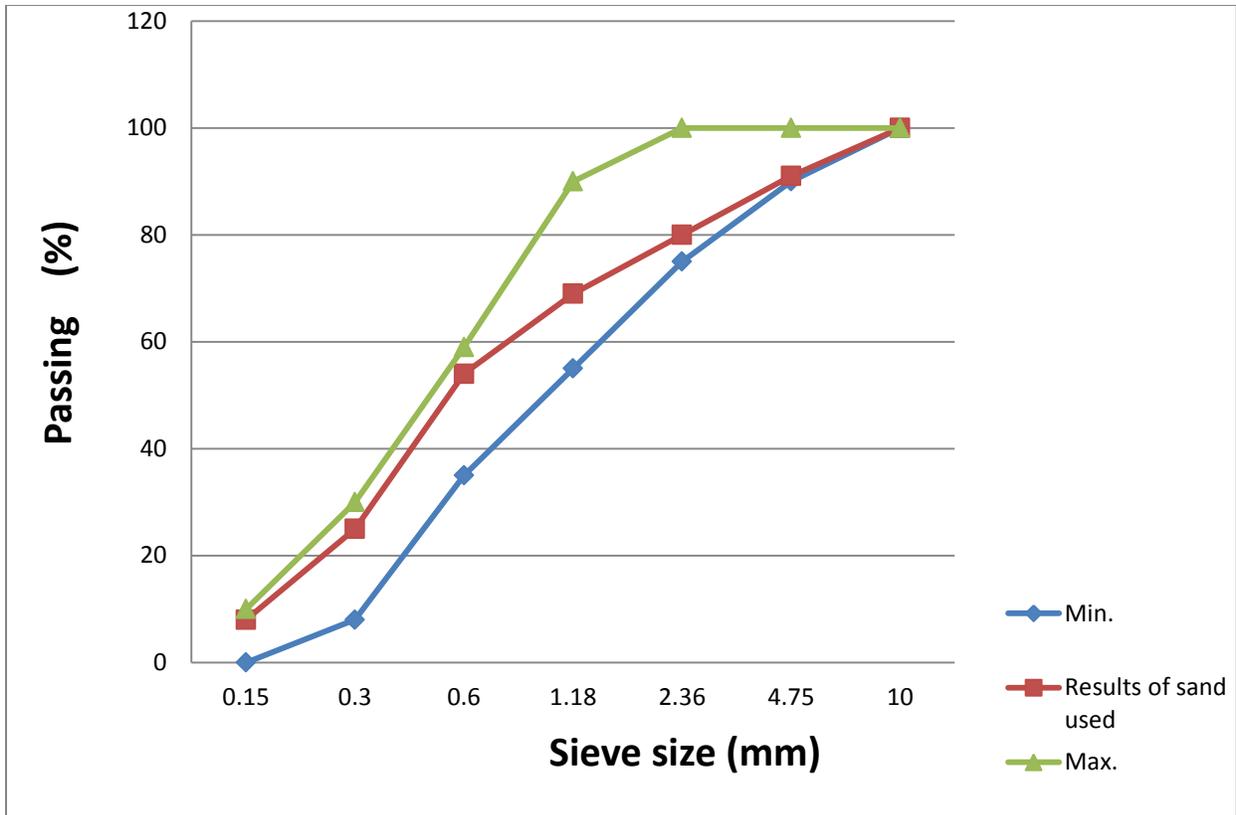
Fig. (3.2) Sieve analysis representation of sand.

Plate (3.2) Fine aggregate (sand).

3.2.3 Coarse Aggregate

3.2.3.1 Natural Weight Coarse Aggregate

The coarse aggregates with a bulk density of 1600 kg/m^3, specific gravity of 2.6, and water absorption of 0.80% were used in the experiments of this work. The gravel used has uncrushed shape with a maximum size of 10 mm, which was also collected from local sources in Iraq from a zone called **(Al-Nibaai)** as shown in Plate (3.3). Table (3.5) and Fig. (3.3), show its particle distribution which conformed to the (**IQS No.45/1984**).

Table (3.5) Physical and chemical properties of the normal coarse aggregate*.

Sieve Size (mm)	Cumulative Passing %	Limits of IQS No.45/1984 /zone (2)
14	100	100
10	100	85 - 100
4.75	6	0 - 25
2.36	2.4	0 - 5
Chemical properties		
Sulfate content %	0.04%	≤0.1%

* The test was carried out in the laboratory of construction materials at the University of Babylon.
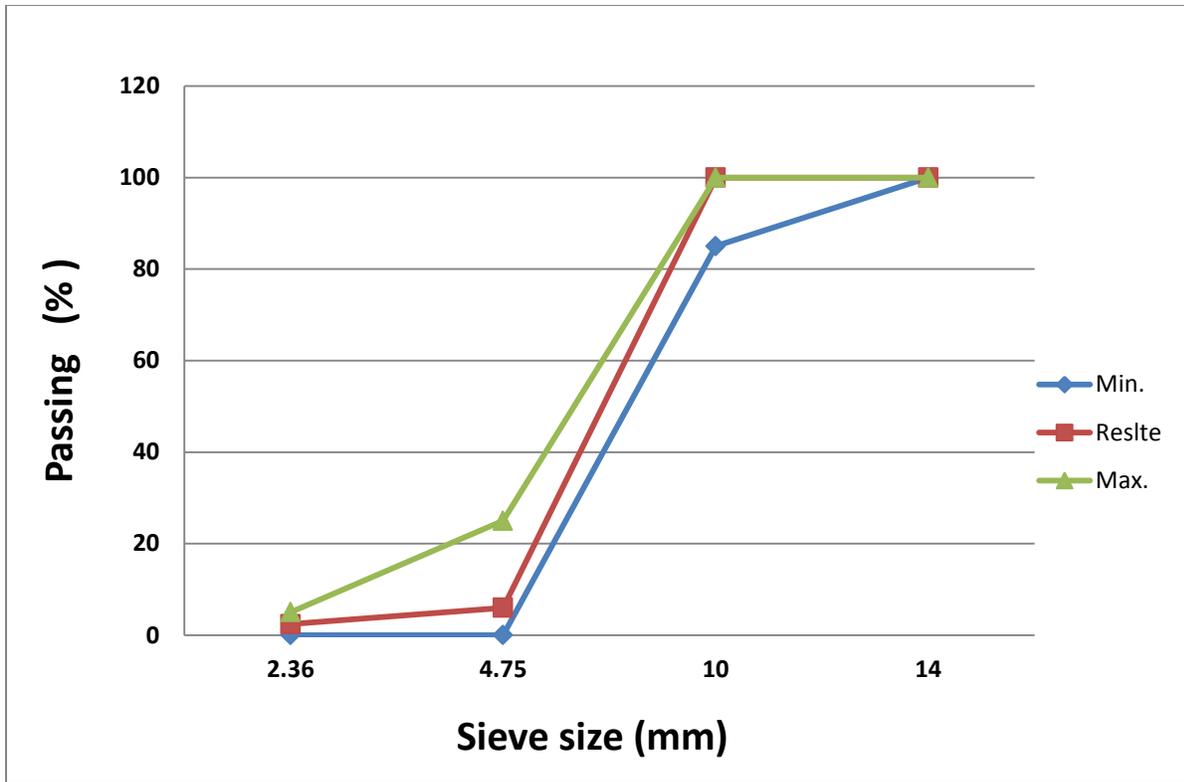
Fig. (3.3) Sieve analysis representation for (5-10) mm maximum size normal coarse aggregate.

Plate (3.3) Natural coarse aggregate (gravel).

3.2.3.2 Lightweight Expanded Clay Coarse Aggregate

Two types of lightweight expanded clay aggregate (LECA) which was brought from Tehran, Iran. The LECA was used in two different densities(320 and 700 kg/m^3)which had a specific gravity of 0.6 and 1.2, respectively. The former had a water absorption of 24% while the latter had a water absorption of 12%. The low-density LECA and high-density LECA were defined by the symbols LDLECA, and HDLECA, respectively. The grading of all types of lightweight coarse aggregate used was given in Tables (3.6) and (3.7) which conformed with (**ASTM C330-17a,2017**) for coarse aggregate specification, as shown in Plate (3.4).

Table (3.6) Physical properties of LECA Low-Density coarse aggregate*.

Sieve Size (mm)	Cumulative Passing %	Limits of ASTM C330-2017
12.5	100	100
10	100	80-100
4.75	5	5-40
2.36	1	0-20
1.18	0.2	0-10

* The test was carried out in the laboratory of construction materials at the University of Babylon.

Table (3.7) Physical properties of LECA High-Density coarse aggregate*.

Sieve Size (mm)	Cumulative Passing %	Limits of ASTM C330-2017
12.5	100	100
10	100	80-100
4.75	7	5-40
2.36	2	0-20
1.18	0.3	0-10

* The test was carried out in the laboratory of construction materials at the University of Babylon.
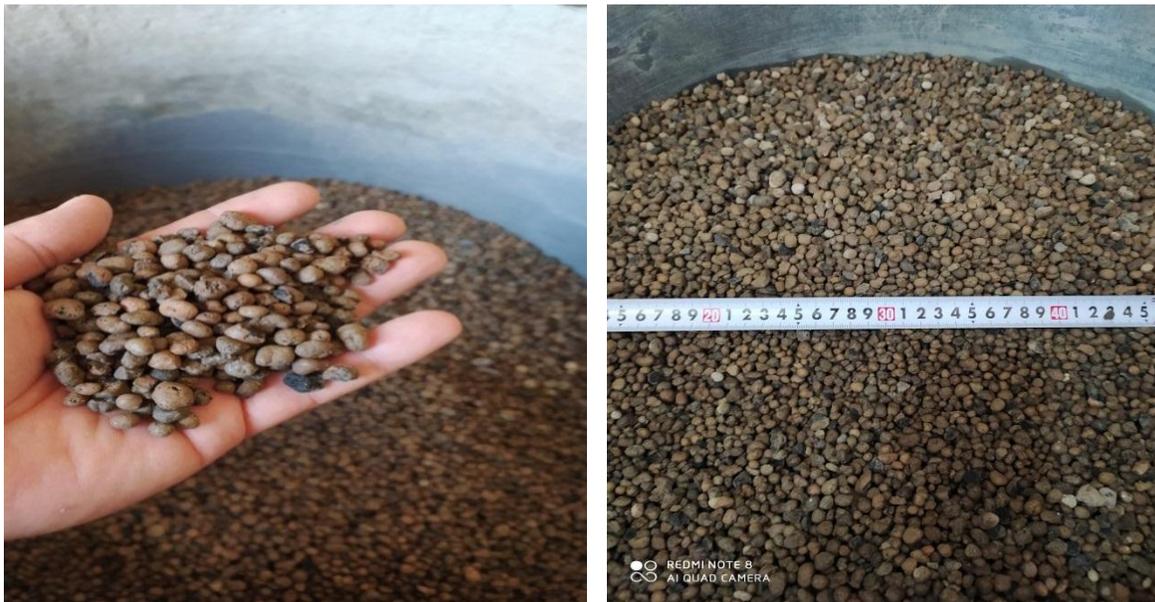
Plate (3.4) Lightweight expanded clay (LECA).

3.2.4 Super-Plasticizers

In mixes, a high range water reducing admixture (HRWRA) was used, as shown in Plate (3.5). The manufacturer advised the dosage of (0.75-2) liters /100 kg of cementitious material. The **ASTM C494-04 type (F)** standard is followed when using this superplasticizer. The primary features of the superplasticizer are listed in Table (3.8).

Table (3.8) Properties of the superplasticizer*.

Technical Description	Properties
Appearance	Dark Brown / Black liquid
Specific gravity	1.235 at 25± 2 C
Chloride content	Nil
Storage life	Up to one year in airtight container.

* The results were given by the manufacturer.

Plate (3.5) Superplasticizer used.

3.2.5 Water

Drinkable water from the unit of water supply was used in this study, so it was clear of residual and organic materials that could have impacted on concrete properties.

3.3 Mixtures Proportion for Concrete

To reach the appropriate mixing ratio, which achieves acceptable compressive strength, light in weight, good workability, and an acceptable percentage of cement content per unit volume, The concrete mix was designed according to **ACI Committee 211.2-98.** Thereafter, a set of experimental mixtures was made using lightweight coarse aggregate (HDLECA), as shown in Table (3.9).While in Table (3.10) summarizes the mix proportions of three types of concretes from which the samples were cast. The first type was normal weight concrete (NWC) which was considered as a reference concrete. The second type was lightweight concrete incorporating with LECA of low density while the third type was lightweight concrete incorporating with LECA of high density. Indeed, the mixture proportions of all types were the same except for the amount of coarse aggregate which was changed depending on its specific gravity, as shown in Fig. (3.4).

Table (3.9) Details of trial mixes for LWC-HD (kg/m^3).

Trial Mix No.	1	2	3	4
Cement (kg/m^3)	500	570	505	570
Sand (kg/m^3)	650	630	655	620
HDLECA (kg/m^3)	440	385	430	390
Water (kg/m^3)	200	228	202	228
SP by wt. of cement (%)	0.75	1.00	0.75	1.00
W/C ratio	0.40	0.40	0.40	0.40
Slump (mm)	90	70	55	80
Fresh Density (kg/m^3)	1805	1832	1820	1827
28-day Compressive Strength (MPa)	30.5	44.2	31.8	42.3

Table (3.10) Mix proportion of NWC, LWC-LD, and LWC-HD.

	NWC	LWC Low Density	LWC High Density
Cement (kg/m^3)	505	505	505
Sand (kg/m^3)	655	655	655
LDLECA (kg/m^3)	------	215	-----
HDLECA (kg/m^3)	-----	-----	430
Gravel (kg/m^3)	940	------	------
Water content (kg/m^3)	202	202	202
S.P (kg/m^3)	0.379	0.379	0.379
Slump (mm)	40	60	55
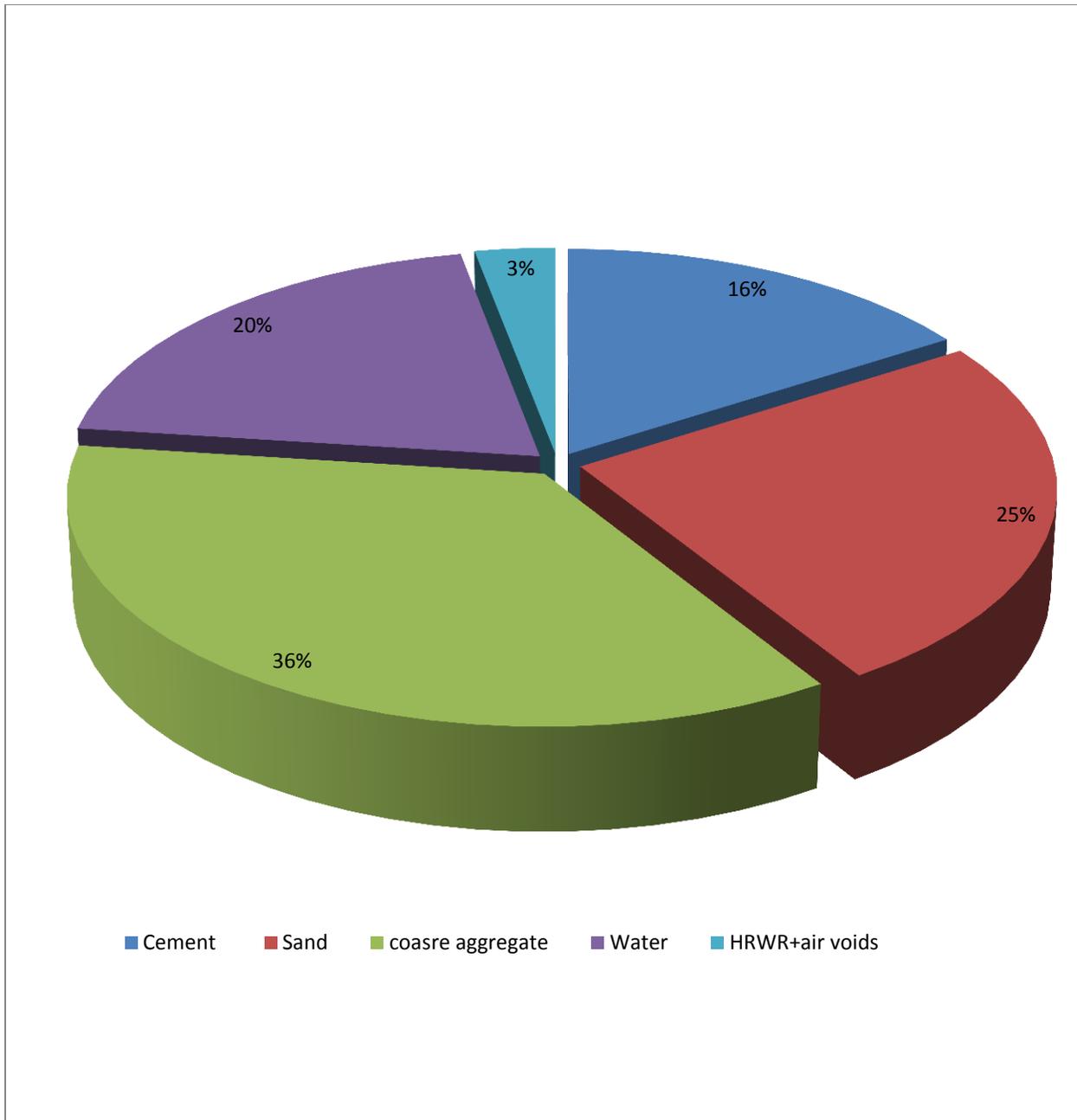
Fig. (3.4) Materials proportion (by volume) used in mixtures.

