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Structural Sustainability of Lightweight Concrete girder

A Thesis
Submitted to the College of Engineering of the University of Kerbala in Partial Fulfillment of the Requirements for the Degree of Master in Civil Engineering
(Infrastructure)

By

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بسم الله الرحمن الرحيم

شهد الله انه لا اله إلا هو والملائكة وأولي العلم قائما بالقسط لا اله إلا هو العزيز
الحكيم﴿18﴾إن الدين عند الله الإسلام وما اختلف الذين أوتوا الكتاب إلا من بعد ما
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Dedication

To the great person

who will find the exact solution for all the problems in the world in all areas of the life. The person will make the world a safe and peaceful place and achieves justice.

Who..

....

....

....

That there is no problem with his presence. When do you come to us? The world needs you. We wait ....

Sajjad Abdul Amir Badr

SUPERVISOR CERTIFICATE

We certify that this thesis entitled **"STRUCTURAL SUSTAINABILITY OF LIGHTWEIGHT CONCRETE GIRDER"**, which is prepared by **"Sajjad Abdul Amir Bader"**, is under our supervision at University of Kerbala in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Infrastructure Engineering).

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Abstract

Due to the limitations of natural materials which uses in concrete production, the use of waste and recycle materials in concrete production can eliminate the negative impact of concrete on the environment. Therefore, Attapulgite and crushed clay bricks were used as a coarse lightweight aggregate to produce a structural sustainable lightweight aggregate concrete. The present study includes an experimental investigation of the behavior of a simply supported beams. The experimental program consists of testing eight reinforced concrete rectangular beams. Five of these beams are tested under symmetric two-point concentrated loads (STPCL) and the others tested under one point concentrated load (OPCL). All beams have the same dimensions; 140 mm width, 180 mm depth and 1200 mm length. The main considered variables in the experimental study were the type of aggregate (Attapulgite aggregate, crushed clay bricks aggregate and normal weight aggregate), type of loading system and curing time. Cylinders and cubes for each concrete mix, were tested to find the mechanical properties of concrete. The experimental program shows that a structural lightweight aggregate concrete can be produced by using Attapulgite aggregate with 25 MPa cube compressive strength and 1805 Kg/m^3 oven dry density and by using crushed clay bricks aggregate with 43.7 MPa cube compressive strength and 1977 Kg/m^3 oven dry density. The weight of Attapulgite aggregate concrete and crushed clay bricks aggregate concrete beam specimens were lower than normal weight aggregate concrete beams by about 20.56% and 13.65% respectively at 28 days. As for the ultimate load capacities of beam specimens, the ultimate load of Attapulgite aggregate concrete beams tested under STPCL were lower than that of crushed clay bricks aggregate concrete beams and normal weight aggregate concrete beams by about 4.85% and 5% respectively. While the ultimate load capacities of reinforced Attapulgite concrete beams tested under OPCL were lower than that of reinforced crushed clay bricks aggregate concrete beams and reinforced normal weight aggregate concrete beams by about 10.3% and 10.5% respectively. Finally, Attapulgite aggregate concrete and crushed clay bricks aggregate concrete showed ductility and toughness less than that of normal weight aggregate concrete.

List of Contents

Abbreviations

Symbol	Description
LWC	Lightweight Concrete
NWC	Norma-weight Concrete
SLWC	Structural Lightweight Concrete
A	Attapulgite Coarse Aggregate
B	Crushed Clay Bricks Coarse Aggregate
N	Normal Weight Coarse Aggregate
RPC	Reactive Powder Concrete
ACI	American Concrete Institute
NS	Norway Code
CEN ENV	Unified European Standard
RILEM	International Union of Laboratories and Experts in Construction Materials, Systems and Structures
BS EN	British Standard European Norm
ASTM	American Society for Testing and Materials
BS	British Standards (BSI: British Standard Institute)
IQs.	Iraqi Specification
USA	The United States of America
UK	The United Kingdom
STPCL	Symmetric Two Point Concentrated Load
OPCL	One-Point Concentrated Load