3.4 Concrete Mixing, Placing, and Curing Procedures

The mixing procedure is essential to achieve the necessary concrete mixture homogeneity and workability. The mixing is carried out in a pan-type laboratory mixing machine with a capacity of 0.09 m^3 as demonstrated in Plate (3.6-a). The mixing machine should be kept clean, moist and without water before beginning to mix. This mixer was used for mixing LWC-LD, LWC-HD, and NWC. In the process of mixing, all the materials were backed into the plastic container after weighing. Because of the high lightweight aggregates capacity for absorption water, the aggregates were before-soaked for at least 48 hr. As in Plate (3.7), then the extra water has been dried and the mass of the materials has been weighted as advised by (**ACI Committee 211.2-98**). The coarse aggregate (LECA or gravel) and fine aggregate were blended with 50 percent of the mixing water for three minutes, then the sulfate resisting Portland cement was put in the mixer and blended for an extra 60 seconds. Finally, the remaining water and superplasticizer were added to the mixture and mixed for another 4 minutes. Two minutes was taken as Break time before Placing the fresh mixes in molds. The entire mixing cycle takes approximately 11 minutes. The mixing process series is shown in Fig. (3.5). Beyond mixing, the slump test was performed. The interior surfaces of models are oiled after a good cleaning to prevent adhesion with concrete after hardening as in Plate (3.8). Cube molds are filled with concrete in the form of layers and compacted with a stick to expel the gaps and voids and weighed to know the fresh density of the concrete, while the concrete tiles molds are placed over the vibration device as in Fig. (3.6-b) and shaken for a few seconds to become completely compacted. Thermal conductivity test molds are filled with concrete and subjected to the same conditions as other molds in terms of temperature and curing period. The samples were remained for 24h in the molds before placing

them in the water tank as in Plate (3.9) to start the curing process which continued up to the age of 3 days,7days, and 28 days. Some samples remain in the air for 3 days, 7 days, or 28 days, after which they are taken for testing.

Plate (3.6): (a) Laboratory mixing machine, (b) Laboratory vibration machine.

Plate (3.7): (a) LECA of low density, (b) LECA of high density.

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┌─────────────────────────────────────────────────────────┐
│     Mixing the sand and LECA or Gravel with 50% of water  │
└─────────────────────────────────────────────────────────┘
                    │  3 MIN
                    ▼
┌─────────────────────────────────────────────────────────┐
│          Adding Sulfate Resisting Portland Cement         │
└─────────────────────────────────────────────────────────┘
                    │  2MIN
                    ▼
┌─────────────────────────────────────────────────────────┐
│         Addition 50% of Water containing  HRWR            │
└─────────────────────────────────────────────────────────┘
                    │  4 MIN
                    ▼
┌─────────────────────────────────────────────────────────┐
│                        Break Time                         │
└─────────────────────────────────────────────────────────┘
                    │  2 MIN
                    ▼
┌─────────────────────────────────────────────────────────┐
│            End of Mixing and Ready of Casting             │
└─────────────────────────────────────────────────────────┘
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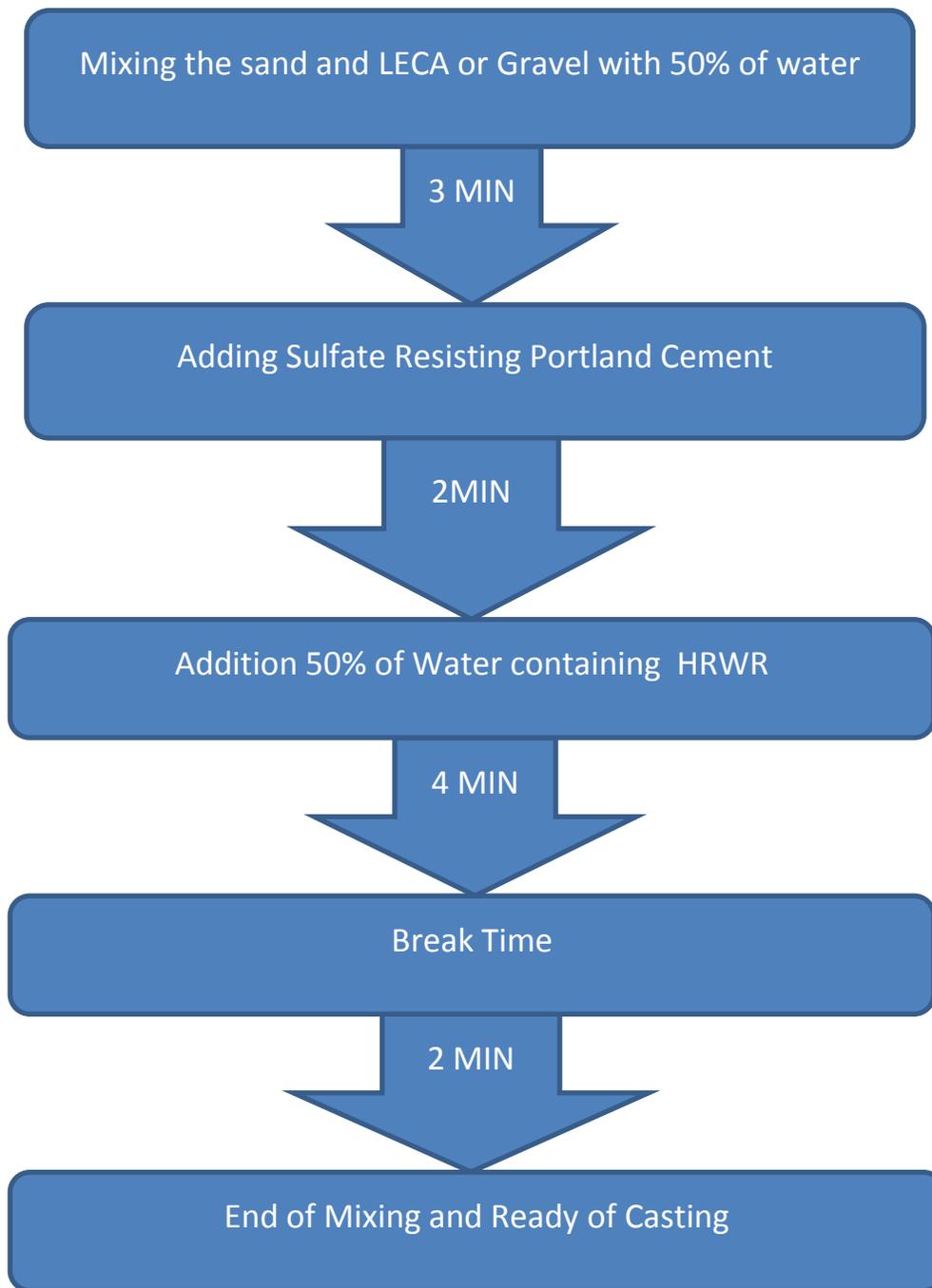
Fig. (3.5) Mixing time process.

Plate (3.8) Cleaning, lubrication pouring the molds with concrete, and leaving them.
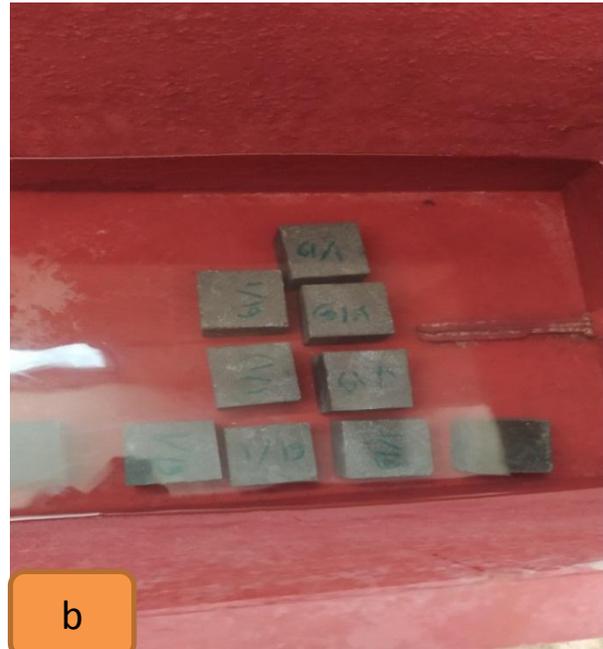
Plate (3.9) Curing for concrete (a) Air curing of concrete cubes and tiles, (b) Water curing of concrete cubes, and (c) Water curing of concrete tiles.

Plate (3.10) Some of the concrete tiles before fracture load test.

3.5 Test Methods for Fresh Concrete

3.5.1 Fresh Density Test

The fresh density is the summation of the mass of all the fresh constituents of concrete divided by the bulk size occupied by the concrete. Fresh unit weight was measured directly after pouring , as shown in Plate (3.11).

Plate (3.11) Fresh density measuring.

3.5.2 Slump Test

The slump was done in order to determine the consistency of concrete in its soft state, using a metal mold in the form of a cone minus 30 cm in height, with a base diameter of 20 cm and a diameter of its top 10 cm, where the cone was placed on a base made of wood and the soft concrete was poured into the mold in the form of three layers. Each layer was compacted by a metal stapling stick 16 mm in diameter and 600 mm in length, with one end rounded, then the mold was slowly lifted up and placed near the poured concrete, and the height difference was measured using a length measuring tool. This test was approved by the American Standard **(ASTM C 143/C 143M-05)** as shown in Plate (3.12).

Plate (3.12) Slump test for concrete mixture.

3.6. Test Methods for Hard Concrete

3.6.1 Compressive Strength Test

Measurement of compressive strength of concrete gives a perception to the researcher about its quality and other characteristics such as tensile and bending resistance, durability...etc. Cubes (100x100x100 mm) were cast and cured similarly as for tiles specimens to determine concrete resistance and an average value of these cubes were checked with the requirements of the British Standard (**BS EN.12390:Part3;2000**). The compressive strength test was determined by rupturing the cubes at ages of three, seven, and twenty-eight days. The rate of loading was equal to **(300 KN/sec)** as shown in Plate (3.13).

Plate (3.13) The device used for testing concrete cubes under compression.

3.6.2 Fracture Load and Modulus of Rupture Test for Tiles

This test is important for determining the strength needed to break concrete tiles, The 150 kN flexural apparatus shown in Plate (3.14) was used for the purpose of this test. The sample was placed in the testing machine so that its outer edges were 50 mm away from the device supports, as in Fig. (3.6). An iron pallet or a piece of wood 50 mm wide was placed under the load point in the middle of the sample in order to ensure a homogeneous distribution of the load. The type of load was a three-point loads that was applied at a rate (1 kN/10 sec) according to the Iraqi Standard Specification No.1107:1988. After finding the value of the fracture load (P) by means of a flexural test device, the modulus of rupture (M.O.R) was determined by using Eq. (3.1).

$$\text{M.O.R} = \frac{3Pl}{2bh^2} \qquad \qquad \text{.......(3.1)}$$

where:

M.O.R= Modulus of Rupture in (MPa).

P= Fracture load in (N).

l = The distance between the supports which equal to 400 mm.

b= Concrete tile width which equal to 500 mm.

h= Thickness of concrete tile which equal to 50 mm.
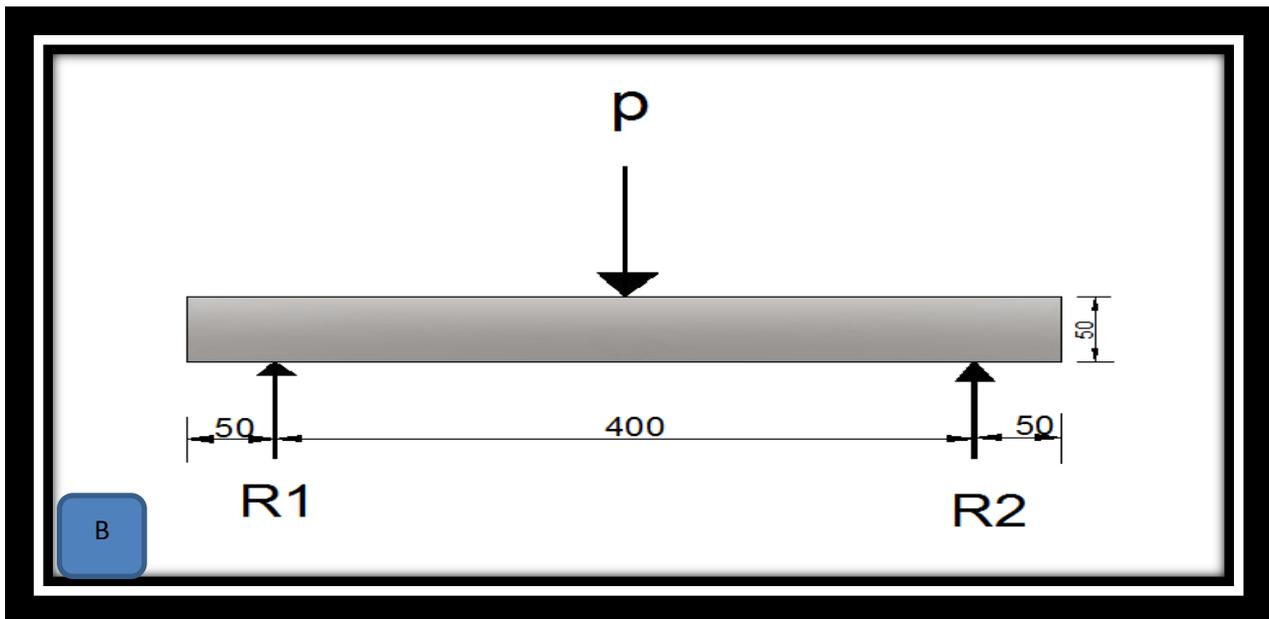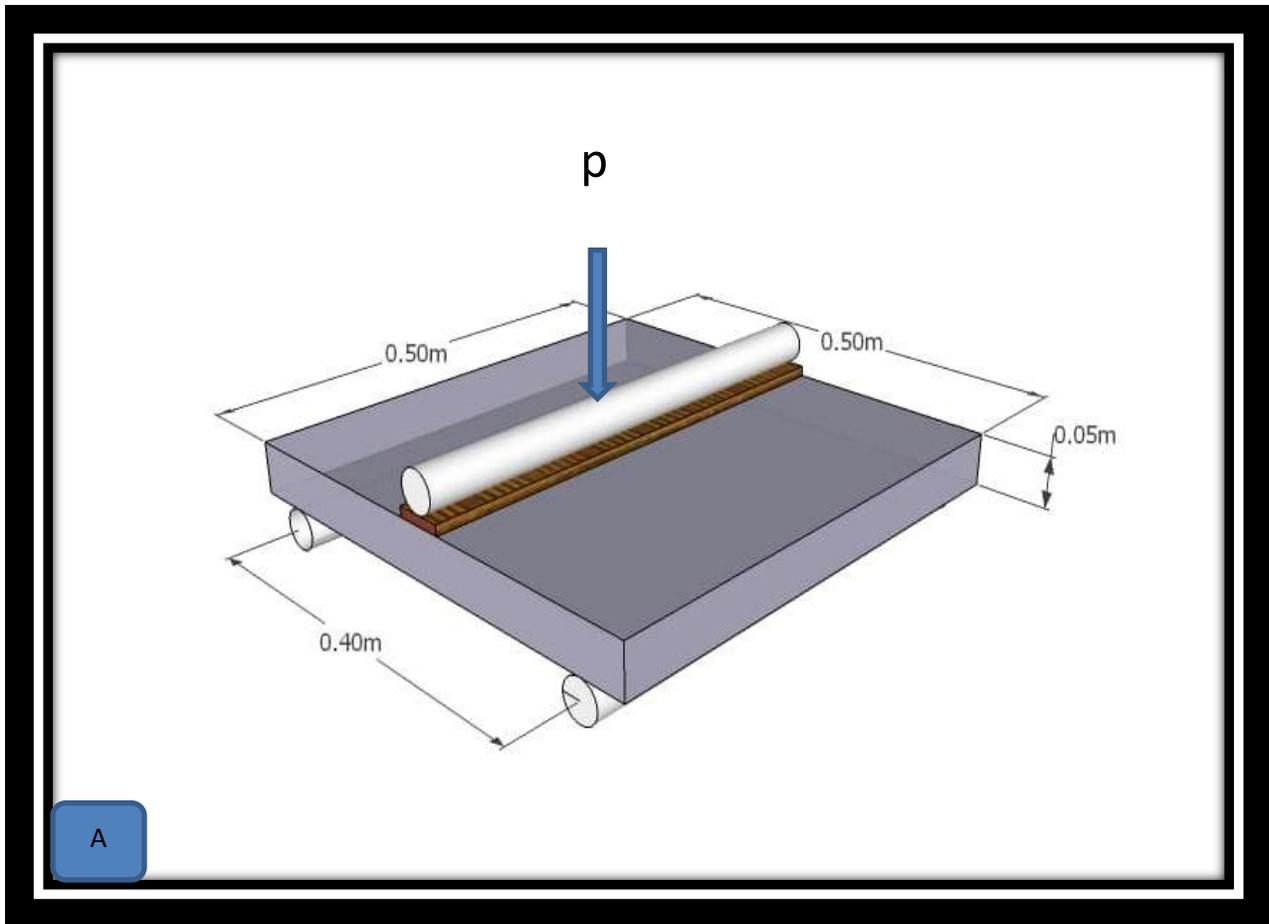
Fig. (3.6) A and B shown apply load on concrete tile.

Plate (3.14) The 150 kN flexural apparatus.

3.6.3 Dimensions and Shapes Test for Concrete Tiles

The Iraqi specifications No. 1107:1988 specified the dimensions of the precast concrete tiles according to Table (3.11) shown below:

Table (3.11) Types and dimensions of precast concrete tiles according to IQS 1107:1988.

Tile type	Length (mm)	Width (mm)	Thickness (mm)
A	500±2	500 ±2	50±3
B	600±2	400 ±2	50±3
C	400±2	200 ±2	50±3
D	800±2	800±2	42±3
E	400±2	400±2	50±3
F	600±2	200±2	50±3

The measurement of length, width, thickness, and angles was checked on precast concrete tiles specimens using a length measuring instrument and a vernier scale.

Plate (3.15) Measurement of dimensions.

3.6.4 Measurement of Oven-Dry Density of Concrete

The dry density of three types of investigated concretes was measured at 28 days only using the method of the (**ASTM C567,14**) where the cubes (100 x 100 x 100) mm were dried at 100 ± 5 °C in the oven 24 hours to achieve a constant mass, then they were weighed. So, the value of such property was calculated from Eq. (3.2), as shown in Plate (3.16).

$$\textbf{Dry Density} = \frac{dry\ weight\ of\ concrete}{Volume\ of\ concrete} \quad \text{----- (3.2)}$$

where:

Dry density of concrete in (kg/m^3).

Dry weight in (kg).

Volume in (m^3).

Plate (3.16) The measurement oven-dry density of concrete.

3.6.5 Water Absorption Test for Tiles

The water absorption of concrete tiles was measured according to the Iraqi Standard Specification No. (1107: 1988). The procedure for evaluating the water absorption is illustrated in Plate (3.17).

Two parts of dimensions (10 * 10 * 5) cm^3 were cut from two opposite corners in each precast concrete tile, then placed in the oven at a temperature of (105) ℃ for 24 hours. Then they were extracted from the oven and placed in an airtight container for another 24 hours. After that, each part was weighed (A), then placed over a plastic clip at a depth of 25 mm underwater for half an hour. The segments were extracted and wiped with a cloth and weighed again (B), then immersed in water for 24 hours and extracted and wiped with a cloth and weighed a third time (C). Eq. (3.3) was used to calculate the percentage of water absorption after half an hour of immersion, while Eq.(3.4) was used to calculate the percentage of absorption after 24 hours of immersion. The Iraqi Standard No. (1107:1988) specified that the percentage of water absorption in concrete tiles should not exceed 4% after half an hour, while it should not exceed 10% after 24 hours of immersion in water.

$$\text{Absorption(\%) after half an hour} = \frac{B-A}{A} * 100\% \quad ....(3.3)$$

$$\text{Absorption(\%) after 24 hour} = \frac{C-A}{A} * 100\% \quad ......(3.4)$$

where:

A: Dry weight of parts (gm).

B: Weigh the parts after absorption for half an hour (gm).

C: Weigh the parts after absorption for 24 hours (gm).

Plate (3.17) Water absorption test procedures.

3.6.6 Thermal Conductivity Test for Concrete

The study of the thermal properties of concrete is one of the important studies in identifying the extent of thermal insulation of concrete. Thermal conductivity is one of the phenomena of heat transfer, in which heat is transferred from one location to another due to the irritation of molecules accompanied by a change in temperature.

Heat transfers from hot to cold objects in three ways: conduction, convection, and radiation. This experiment was carried out according to the principle of **(Lee's Disc),** (**ASTM-D7340,2012**) for heat transfer and the standard specification of the device (**Griffin & George**) and manufactured in England as shown in Plate (3.18-a). The method of work thermal conductivity test for concrete is mentioned in the passage below:

1-The electrical circuit is connected and the device is placed in a tightly closed place to stabilize the ambient temperature after cleaning the sample and discs to obtain the best heat transfer through it.

2- A voltage of 6V is shed from the power supply to the heater, and a current of 0.25 A is applied. When the power supply is turned on, the discs are heated up and the heat transfer starts from the heater to the next disc until it reaches the last disc.

3-The temperature of the discs (TA, TB, TC) is calculated by the thermometers fixed inside them in succession when the three discs reach thermal equilibrium. After measuring (r, dA, dB,dC , and dS) is calculated and the Equation (3.5) is applied to extract the value (e) and then apply the Equation (3.6) and find (K).

Thermal conductivity test discs were cast and cured in conditions similar to concrete cubes and concrete tiles, as shown in Plate (3.19), this discs have 40mm diameter and 17mm thickness.

$$H=I.V=\pi r^2 e(TA+TB)+2\pi re[dATA+dS\ 0.5*(TA+TB)+dB\ TB+dC\ TC] \quad ......(3.5)$$

$$K\left(\frac{TB-TA}{ds}\right) = e\ [\ TA+\frac{2}{r}(\ dA+\frac{1}{4}dS\ )\ TA+\frac{1}{2r}dS\ TB\ ] \qquad .... (3.6)$$

where:

K: thermal conductivity in $(\frac{W}{m.k°})$.

w: Energy measurement unit in (watt).

k°: Temperature unit in (Kelvin).

m: Length unit in (meter).

e: The amount of heat energy passing through a unit area in $(\frac{W}{m2.k°})$.

H: The average time of the power applied to the heating coil.

TA, TB, TC: degree of temperature for the discs A, B, and C, respectively in (k̊).

dA, dB, dC: The thickness of the discs A, B, and C, respectively in (m).

dS: Thickness of the samples test in (m).

r: Disc radius (m).

I: Electric current in (ampere).

V: Voltage in (Volt).
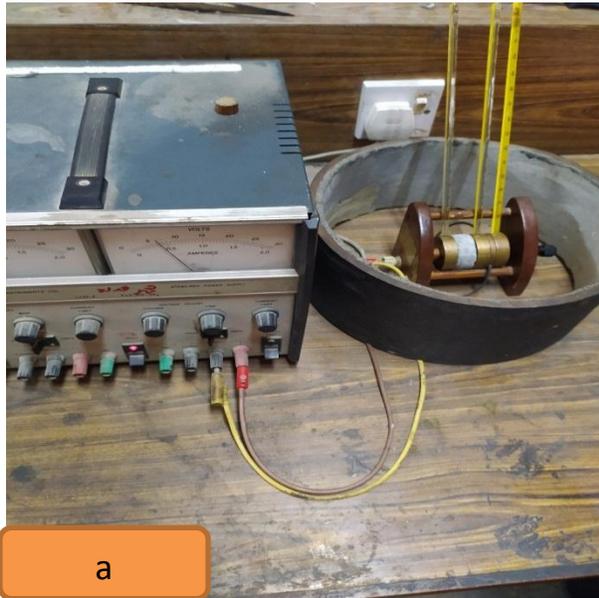
Plate (3.18): (a) Griffin& George apparatus, (b) sensitive scale.

Plate (3.19) Samples of thermal conductivity test for concrete during casting.

Chapter Four

CHAPTER FOUR

Results and Discussion

4.1 Introduction

In this chapter, the results of the experiments related to this thesis will be discussed in detail. The effects of replacing the natural weight coarse aggregate having maximum size of 10 mm with two types of lightweight expanded clay aggregate (LECA), one of which had high density (HDLECA) and the other had low density (LDLECA). Also, the effect of changing the conditions and duration of curing on the investigated properties of various types of concretes, namely normal weight concrete and lightweight concrete.

4.2 Characteristics of Fresh Mixture

Table (4.1) presents observations of density in a fresh state, slump flow, for normal weight concrete (NWC), lightweight concrete having low density LECA (LWC-LD), and lightweight concrete having high density LECA (LWC-HD).

4.2.1 Fresh Density

From Table (4.1) and Fig. (4.1), it could be seen that the fresh density of NWC has been 2343 kg/m^3, while its value decreased to (1820 and 1640) kg/m^3 when substituting NCA with HDLECA and LDLECA, respectively. Indeed, the mix proportions (by volume) of the three types of concrete were the same, so the decrease in density was expected and related to the variation in the relative density of the coarse aggregate used in the concrete mix. It was 2.6 for NCA, while it was 1.2 and 0.60 for HDLECA and LDLECA, respectively.

Table (4.1) The results of the slump test and fresh density test.

mix	w/c	HRWR % by wt. of cement	Fresh density (kg/m^3)	Slump test (mm)
NWC	0.4	0.75	2343	40
LWC-LD	0.4	0.75	1640	60
LWC-HD	0.4	0.75	1820	55
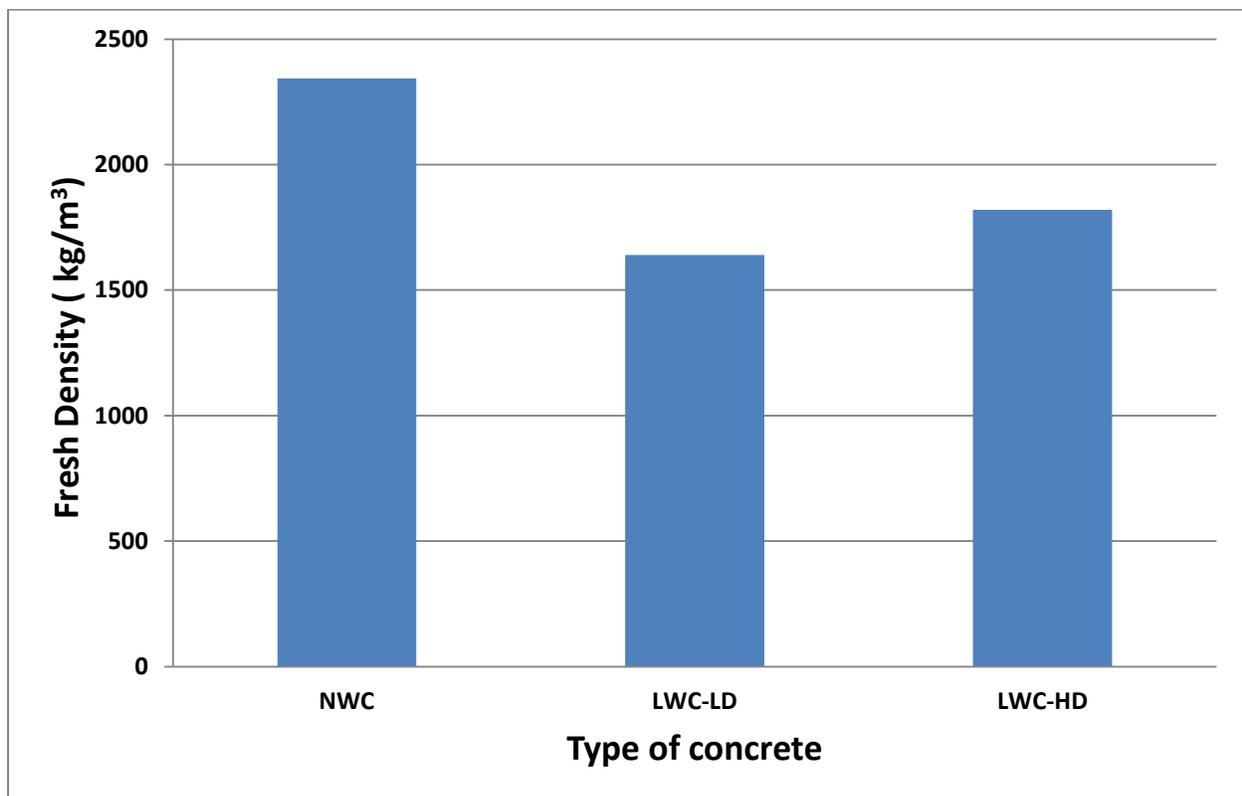
Fig. (4.1) Fresh density for concrete mixtures.