KN	Kilo-newton
GPa	Gigapascal
MPa	Megapascals
Kg	Kilogram
LVDT	Linear Variable Differential Transformer
W/C	Water-Cement ratio
λ	Reduction Factor
OD	Oven Dry
SSD	Saturated Surface Dry Condition
B.C	Before Christ
A.D	Anno Domini
LECA	Light Expanded Clay Aggregate
OPBC	Oil-Palm-Boiler Clinker
OPS	Oil Palm Shell
RHA	Rice Husk
FA	Fly Ash
No.	Number
^{o}C	Centigrade
Min.	Minimum
%	Percentage
≤	Less than or Equal
≥	Greater than or Equal

≈	Approximately Equal
Ø	Bar Diameter
3rd	Third
4th	Fourth

List of Figures

List of Plates

List of Tables

Chapter One

Introduction

Introduction

1.1 General

One of the most important available construction materials in the world is reinforced concrete [1]. The composition of reinforced concrete consists of steel and concrete which is successfully used in infrastructure for decades. However, every material has advantages and disadvantages. One of the disadvantages of reinforced concrete is its high self-weight, where its density ranges between 2200 kg/m^3 to 2600 kg/m^3. Thus, high weights will be imposed on the building, especially on the foundations. Therefore, lightweight concrete can tackle this problem by reducing the weight of concrete [2].

The concrete industry today is the largest consumer of limited natural resources, such as water, sand, gravel and crushed rock[3]. It has been reported that the concrete industry will consume 8 to 12 billion tons of natural aggregates annually after 2010[4]. Construction by its very nature is not necessarily an environmentally-friendly activity,[5] and this industry has a significant environmental impact[6]. The best alternative to achieve sustainable development of the concrete industry is the use of waste and by-product materials instead of raw materials in the concrete mixture[7]. In this way, for a large number of applications in the civil and structural engineering sector, concrete can be considered an environmentally friendly and sustainable construction material, which can contribute to a better quality of life for all mankind[8]. lightweight aggregate concrete (LWAC) made of artificial LWA such as expanded clay, slate, shale, or blast furnace slag, is a type of environmentally-friendly material for the construction industry. The reasons include that lightweight concrete reduces the dead load of construction. However, it should be noted that the manufacture of a lightweight aggregate needs to a lot of energy. This energy comes from the burning of coal, and, recently, a major part is from the burning of combustible liquid waste products[9]. There are other resources for lightweight aggregate, namely natural lightweight aggregates, which do not require a significant energy demand in their preparation compared to artificial lightweight aggregates. Some of these aggregates can be provided from natural lightweight rocks. The use of solid wastes from industry, such as oil palm shell (OPS), in lightweight concretes will be more sustainable in the construction industry(10).

Lightweight concrete was successfully used in a variety of structures and for several years. The most important purpose for using lightweight concrete is to decrease the weight of the structures, which can reduces the costs of construction as the density of lightweight concretes is less than the density of normal weight concrete by about 20% (11).

1.2 Lightweight Concrete (LWC)

Lightweight concrete is a type of concrete with a density less than conventional (normal) concrete.

To produce lightweight concrete, there are three techniques which can be summarized as follow (12):

1- No-Fines Concrete: This type of lightweight concrete contains only cement and normal-weight coarse aggregate.

2- Aerated Concrete: This type of concrete can be produced by entrapping the air into the concrete with an amount ranges between 30% to 50%.

3- Lightweight Aggregate Concrete: This concrete can be produced by partially or fully replacing the normal aggregate by lightweight aggregate.

Also, ACI 318-14 (13) defines two types of lightweight concrete:

1- All lightweight aggregate concrete: This concrete can be produced by using lightweight fine aggregate and coarse aggregate.

2- Sand-lightweight concrete: Is structural lightweight concrete with all of the fine aggregate replaced by sand.

1.3 Structural Lightweight Concrete (SLWC)

There are two important parameters of structural lightweight concrete, which are compressive strength and density. In several codes, the oven dry density of structural lightweight concrete is less than 2000 kg/m^3 [14]. The structural lightweight concretes can be defined by **ACI 213R-14[15]** as concrete of a minimum cylinder compressive strength of 17 MPa and an equilibrium density of 1120-1920 kg/m^3 at 28 days.

- The structural lightweight concrete is also defined by Norway code, (NS 3473, 1992) [16] as a concrete with 1200-2200 kg/m^3 as an oven dry density and contains lightweight aggregate.
- The unified European standard (CEN ENV 1992-1-4, 1994)[17] and RILEM [18] has also define the structural lightweight concrete as a concrete with an oven-dry density less than 2000 kg/m^3.
- The British code (BS EN1992-1-1, 2004)[19] defines the structural lightweight concrete as a concrete with an oven-dry density not more than 2200 kg/m^3.