4.2.2 Slump Test

It can be seen from Table (4.1) and Fig. (4.2) that the amount of slump of lightweight concrete (LWC) was more than that of natural weight concrete, this increase was 15 mm and 20 mm in LWC-HD and LWC-LD, respectively. The explanation of such behavior could be related to the differences in the density of coarse aggregates, as well as to the differences in the amount of water absorption of coarse aggregates. The concrete with LECA flows easier than that with NCA because of the effect of weight. Since the LECA was pre-soaked before the mixing, the water absorbed and retained in the LECA particles may positively improve the concretes' consistencies. The highest water absorption capacity was recorded for LDLECA (24%) followed by HDLECA (12%) while the minimum water absorption capacity was recorded for NCA (0.8%). Similar results were also reported by **(Othman et al., 2020)** who confirmed that the water absorbed by the expanded clay particles affected the consistency of the concrete mixture, such that the amount of slump increased from 100 mm to 150 mm when the percentage of LECA was increased from 30% to 100%. **Bogas & Nogueira, (2014)** noticed the ease of casting and compaction of the mixture containing lightweight aggregates as compared to normal concrete, such that there was an increase in the slump flow of about 8 mm in LWC mixture compared with NWC mixture with the same mixing ratios. **Kumar Mehta & Monteiro, (2014)** have also noted that lightweight concrete aggregates with a slump value of nearly 50 mm may achieve adequate workability.
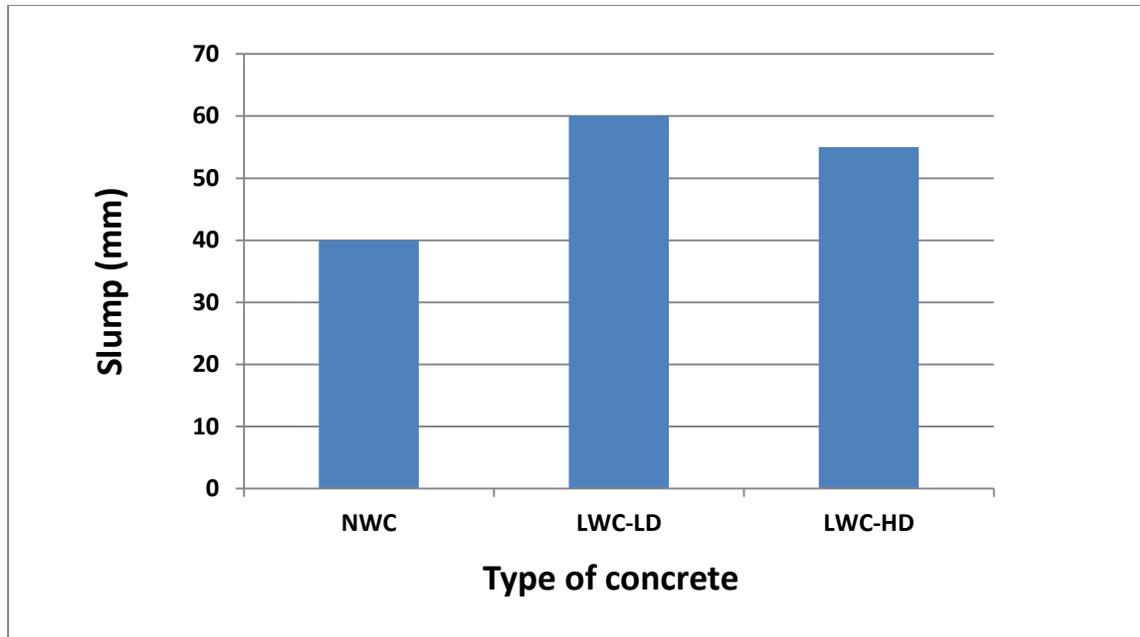
Fig. (4.2) The result of a slump for concrete mixtures.

4.3 Hardened Properties of Concrete.

4.3.1 Compressive Strength

By examining the result of concrete cubes listed in Table (4.2)and Plate (4.1) , it could be seen that the compressive strength of LECA concretes were lower than that of NCA concrete as expected, though the mixes made with HDLECA showed higher strength than the mixes made with LDLECA regardless of the curing regime. At 3 days, the compressive strength of LWC with LDLECA and HDLECA was up to 55% and 73%, respectively of that of NWC. These values were up to 56% and 72% at 7 days and 52% and 71% at 28 days.

Unlike ordinary concrete, the weakest part in lightweight concrete is the aggregate and not the interface between aggregate and cement paste, so its properties play a key role in determining the properties of the resulting lightweight concrete.

Among the most important of these properties is its density. The higher this means, the greater the strength of the aggregate, and consequently, the improvement of the compressive strength of the mix. This is what actually happened, as the 28-day compressive strength using HDLECA of 700 kg/m^3 bulk density reached 31.8 MPa, while it was only 21.2 MPa when LDLECA of 320 kg/m^3 was used.

Among the three types of curing regimes, the best one was the type I regime at which the samples were cured in water till the testing age, followed by the type II regime at which the samples were cured in water for 3 days and then in air for the rest of age, i.e. partial water curing regime. On the other hand, the worst strengths were achieved when the time III regime was conducted at the samples where they were treated in air. As compared to the compressive strength of water-cured NWC samples, the air cured samples and partially water-cured samples had 20% and 9% lower compressive strength at 28 days. In the case of LWC, the air cured samples and partially water-cured samples had 19% and 9% lower compressive strength for HDLECA and 10% and 6% for LDLECA, respectively compared to water-cured samples. Somewhat similar reductions were also occurred at 3 and 7 days due to the different curing methods.

The importance of treatment lies in provide an external agent to hydrate the cement, and this is done in several ways, the most important of which are: control the concrete temperature and the movement of moisture in and out of the concrete. Continuous ripening with water provides additional moisture, which contributes to the formation of hydration products (cement gel) necessary to gain the required strength. As soon as treatment stops, the relative humidity inside the capillary pores begins to decrease and when it reaches a limit below 80%, the cement hydration process stops, **(Neville,1996)**.

On the other hand, placing the concretes in the air without immersing them in water causes evaporation of water, as well as no water entering from the outside to hydrate the cement granules. Therefore, the compressive strength is low compared to the samples immersed in water continuously. While, placing the samples in water for three days and then leaving them in the air saves external water and prevents evaporation during the first three days. So, it is expected to obtain better results than if the samples were left in the air.

Table (4.2) Compressive strength for cubes (MPa).

Mix type	Curing in water			Curing in water for 3 days only			Curing in air		
	3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days
NWC	27.1	34.1	45.4	27.1	31.1	41.2	24	28.1	36.2
LWC-LD	13.9	18.6	21.2	13.9	17.4	20	13.2	15.3	19
LWC-HD	19.2	24.40	31.8	19.2	22.1	28.9	17.5	19.9	25.6
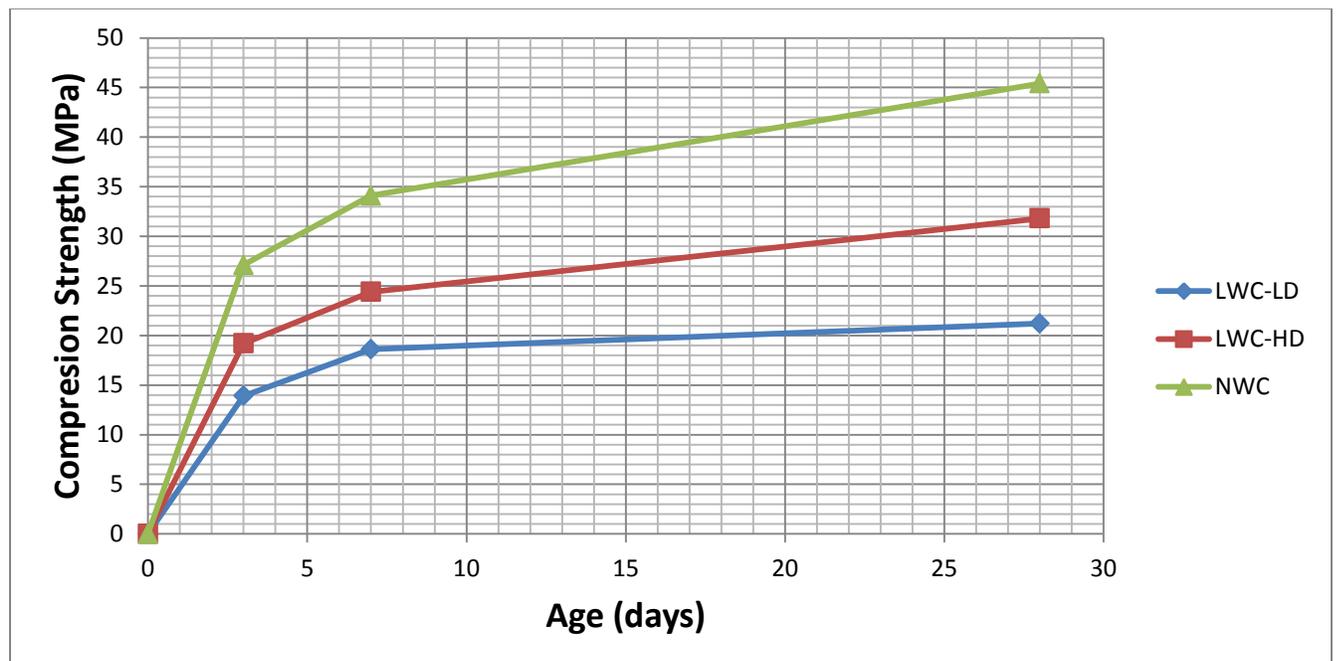
Fig. (4.3) The compression strength of concrete in case curing in water.
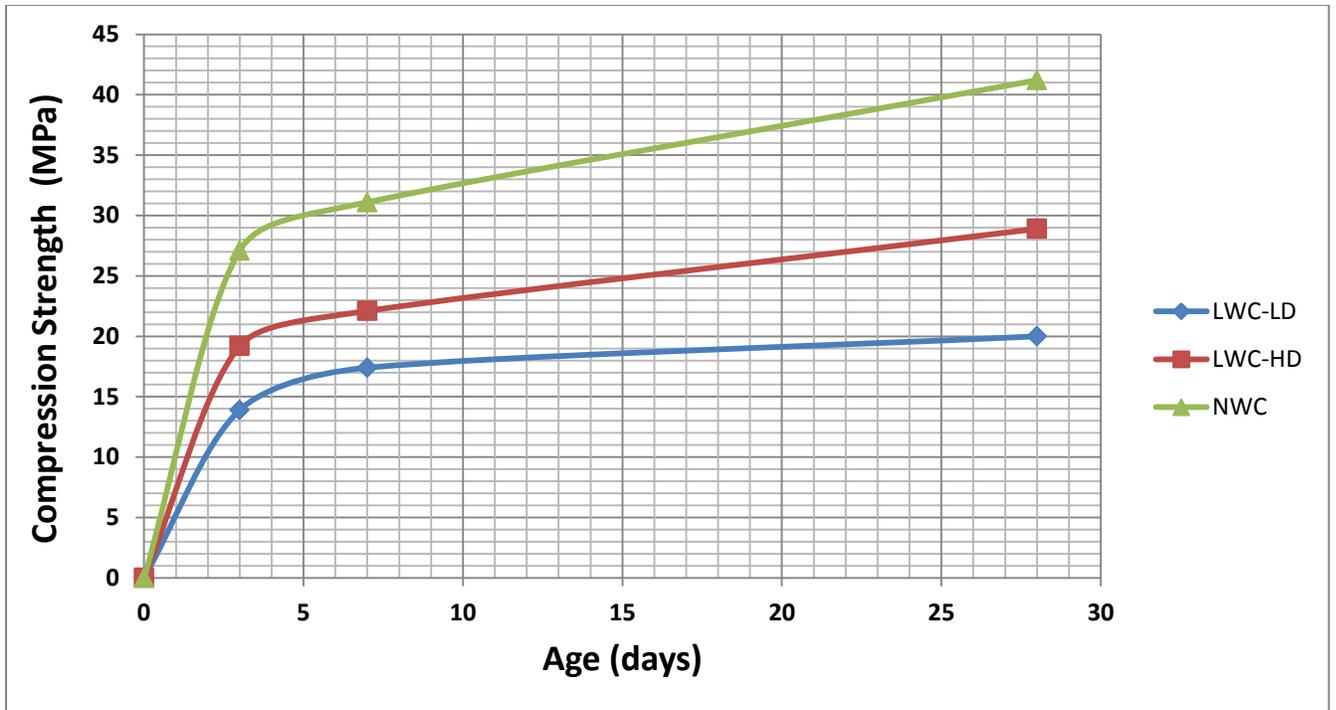
Fig. (4.4) Compression strength of concrete in case curing in water for 3days only.
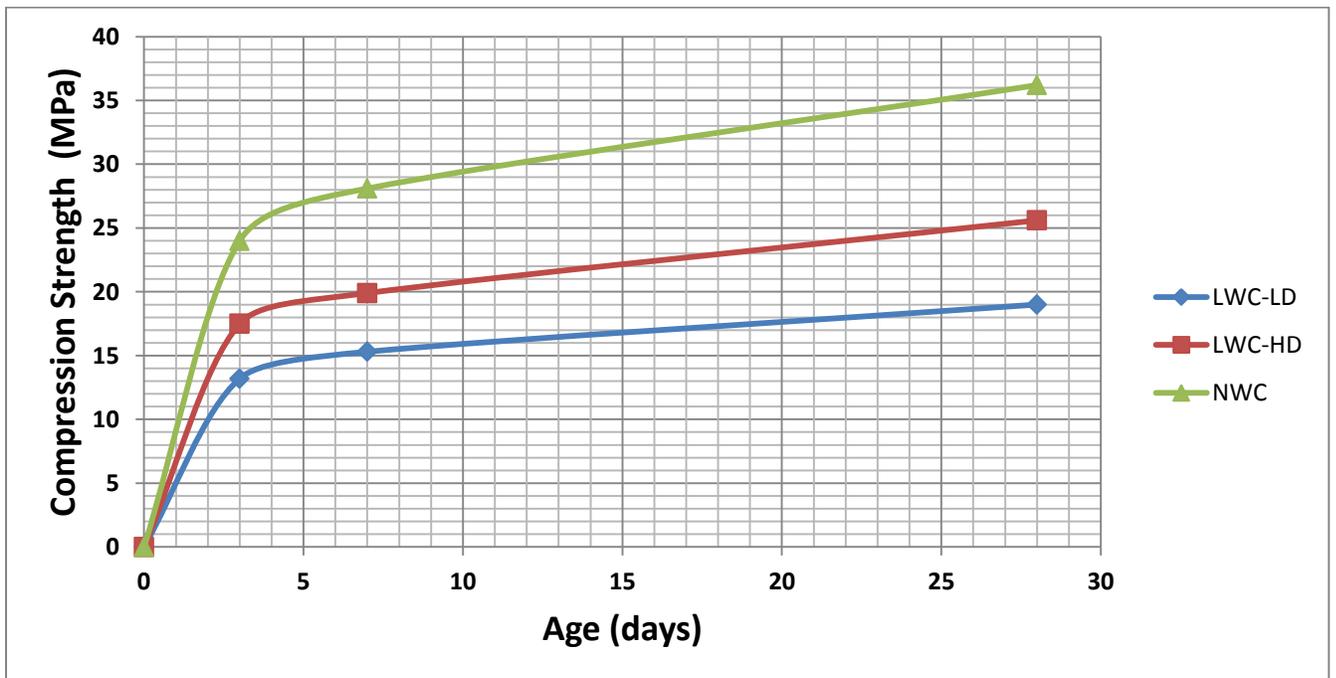
Fig. (4.5) Compression strength of concrete in case curing in air.
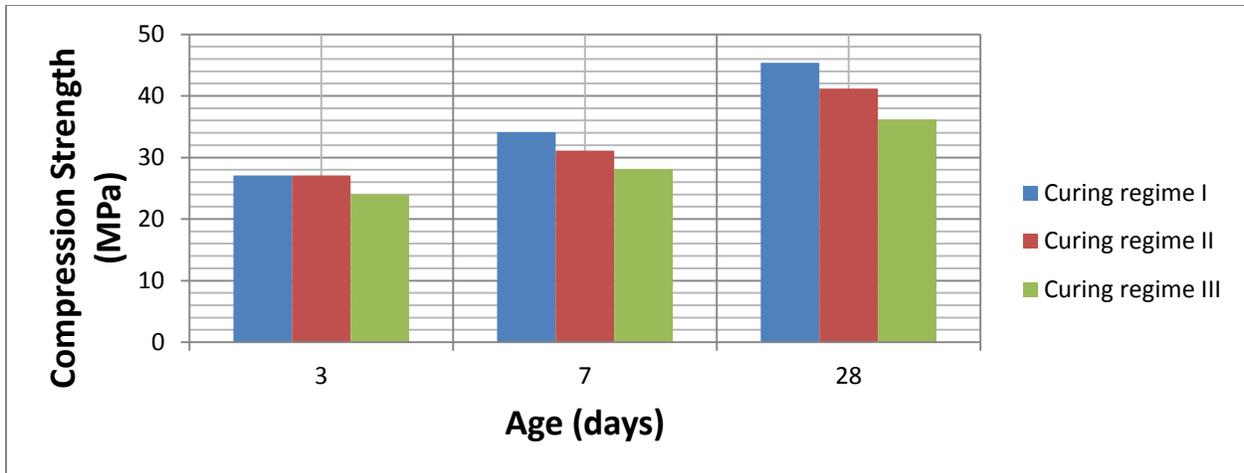
Fig. (4.6) Compression strength of NWC in different curing cases.
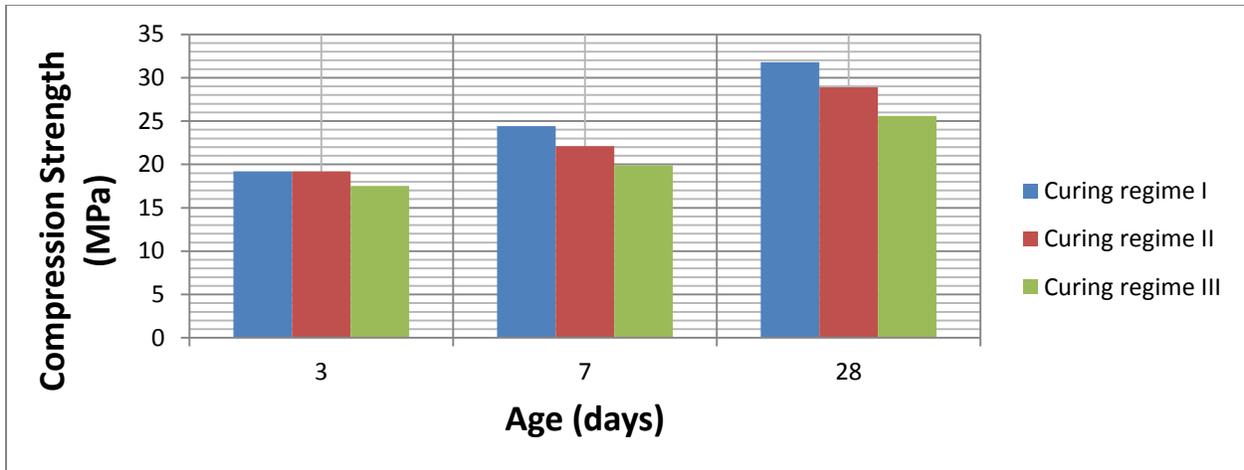
Fig. (4.7) Compression strength of LWC-HD in different curing cases.
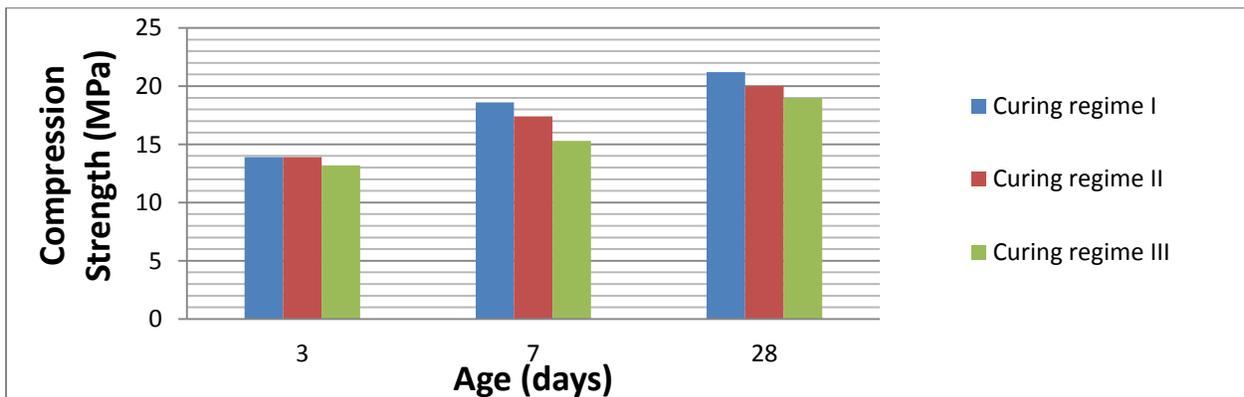
Fig. (4.8) Compression strength of LWC-LD in different curing cases.
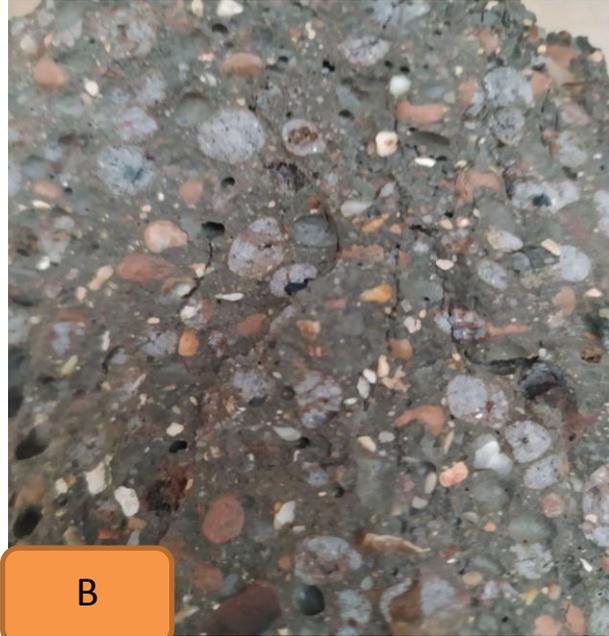
Plate (4.1) Some cross-section for cubes after the compression strength test:

A) Cross-section of a cube of concrete (Type LWC Low-Density).

B) Cross-section of a cube of concrete (Type LWC High-Density).

C) Cross-section of a cube of concrete (Type NWC).

4.3.2 Dimensional Measurement of Precast Concrete Tiles

The results of examining the dimensions of the concrete tiles listed in Table (4.3) indicate their conformity with the Iraqi specifications Standard No. (1107:1988). Dimensional measurement results of the concrete tiles were acceptable due to the excellent quality of the molds used in the sample casting.

Table (4.3) The dimensional measurement of precast concrete tiles type (A) for age 28 days.

Group Name	Mix types	Length (mm)	Width (mm)	Average thickness (mm)	Length and width(mm) according to IQS.	Thickness (mm) according to IQS.
Water curing	NWC	501	501	52	500 ±2	50±3
		502	498	50	500 ±2	50±3
		500	500	50	500 ±2	50±3
	LWC-LD	501	502	51	500 ±2	50±3
		502	501	49	500 ±2	50±3
		499	500	52	500 ±2	50±3
	LWC-HD	502	501	51	500 ±2	50±3
		500	500	48	500 ±2	50±3
		499	501	53	500 ±2	50±3
3 days water curing only	NWC	500	500	49	500 ±2	50±3
		502	498	52	500 ±2	50±3
		500	501	48	500 ±2	50±3
	LWC-LD	501	499	51	500 ±2	50±3
		500	500	50	500 ±2	50±3
		499	499	52	500 ±2	50±3
	LWC-HD	498	501	51	500 ±2	50±3
		502	502	47	500 ±2	50±3
		499	498	53	500 ±2	50±3
Air curing	NWC	501	500	52	500 ±2	50±3
		500	499	50	500 ±2	50±3
		500	500	50	500 ±2	50±3
	LWC-LD	501	501	51	500 ±2	50±3
		502	500	49	500 ±2	50±3
		499	500	52	500 ±2	50±3
	LWC-HD	500	501	51	500 ±2	50±3
		500	500	50	500 ±2	50±3
		499	501	51	500 ±2	50±3

4.3.3.1. Fracture Load Test for Concrete Tiles

The results of fracture load are seen in Table (4.4) and Fig. (4.12) where the effects of LECA type and curing regime are shown. As expected, the substitution of natural aggregate with lightweight aggregate reduced the fracture load of concrete, though the use of HDLECA exhibited better results such that the reduction was 27% compared to 40% when LDLECA was used. This is because lightweight coarse aggregate is weaker and less hard than natural coarse aggregate. When the content of expanded clay aggregate in the concrete mixture becomes more and the content of normal weight aggregate becomes less, the flexural strength in concrete becomes less (**Real et al., 2015**).

As with the compressive strength, the curing regime I (curing in water) performed the best fracture load capacity compared to the other two types of curing. As compared water-cured NWC samples, the air cured samples and partially water-cured samples had 20% and 9% lower fracture loads at 28 days. In the case of LWC, the air cured samples and partially water-cured samples had 19% and 10% lower fracture load for HDLECA and 12% and 6% for LDLECA, respectively compared to water-cured samples. Somewhat similar reductions were also occurred at 3 and 7 days due to the different curing methods. The explanation of good results of water curing regime is due to that the amount of hydrated cement in the case of curing in water is greater than in the case of curing in air, and therefore the concrete texture is more dense and fewer gaps due to the increase in the volume of the hydrated part of the cement.

The Iraqi Standard Specification No. (1107:1988) determined the minimum fracture load for concrete tiles as 8.3 kN. It is noted from Fig.(4.11) that the results of LWC with low density LECA do not reach the requirements of the mentioned Iraqi standard for all curing cases, while the results of LWC with high density

LECA achieved the requirements of the Iraqi standard specification at the age of 28 days when cured in water for a period of at least 3 days. On the other hand, NWC tiles satisfied the specification at all ages and for all curing regimes except for the case of air treatment at the age of 3 days, where the fracture load was 8.2 kN. It can also be seen from Table (4.4) that fracture load at the age of 3 days reached 65%,66%, and 71% of the fracture load at the age of 28 days for NWC, LWC-HD, and LWC-LD respectively, while at the age of 7 days it reached 79.5%,80%, and 91%. The failure line in concrete tiles is usually in the middle and below the line of shedding the load in a semi-straight shape as in Plates (4.2), (4.3), (4.4) and (4.5).

Table (4.4) Fracture load for concrete tiles (kN), in different types of curing.

Mix type	Curing in water			Curing in water for 3days only			Curing in air		
Age	3days	7days	28days	3days	7days	28days	3days	7days	28days
NWC	8.9	10.9	13.7	8.9	9.9	12.4	8.2	9	10.9
LWC-LD	5.8	7.4	8.1	5.8	6.7	7.6	5.5	6.2	7.1
LWC-HD	6.6	7.9	9.9	6.6	7.2	8.9	5.9	6.5	8
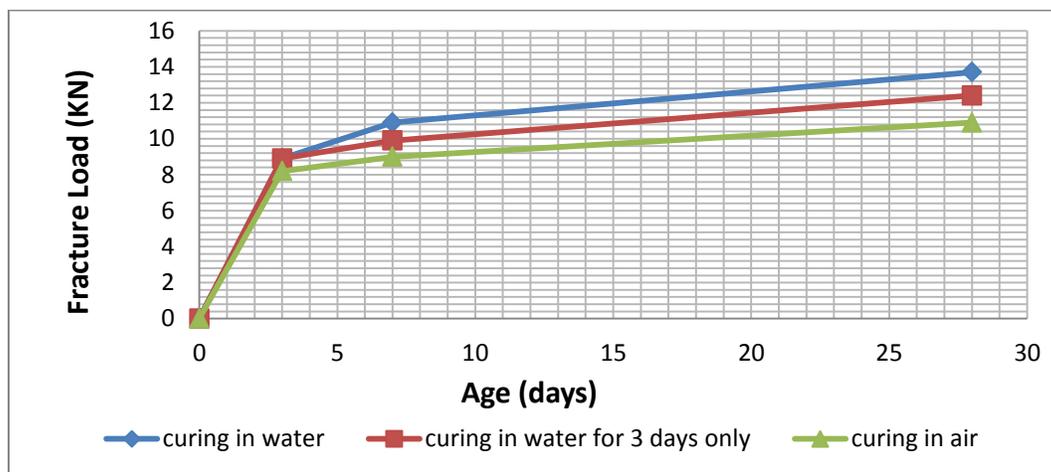
Fig. (4.9) The effect of curing type on fracture load for concrete tiles for NWC.
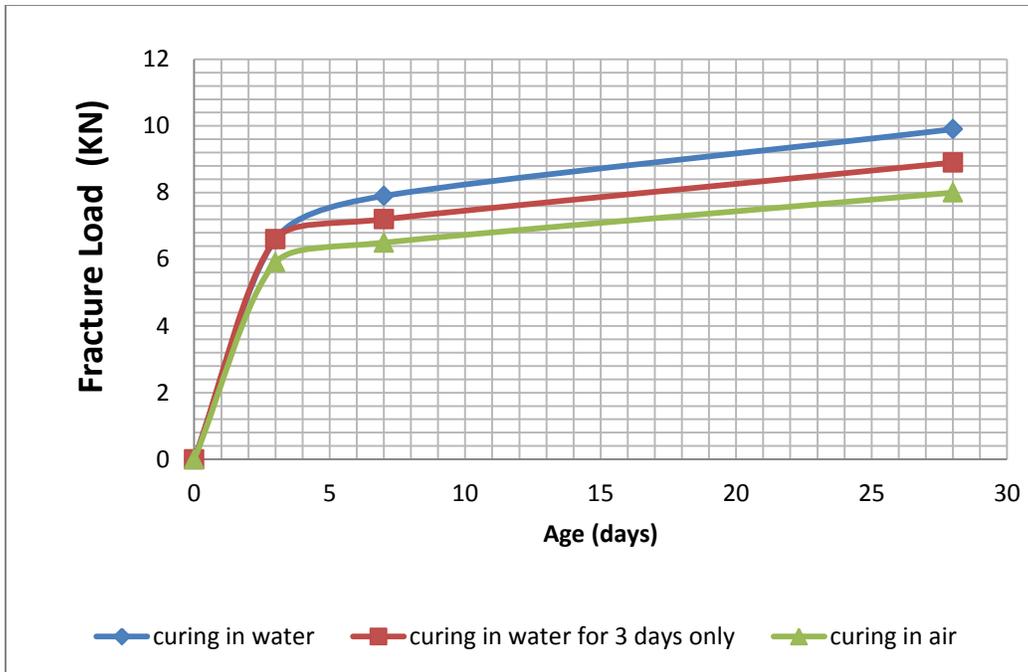
Fig.(4.10) The effect of curing type on fracture load for concrete tiles for LWC-HD.
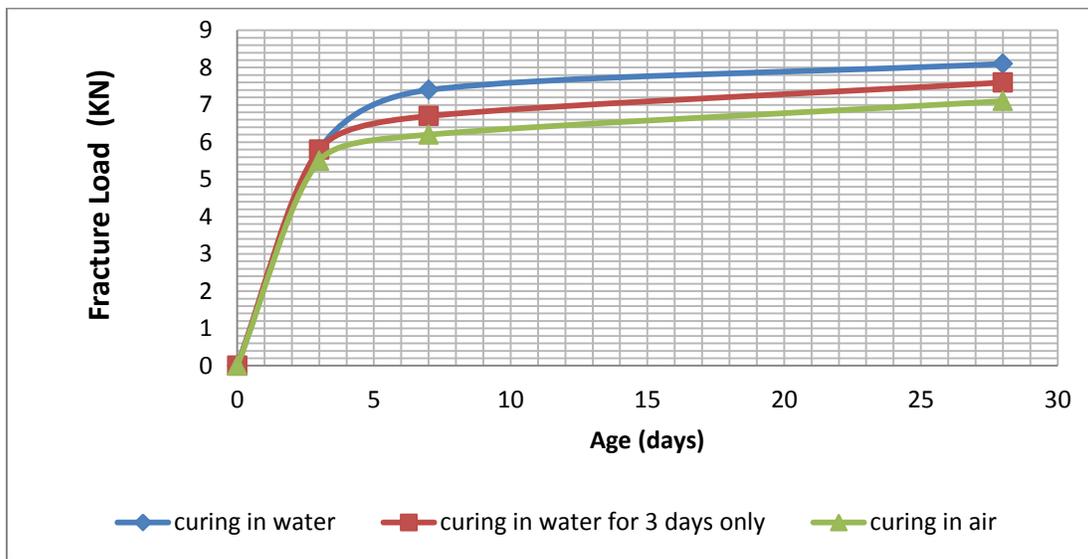
Fig. (4.11) The effect of curing type on fracture load for concrete tiles for LWC-LD.