1.3.1 Advantages of Structural Lightweight Concrete

The advantages of using structural lightweight concrete can be listed as follows[20]:

1- Reduce dead load
   - Decrease the cross-section of structural elements.
   - Reducing the required supports, therefore it can obtain longer spans.

2- Provide better thermal and sound insulations than ordinary concrete.

3- Provide good resistance to chloride penetration because its pores are not interconnected.

4- Provide good bond between aggregate and cement paste.

5- Reduce damages resulting from fires because of the lower thermal conductivity of lightweight concrete than normal weight concrete[21].
6- Reduce the cost of construction because of the reduction in cross-section of structural elements due to the reduction in the dead load.
7- Preserving natural resources by using manufacturing waste products to produce structural lightweight concrete.

1.3.2 Disadvantages of Structural Lightweight Concrete [22]

1- The abrasion strength of structural lightweight concrete is weaker than that of normal weight concrete.
2- In the mixing process, the structural lightweight concrete requires greater attention to achieve the workability and strength requirements.
3- In the pumping process, the structural lightweight concrete needs particular procedures[23].
4- In the placing and finishing process, the structural lightweight concrete needs particular procedures.
5- The ductility of structural lightweight concrete is lower than normal weight concrete due to its high strength cement paste.

1.3.3 Applications and Uses of SLWC

The demand for structural lightweight concrete is increasing and it became an important material due to its advantage. It is used in many structures such as multistory building, precast structural elements, prestressed structural elements, bridges, oil platform [15]. Plate (1-1) shows several of these structures [15, 20, 24, 25].

Bank of America, 1994 (15)

Nordhordland Bridge, Norway (15)

Tunnel built, Norway (20)

Hibernia Offshore Platform (24)

Protocol of finished lightweight concrete precast façade (25)

Plate 1-1: Examples of structures with lightweight concrete

1.4 Objectives and Scope of the Current Work

The main objective of the current work is to investigate experimentally the structural behavior of simply supported lightweight aggregate concrete beams reinforced by steel reinforced bars. Other specific objectives are:

1- Investigate the mechanical properties of Attapulgite and crushed clay bricks lightweight aggregate concrete and normal weight concrete.
2- Investigate the effect of concrete type on the structural behavior of beams.
3- Investigate the curing ages, which are 28 days and 90 days on the mechanical properties of the concrete and structural behavior of beams.
4- Investigate the effect of loading type which is symmetric two-point concentrated load (STPCL) and one point concentrated load (OPCL) on the structural behavior of beams.

1.5 Research Significance

In all over the world and from a long time, researchers showed a great interest in using lightweight aggregate concrete. However, in Iraq, little information is available about the engineering properties of lightweight aggregate concrete due to the limited use of lightweight aggregate concrete in structures. Therefore, the main significance of this research is to produce a structural lightweight aggregate concrete from Attapulgite lightweight aggregate and crushed clay bricks lightweight aggregate, then investigate the flexural behavior of beams casted with these types of lightweight concrete.

1.6 Layout of Thesis

This study consists of six chapters as follow:

Chapter One: includes introduction about structural lightweight concrete, its definition, its advantage and disadvantage as well as the current work aim.

Chapter Two: includes experimental and theoretical studies relevant to the topics of the research.

Chapter Three: includes details of the experimental program such as materials properties, details of beam specimens and tests procedures.

Chapter Four: includes the results from the experimental tests with discussions.

Chapter Five: includes conclusions from current work and recommendations for future work.

Chapter Two

Literature Review

Literature Review

2.1 General

The roots for lightweight concrete are back to ancient times, where natural lightweight aggregates which are used to produce lightweight aggregate concrete are the same materials were used in the construction in ancient times, such as scoria, pumice, etc. In the 3rd millennium B.C, the Sumerians used this in Babylon building as shown in plate (2-1). The Greeks and the Romans were also used pumice in the construction of buildings and some of these structures were still exist such as the great Roman amphitheatre (Colosseum) (plate (2-**2**)) and Hagia Sophia Cathedral in Turkey (plate (2-**3**)), which are built in the 4th century A.D.[20].