LWC-LD   **LWC-HD**   **NWC**

WC: Water curing.
AC: Air curing.
PWC: 3days period water curing.
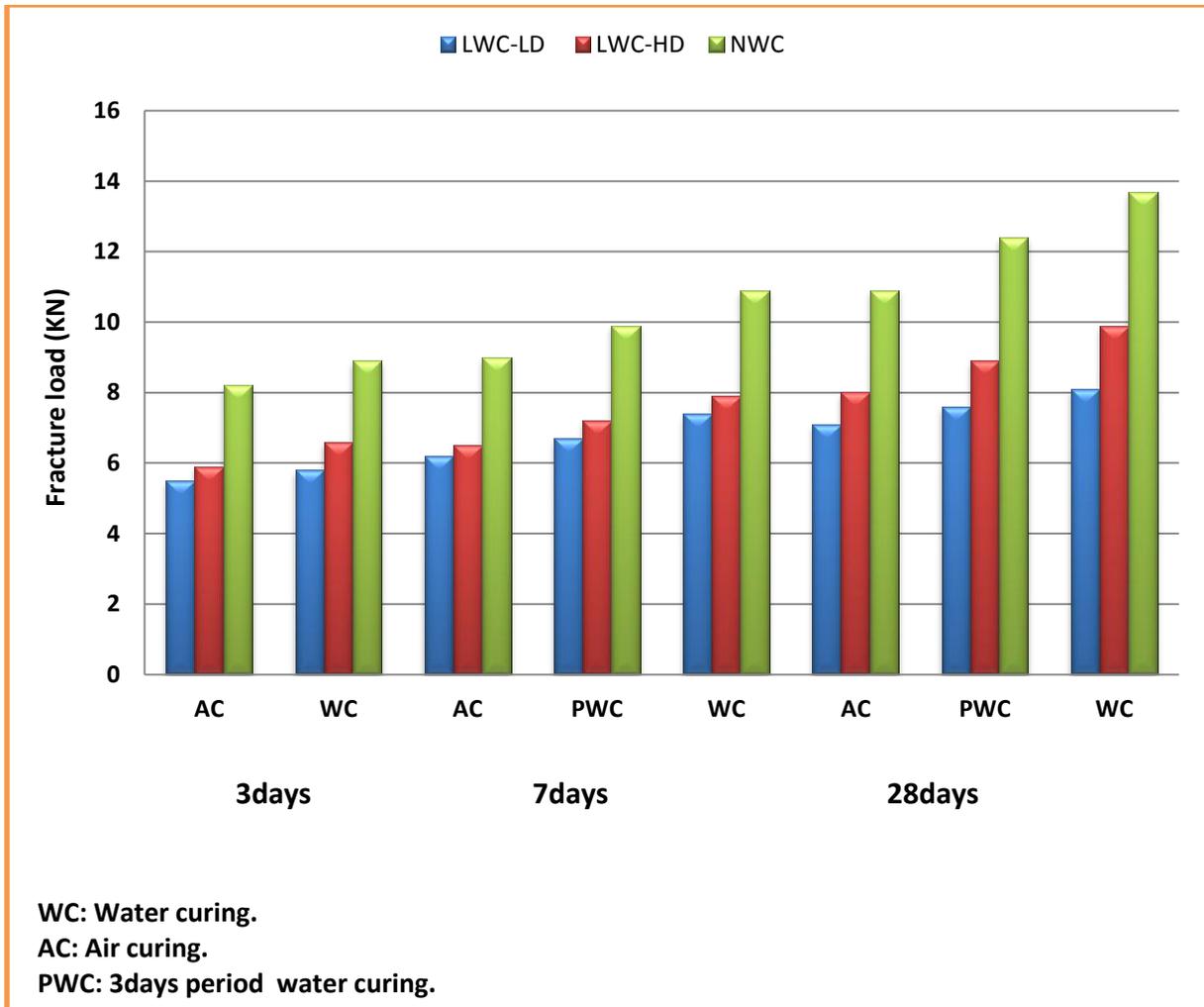
Fig. (4.12) Fracture load for concrete tiles in different curing types.

Plate (4.2) A cross-section for concrete tile type LWC High Density after failure.

Plate (4.3) A cross-section for concrete tile type LWC Low Density after failure.

Plate (4.4) A cross-section for normal weight concrete tile after failure.

4.3.3.2 Modulus of Rupture for Concrete Tiles

By using Equation (3.1) mentioned in chapter three, and by knowing the results of the fracture load, length of span, width, and thickness of the examined concrete tiles, the modulus of rupture (M.O.R.) was found and it listed in Table (4.5). The 28-day modulus of rupture of between 5.23 to 6.58 MPa was recorded for NWC depending on the curing regime. This range became 3.41 to 3.89 MPa for LWC-LD and 3.84 to 4.75 MPa for LWC-HD. The M.O.R. of concrete tiles decreased by 28% and 41% when replacing the natural coarse aggregate with a lightweight coarse aggregate of high and low density, respectively because lightweight coarse aggregate was weaker and less hard than natural coarse aggregate.

Regarding the curing type, the best method was Type I curing regime (Curing in water) followed by Type II curing regime (3 days curing in water). On the other hand, the minimum flexural strengths were reported for tiles cured via the Type III curing regime (curing in the air). At the age 28 days, for example, the MOR for NWC, LWC-HD, and LWC-LD decreased by 20%, 19%, and 12% respectively, when curing the concrete tiles with water instead of leaving them exposed to air only, because the amount of hydrated cement in the case of curing in water was greater than in the case of curing in air, so the concrete texture was denser and had fewer voids due to the increase in the volume of the hydrated part of the cement.

Comparing the results of compressive strength given in Table (4.2) and flexural strength given in Table (4.5), one can be seen that the submerged concrete tile developed its rate of strength gain faster than the cube because the ratio (surface area/volume) of the concrete tile was greater than the cube, wherein the case of continuous treatment with water, the rate of gaining compressive strength at the age of 3 days was equal to (65.5%,60%, and 60%) from the strength at the age of 28 days in concrete type (LWC-LD, LWC-HD, and NWC) respectively. While the rate of increase in the modulus of rupture at the age of 3 days was (71%,67%, and 65%) from the modulus of rupture at the age of 28 days for the same mixtures.

In a somewhat similar way to the compressive strength for concrete, the highest value of the bending strength reached (6.58 MPa) for the case of continuous treatment with water at the age of 28 days, while its lowest value reached (2.64 MPa) in the case of treatment with air at the age of 3 days, as in the Fig. (4.13) and Fig. (4.15).

Table (4.5) Results modulus of rupture for concrete tiles for age 28 days.

Age	Type of mixtures	Curing type	l(mm)	b (mm)	h (mm)	P (N)	M.O.R. (MPa)
3 days	NWC	in water	400	500	50	8900	4.27
		3 day in water	400	500	50	8900	4.27
		in air	400	500	50	8200	3.94
	LWC-LD	in water	400	500	50	5800	2.78
		3 day in water	400	500	50	5800	2.78
		in air	400	500	50	5500	2.64
	LWC-HD	in water	400	500	50	6600	3.17
		3 day in water	400	500	50	6600	3.17
		in air	400	500	50	5900	2.83
7days	NWC	in water	400	500	50	10900	5.23
		3 day in water	400	500	50	9900	4.75
		in air	400	500	50	9000	4.32
	LWC-LD	in water	400	500	50	7400	3.55
		3 day in water	400	500	50	6700	3.22
		in air	400	500	50	6200	2.98
	LWC-HD	in water	400	500	50	7900	3.79
		3 day in water	400	500	50	7200	3.46
		in air	400	500	50	6500	3.12
28 days	NWC	in water	400	500	50	13700	6.58
		3 day in water	400	500	50	12400	5.95
		in air	400	500	50	10900	5.23
	LWC-LD	in water	400	500	50	8100	3.89
		3 day in water	400	500	50	7600	3.65
		in air	400	500	50	7100	3.41
	LWC-HD	in water	400	500	50	9900	4.75
		3 day in water	400	500	50	8900	4.27
		in air	400	500	50	8000	3.84
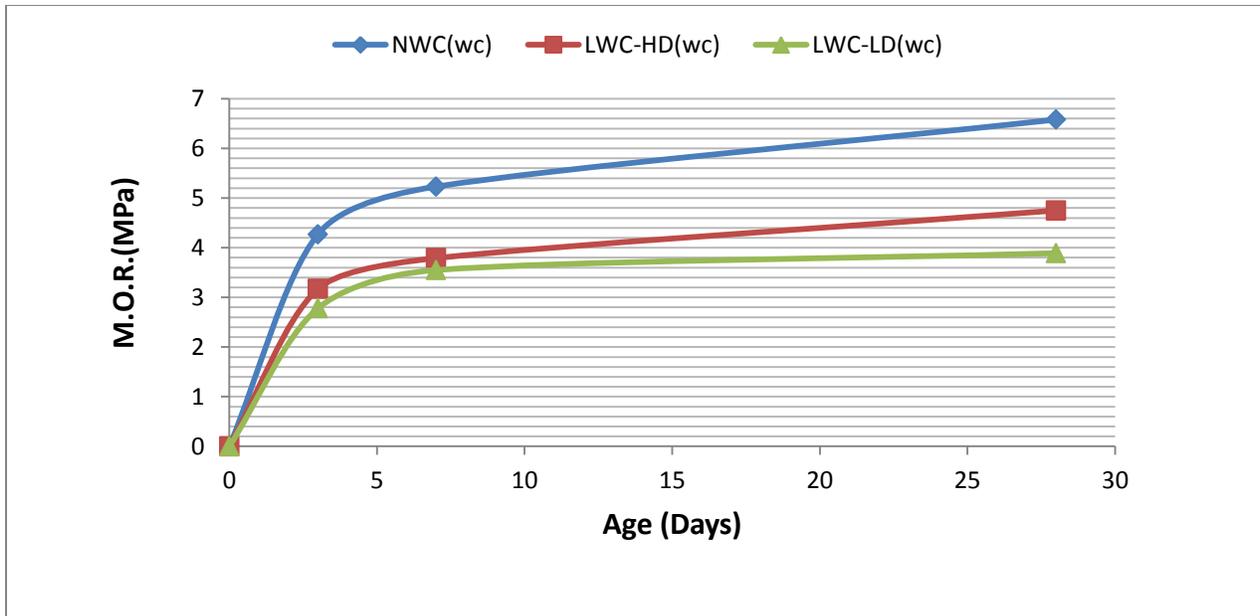
Fig.(4.13) Modulus of rupture for concrete tiles for case water curing.
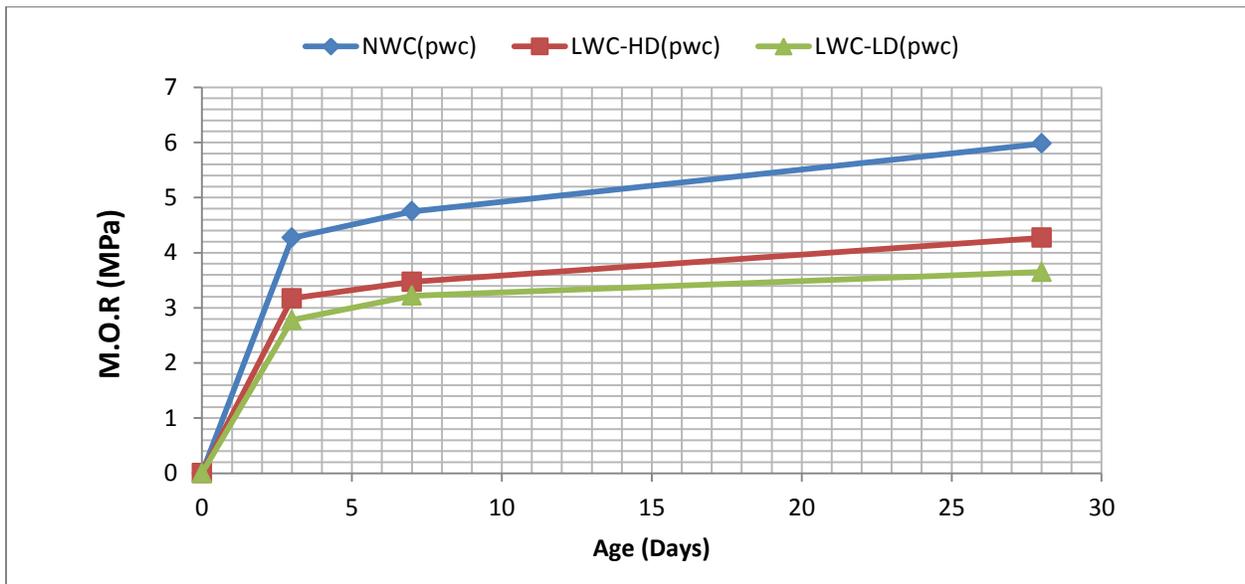
Fig. (4.14) Modulus of rupture for concrete tiles for case 3days particle water curing.
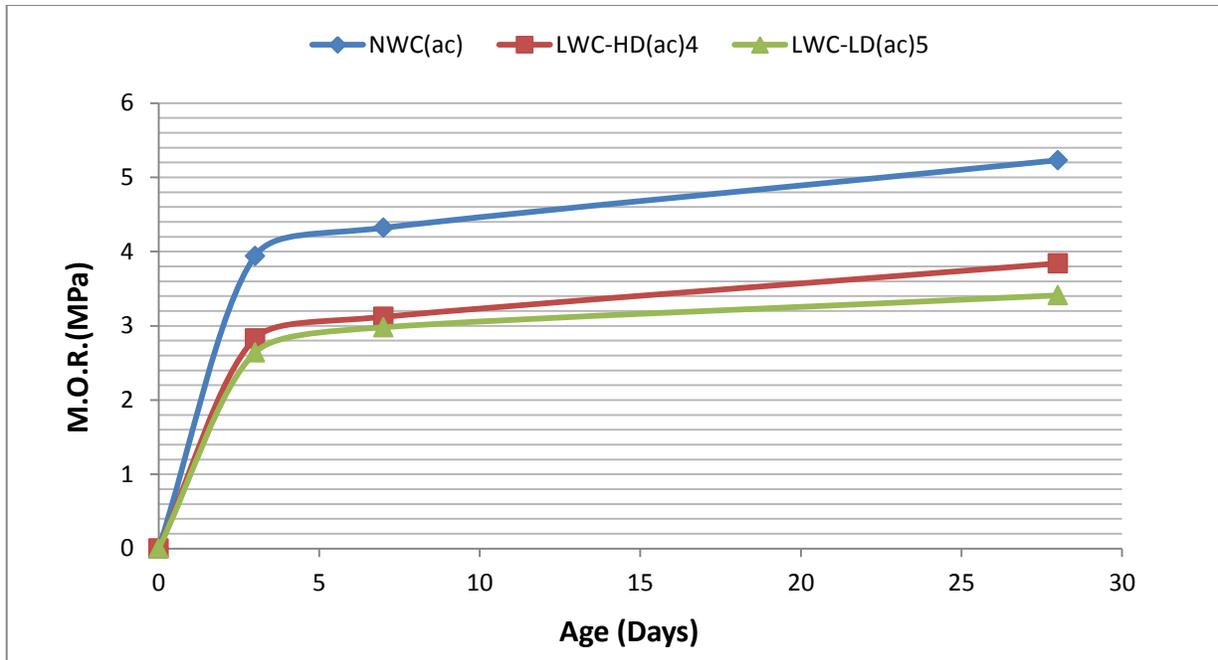
Fig.(4.15) Modulus of rupture for concrete tiles for case air curing.
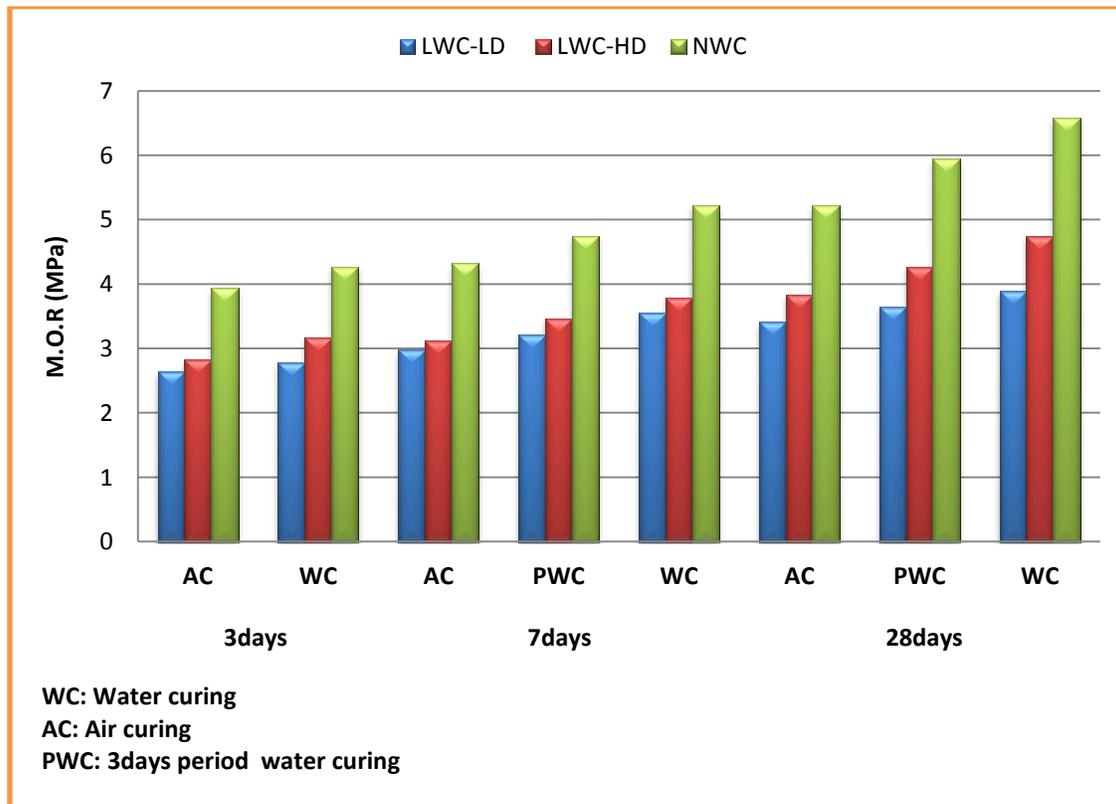
Fig (4.16) Modulus of rupture for concrete tiles in different curing types.

Plate (4.5) The failure line of concrete tiles samples.

4.3.4 Oven-Dry Density of Concrete

Table (4.6) and Fig. (4.17) show the experimental results of oven dry density at the age of 28 days for all investigated concretes. Obviously, the lighter the coarse aggregate the lower was the oven dry density. The values for this property were 2301, 1760, and 1565 kg/m^3 for NWC, HDLECA, and LDLECA, respectively. This decrease was expected and related to the variation in the relative density of the coarse aggregate used in the concrete mix. It was 2.6 for NCA, while it was 1.2 and 0.60 for HDLECA and LDLECA, respectively. By comparing the dry and fresh densities of normal weight and lightweight concretes, one can find that the latter has lost more weight because it lost more water during drying in the oven.

(Real et al., 2015) concluded that in the mortars mixtures, when the content of expanded clay aggregate was higher, the content of natural aggregate became less, then the capillary absorption coefficient of the mortars became higher.

Table (4.6) Measurement of oven-dry density of concrete.

Mixture type	w/c	HRWR % by wt. of cement	Oven-Dry density (kg/m^3)
NWC	0.4	0.75	2301
LWC Low Density	0.4	0.75	1565
LWC High Density	0.4	0.75	1760
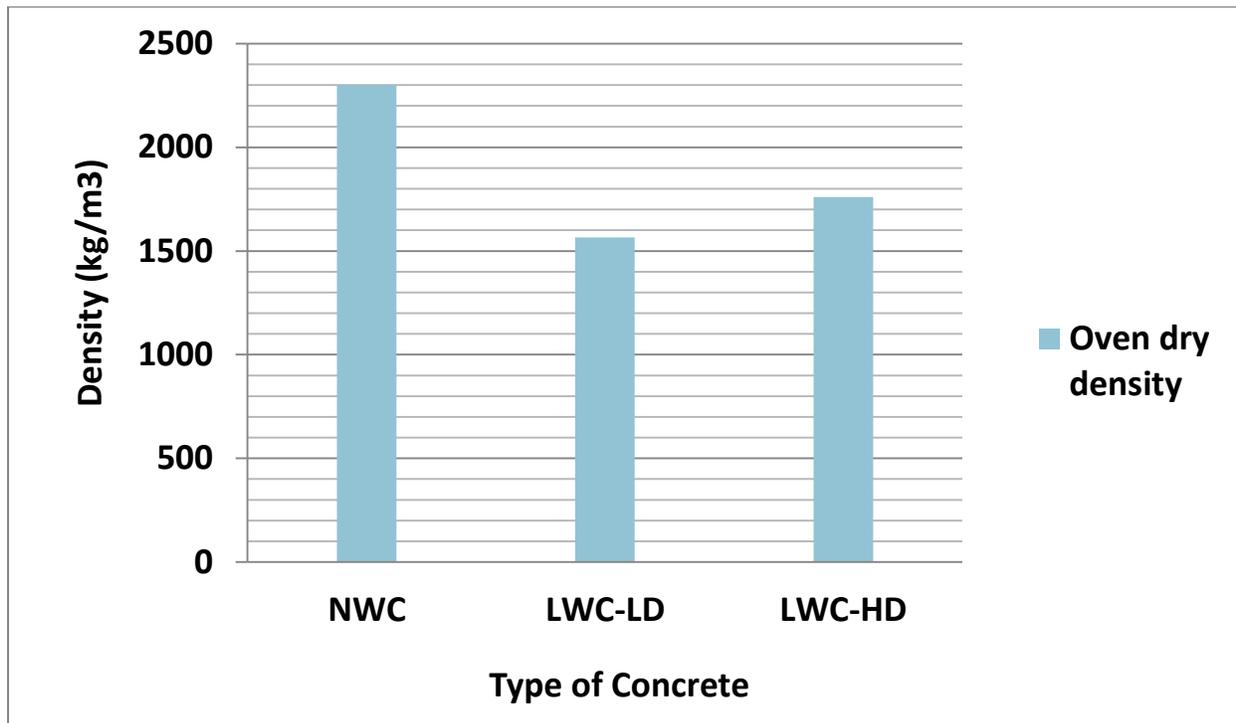
Fig. (4.17) Oven dry density for NWC, LWC-LD, and LWC-HD.

4.3.5 Concrete Tiles Weight Test

After 28 days of curing, the weights of a set of concrete tile samples which were in a dry surface condition were obtained and listed in Table (4.7) and Fig. (4.18). Through these results, it can be seen that the weight of the concrete tile was reduced by 23% and 31% when replacing the natural weight coarse aggregate with HDLECA, and LDLECA, respectively. This out coming result will reduce the dead load on the structure as well as ease the handling of the tiles in the site.

Table (4.7) The weight of concrete tile samples after the age of 28 days for the case of curing in water.

	Sample1 (kg)	Sample2 (kg)	Sample3 (kg)	Average weight (kg)
NWC	28.810	28.890	28.710	28.803
LWC-LD	19.720	19.880	19.905	19.835
LWC-HD	22.070	22.110	22.065	22.081
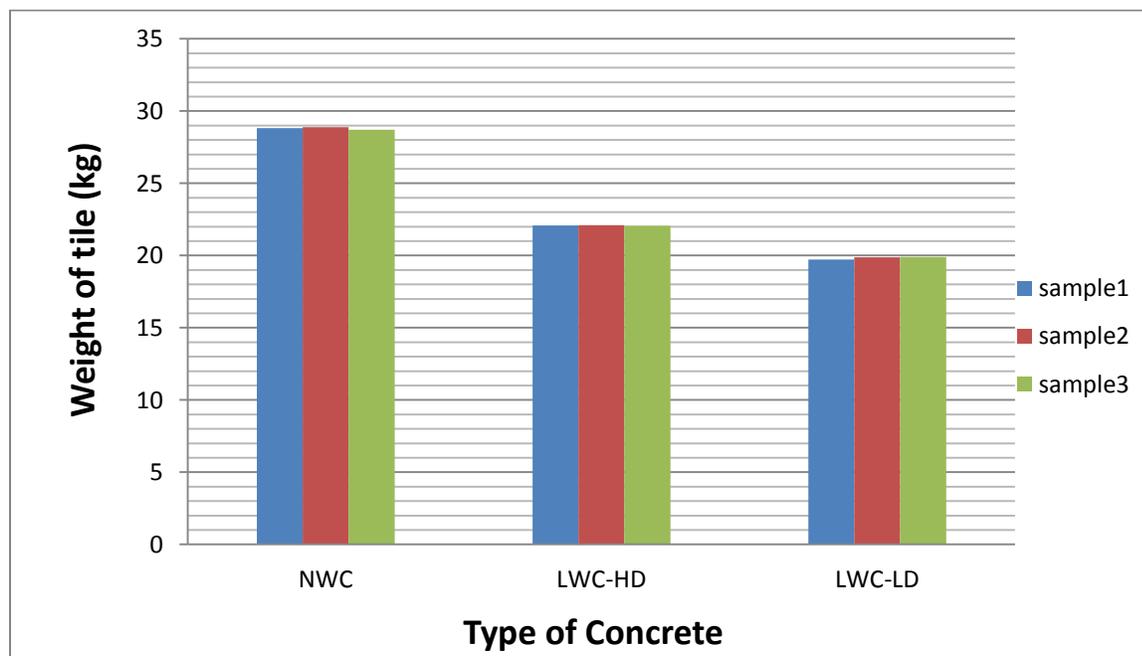
Fig. (4.18) Some weight of concrete tiles.

4.3.6 Water Absorption of Concrete Tiles

The results in Table (4.8), Figures (4.19) and (4.20) show the 28- day results of water absorption of concrete tiles subjected to different curing regimes. It is clear from the table and figures that the amount absorption rate in lightweight concrete was higher than that of natural weight concrete, as well as the absorption rate of lightweight concrete with LECA of low-density was higher than that of LECA with high density. This is because the natural weight coarse aggregate had less water absorption (0.8%) than the lightweight coarse aggregate (12% and 24%). Nevertheless, despite the ability of the coarse lightweight aggregate to absorb water, the results did not exceed the limits of the Iraqi specification No. 1107 of 1988 that limits the percentage of water absorption by 4% in the case of immersion time for half an hour, and 10% in the case of immersion time of 24 hours because the coarse aggregate particles were surrounded by the hydrated cement paste, which led to the closure of its pores and its reduced ability to absorb external water.

Among the three types of concrete, the minimum water absorption rates were recorded for NWC followed by LWC-HD, and LWC-LD, respectively regardless of the curing regime. A half an hour water absorption for NWC, LWC-HD, and LWC-LD was varied between (1.98-2.29%), (2.82-3.26%), and (3.51-3.62%), respectively. The corresponding 24-hour water absorption rates were in the range of (3.22-4.2%), (5.71-6.26%), and (6.08-7.03%), respectively.

Among the three types of curing regimes, the air-cured tiles recorded the highest water absorption percentage while the 28-day water cured tiles showed the lowest water absorption rate. The 24-hour water absorption of air-cured tiles reached 7.03%, while it reached 6.08% for water-cured ones. Indeed, the concrete cured with water for a longer period of time has the lowest water absorption rate

due to better hydration of the cement paste and the lack of pores and clogging of the gaps inside the texture of well-hydrated concrete.

In the previous work, it was found that the percentage of water absorption in mortars containing different types of lightweight aggregates increases as the porosity of the aggregate increases, and the more fractured its grains, **(Bogas et al., 2012).** In addition, **(Salem et al., 2014)** noticed an increase in the percentage of water absorption of concrete when replacing the natural aggregate with expanded clay aggregate.

Table (4.8) Results of water absorption for NWC, LWC-HD, and LWC-LD for age 28 days.

Mix type	Curing type	Average Absorption water after a half-hour (%)	Limits of IQS NO. 1107 of 1988	Average absorption water after 24 hours (%)	Limits of IQS NO. 1107 of 1988
NWC	In air for 28day	2.29		4.20	
	In water for 3day and in air for 25day	2.12		3.90	
	In water for 28 day	1.98		3.22	
LWC-HD	In air for 28day	3.26		6.26	
	In water for 3day and in air for 25day	2.95	≤4%	5.97	≤10%
	In water for 28 day	2.82		5.71	
LWC-LD	In air for 28day	3.62		7.03	
	In water for 3day and in air for 25day	3.54		6.74	
	In water for 28 day	3.51		6.08	
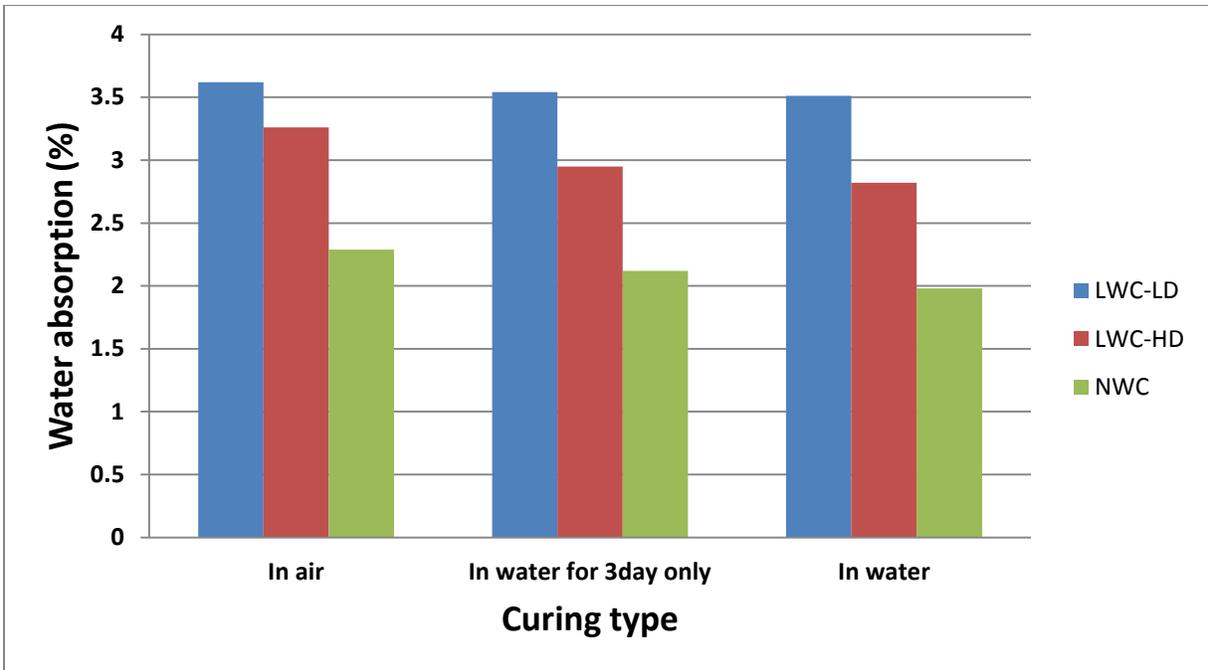
Fig. (4.19) Water absorption after a half-hour.
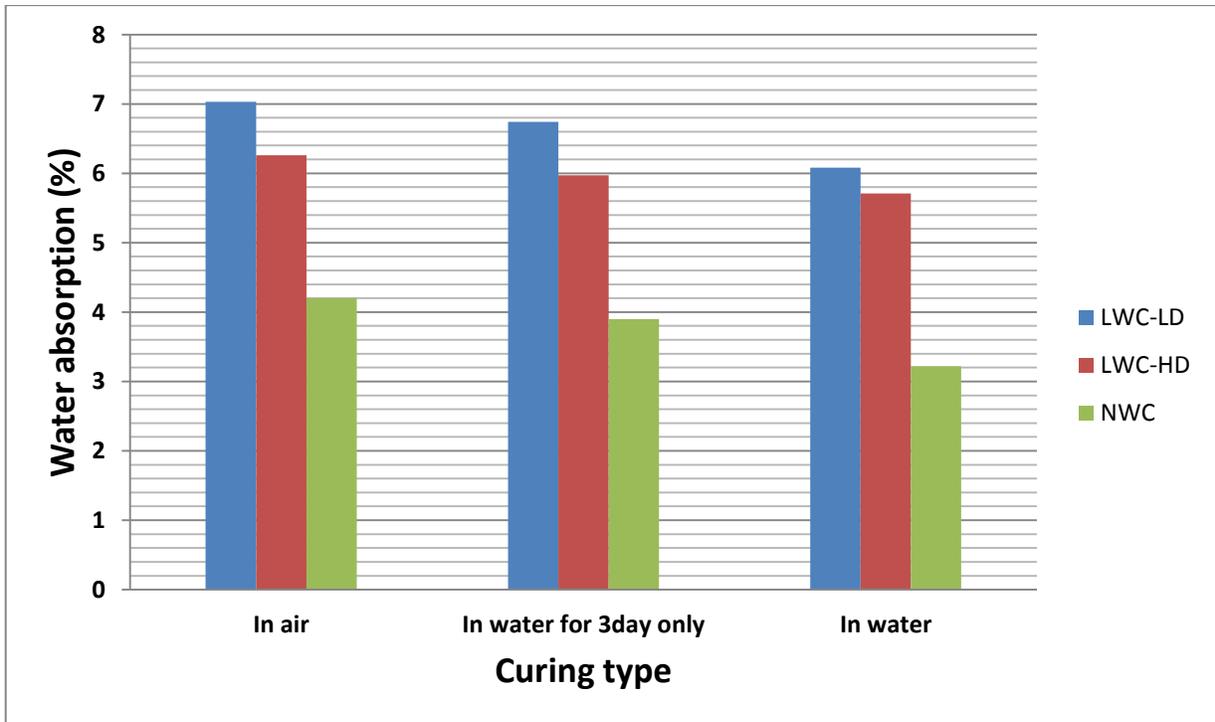
Fig. (4.20) Water absorption after 24 hours.

4.3.7 Thermal Conductivity for Normal Weight and Lightweight Concrete

By studying the results obtained from the thermal conductivity test and listed in Table (4.9), it has been conclude that the thermal conductivity of natural-weight concrete was greater than that of lightweight concrete, and thus the thermal insulation of lightweight concrete is better than that of ordinary concrete because of the large number of a gap, voids and capillary pores that contain air in lightweight aggregates, where the air is a good heat insulator.

The results also indicated that the lightweight concrete incorporated with low density LECA was more heat-insulating and less conductive than that incorporated with high density LECA. Moreover, the air-cured concrete was more insulating than water-cured concrete, the former was more porous, due to the low percentage of hydrated cement in it.

The average value of the highest thermal conductivity value of concrete reached 1.96 W/(m .k^{o}) in NWC and water-cured concrete, while the average value of the lowest thermal conductivity was 0.78 W/(m .k^{o}) in LWC-LD cured in the air as shown in Table (4.9).

Table(4.9) Thermal conductivity test for concrete.

Mixture type	Curing type	TA	TB	TC	ds (mm)	e $(\frac{W}{m2.k})$	K. $(\frac{W}{m.k°})$	Average K. $(\frac{W}{m.k°})$
NWC	In air	306	311	311	17	0.5242	1.6808	
		299	304	304	17	0.5364	1.6806	1.68
		300	305	305	17	0.5346	1.6806	
	In water for 3 day	309	314	314	17	0.5190	1.6810	
		309	313	313	17	0.5201	2.1042	1.82
		297	302	302	17	0.5399	1.6805	
	In water	303	307	307	17	0.5306	2.1039	
		300	305	305	17	0.5346	1.6806	1.96
		297	301	301	17	0.5410	2.1037	
LWC-HD	In water	297	305	305	17	0.5369	1.0457	
		301	309	309	17	0.5298	1.0459	1.00
		299	308	308	17	0.5320	0.9282	
	In water for 3day	301	309	309	17	0.5298	1.0458	
		296	305	305	17	0.5376	0.9281	0.97
		303	312	312	17	0.5253	0.9284	
	In air	296	305	305	17	0.5375	0.9281	
		302	312	312	17	0.5261	0.8343	0.90
		298	307	307	17	0.5340	0.9282	
LWC-LD	In water	299	308	308	17	0.5322	0.9283	
		300	309	309	17	0.5305	0.9282	0.97
		300	308	308	17	0.5315	1.0458	
	In water for 3day	301	309	309	17	0.5298	1.0459	
		299	308	308	17	0.5322	0.9282	0.94
		296	306	306	17	0.5365	0.8340	
	In air	296	307	307	17	0.5355	0.7571	
		297	308	308	17	0.5337	0.7572	0.78
		298	308	308	17	0.5330	0.8341	
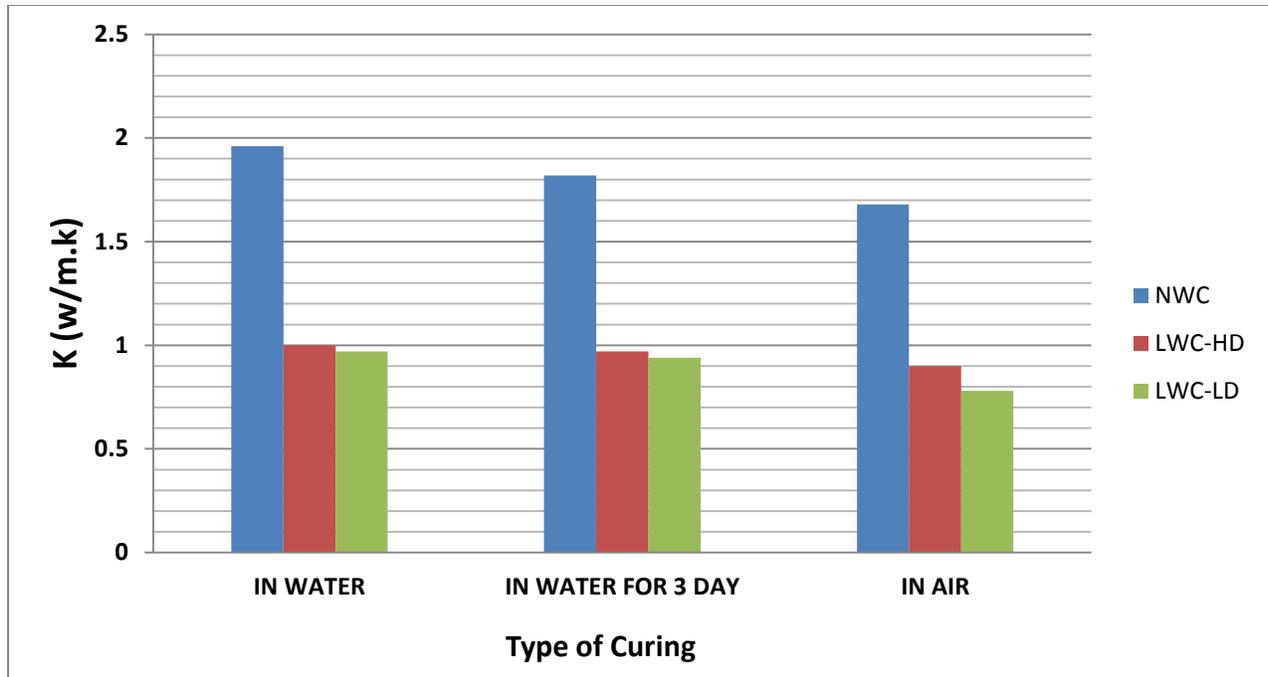
Fig. (4.21) The results of thermal conductivity (K) of lightweight concrete and natural weight concrete under different curing conditions.

   Holm & Bremner, (2000) and Matos & Dos Santos,(2006) found that the thermal conductivity in concrete increases as the density of the concrete increases, and the values they obtained confirm that the natural weight concrete is more thermally conductive than the lightweight concrete, as recorded in Table (4.10).

Table (4.10) The relationship between concrete density and thermal conductivity(k).

Source Name	Density of Concrete	Thermal Conductivity
According to Holm and Bremner (2000).	about 1850 kg/m3	0·58 to 0·86 W/m K
	about 2400 kg/m3	1·4 to 2·9 W/m K
According to Santos and Matias (2006).	1400 to 1800 kg/m3	0·85 and 1.05 W/m K
	2000 to 2600 kg/m3	1·65 to 2·0 W/m K

Chapter Five

CHAPTER FIVE

Conclusion and Suggestion

5.1 Conclusions

Depending on the experimental work of this study and the interpretation of the consequence, the following conclusions can be drawn:

- The fresh density of concrete dropped from 2343 kg/m^3 to 1820 kg/m^3 and 1640 kg/m^3 when LECA of high density (HDLECA) and LECA of low density (LDLECA) were used, respectively.

- When the normal coarse aggregate was totally replaced by LECA, the slump increased by 37.5% and 50% when HDLECA and LDLECA were used, respectively.

- The LWC with HDLECA performed better compressive strength than LWC made with LDLECA though the two types of LWCs showed lower compressive strength as compared to NWC. At 28 days, the compressive strength decreased by up to 53% and 30% due to the inclusion of LDLECA and HDLECA, respectively depending on the curing regime.

- The compressive strength of all types of investigated concrete was affected by the type of curing regime such as the best strengths were obtained when continuous water curing was conducted followed by partial water curing (3 days curing in water followed by air curing). On the other hand, the lowest strengths were reported for air-cured samples. The recorded compressive strengths were in the range of (21.2-45.8 MPa), (20-41.2 MPa), and (19-36.2

MPa) for water curing, partial water curing, and air curing for all types of investigated concrete.

- The LWC with HDLECA showed better fracture load and modulus than LWC with LDLECA regardless of curing regime. The fracture load was in the range of between (8- 9.9 kN) and (7.1- 8.1 kN) for LWC with HDLECA and LWC with LDLECA, respectively. The corresponding values for modulus of rupture were (3.84–4.75 MPa), and (3.41–3.89MPa), respectively.

- As with the compressive strength, among the three types of curing regimes, the continuous curing in water gave the best fracture load and modulus of rupture.

- It was found that the incorporation of LDLECA in concrete tiles led to fracture load lower than the limit of Iraqi Standard No. 1107, 1988, which requires a breaking load of not less than 8.3 kN. On the other hand, the concrete tiles incorporated with HDLECA satisfied the above standard with the exception of tiles treated in air.

- Comparing the results of compressive strength and flexural strength for continuous water curing, it can be seen that the submerged concrete tiles developed their rate of strength gain faster than the cube because the ratio (surface area/volume) of the concrete tile was greater than the cube, such that the rate of gaining compressive strength at the age of 3 days was equal to (65.5, 60, and 60%) from the strength at the age of 28 days in concrete type (LWC-LD, LWC-HD, and NWC) respectively. While the rate of increase in the modulus of rupture at the age of 3 days was (71, 67, and 65%) from the modulus of rupture at the age of 28 days for the same mixtures.

- By using LECA of high density with a curing period of at least 3 days in water, concrete tiles satisfied the requirements of the Iraqi standard with a weight of 6.7 kg lighter than traditional weight tiles.

- All types of precast concrete tiles in this thesis achieved an acceptable water absorption rate according to the Iraqi Standard No. 1107, 1988.

- The water absorption rate in NWC was lower than in LDLWC and HDLWC which was 3.22%, 6.08%, and 5.71%, reactively.

- The air-cured tiles recorded the highest water absorption percentage while the 28-day water cured tiles showed the lowest water absorption rate. The 24-hour water absorption of air-cured tiles reached 7.03%, while it reached 6.08% for water-cured ones.

- It was found that the lower the density of concrete the lower was the thermal conductivity and thus better thermal insulation.

- It was found that the air-cured concrete was more insulating than water-cured concrete.

- In conclusion, the satisfactory and lighter than traditional concrete tiles can be made by incorporating light expanded clay LECA having density of (700 kg/m^3).

5.2 Recommendations for future researches

The following recommendations are important to develop and improve this work:

- Study of the use of other dimensions of concrete tiles.

- Study of the use of reinforcing mesh in concrete tiles mold and its effect on flexural resistance.

- Study the effect of changing the water/cement ratio on the breaking strength of concrete tiles.

- Study of the effect of other concrete mixing ratios on the mechanical and thermal properties of concrete tiles.

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الخلاصة

يعتبر البلاط الخرساني التقليدي المسبق الصب المستخدم في الأسقف ثقيل للغاية لذلك يمكن اعتبار هذا العمل بمثابة بداية لمعرفة خصائص ومواصفات البلاط المنتج باستخدام ركام الطين التمددي الخفيف الوزن والتي تمثل بديلاً جيدًا للإنتاج التقليدي.

تشمل هذه الدراسة إنتاج البلاط الخرساني باستخدام نوعين من الركام الطيني التمددي الخفيف الوزن (LECA) ونوع واحد من الخرسانة الركام ذات الوزن الطبيعي. كما تسلط هذه الدراسة الضوء على تأثير اختلاف كثافة الركام الخشن ونوع المعالجة ومدتها على مقاومة الانضغاط وقوة الكسر وتغير الوزن للخرسانة الاعتيادية والخرسانة خفيفة الوزن في الاعمار 3 يوم و7 يوم و 28 يومًا.

تم عمل ثلاث خلطات خرسانية رئيسية ذات محتوى سمنتي 505 كغم/ م^3 وبنسبة وزن (سمنت/ ماء) بلغت 0.4 في الخلطتين الاول والثانية تم استخدام نوعين من الطين التمددي الاول ذي كثافة نوعية تساوي 1.2 والثاني بكثافة نوعية بلغت 0.6 ، بينما بلغت الكثافة النوعية للركام الطبيعي الوزن 2.6 في الخلطة الثالثة. لقد بلغ المقاس الاقصى للركام الخشن 10ملم في جميع الخلطات. تم صب 72 عينة من البلاط الخرساني بقياس (5*50*50) سم و81 عينة من المكعبات ذات القياس (10*10*10) سم و27 عينة على شكل قرص صغير ذات قطر (40) ملم. خضعت العينات لثلاث حالات من المعالجة ففي الحالة الاول تم معالجتها بالماء بشكل مستمر بينما في الحالة الثانية تم معالجة بالماء لثلاثة ايام فقط بينما في الحالة الثالثة فتم تركها معرضة للهواء داخل المختبر. تم اجراء فحوصات الهطول وقياس الكثافة الطرية بعدها تم اجراء فحوصات قياس الابعاد ونسبة امتصاص الماء ومعايير قوة الكسر لعينات البلاطات الخرسانية كما تم فحص مقاومة الانضغاط وقياس الكثافة الجافة لعينات المكعبات بينما تم اجراء فحص التوصيل الحراري لعينات الاقراص الصغيرة.

أظهرت النتائج أن الكثافة الطازجة للخرسانة انخفضت من 2343 كغم / م^3 إلى 1820 كغم / م^3 و 1640 كغم / م^3 عند استخدام ركام الطين التمددي عالي الكثافة (HDLECA) والمنخفض الكثافة (LDLECA) ، على التوالي. كما تم ملاحظة أفضل مقاومة للانضغاط و اكبر قوة كسر تم الحصول عليها في العينات المعالجة بالماء ، تليها العينات المعالجة بالماء جزئيًا والعينات المعالجة بالهواء.

لـوحظ ان مقاومــة الانضــغاط بعمــر 28يـوم وفـي حالــة المعالجــة المسـتمرة بالمــاء قـد انخفضـت بمقدار(53%) عند استبدال الركام الخشن الطبيعي الوزن بركـام الطين التمددي ذات الكثافـة النوعيـة (0.6) بينما بلغ مقدار الانخفاض (30%) فقط عند استبداله بالطين التمددي ذات الكثافة النوعية(1.2). كمـا اظهرت النتائج ايضا نقصـان في وزن البلاط الخرسـاني بمدى (6.7-9 كغم) عند استبدال الركـام الطبيعي بالركـام الخفيف الوزن كما تم الاستنتاج على أن البلاط الخرساني الذي يلبي متطلبـات المواصفة القياسية العراقيـة يمكن إنتاجه باستخدام الطين التمددي العالي الكثافة (HDLECA) الذي يؤدي إلى انتاج بلاط خرساني ذات وزن أخف وعزل حراري أكبر من البلاط الخرساني ذات الوزن الاعتيادي.

انتاج بلاطات خرسانية خفيفة الوزن باستخدام ركام الطين التمددي

رسالة مقدمة الى كلية الهندسة في جامعة بابل كجزء من متطلبات نيل درجة الماجستير في

الهندسة / الهندسة المدنية / مواد أنشائية

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