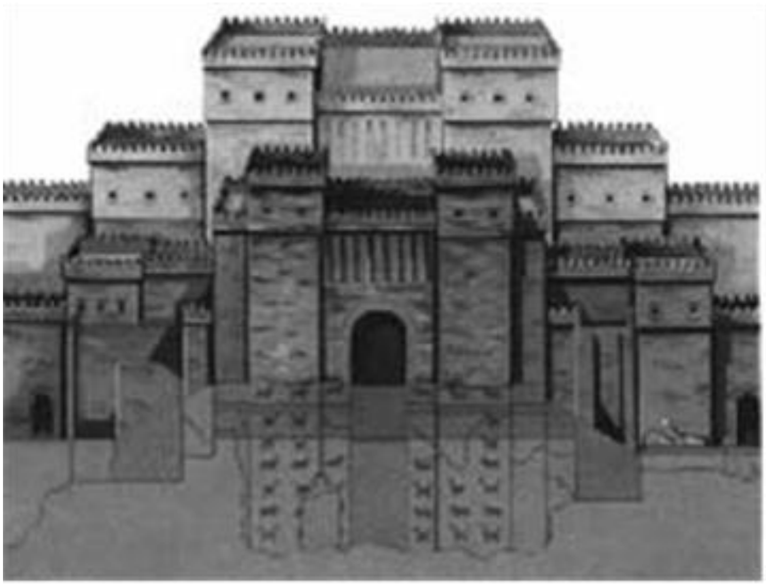


Plate 2-1: Babylonian buildings, Iraq, Built by Sumerian

Plate 2-2: The great Roman Amphitheatre

Plate 2-3: Hagia Sophia Cathedral, Turkey

In 1845, Ferdinand Nebel used pumice to produce masonry blocks, and in 1928, pumice was used in local building industries in Iceland(26). Two years later, lightweight concrete was used for the upper roadway of the San Francisco Oakland Bay Bridge(27).

Lightweight aggregate concrete has been used for large structures and multistory buildings in 1950 such as the Bank of America Corporate Center in Charlotte and Watergate Apartments in Washington. Also, the lightweight aggregate concrete was used in highway bridges(28).

In 1958, at Brentford, near London, the first structure of reinforced lightweight aggregate concrete was built, and it consisted of a three-story. Also, in 1968 the structural reinforced lightweight aggregate concrete was used for a pair of bridges in the Rotterdam in Holland [29].

In U.K. in 1974, two towers with 122 m and 145 m height were constructed by using lightweight aggregate concrete with 30 MPa cubic compressive strength [23] .

In Sweden, in 1975. The first lightweight aggregate concrete bridge was completed. The lightweight aggregate concrete had a cube compressive strength of 35 MPa and a bulk density of 1800 kg/m^3 at 28 days [23].

2.2 Application of Lightweight Aggregate Concrete in Iraq

In Iraq, the use of structural lightweight aggregate concrete in structural construction is limited and the used lightweight aggregate in most cases was imported. Where, expanded clay aggregate was used in the construction of the dome of the Martyr Monument and flooring of telephone exchanges in Baghdad. [30].

In 1980, the Polystyrene aggregate was used in making lightweight concrete to construct the penthouse walls of the University of Baghdad[31].

The building research center from the seventies of the last century shows great interest to produce lightweight aggregates from clay found in the middle and southern parts of Iraq [32].

2.3 Main Components of Lightweight Aggregate Concrete

The components of lightweight aggregate concrete are similar to normal weight concrete except replacing the normal weight aggregate by lightweight aggregate.

2.3.1 Cement

To achieve the same strength, the cement content in the lightweight aggregate concrete mix is more than that in normal weight concrete mix[33].

2.3.2 Mixing Water

Fresh, clean and drinkable water, it is the properties of mixing water which defined by ACI 523.3R (1993) [34].

2.3.3 Chemical Admixtures

The effect of using superplasticizers is similar in both lightweight aggregate and normal weight aggregate concrete, where the workability can be achieved with lower water-cement ratio[35].

2.3.4 Fine Aggregate

There are much different between the effect of using normal weight fine aggregate and the effect of using lightweight fine aggregate on the mechanical properties of concrete, where the density, compressive strength and tensile strength of concrete increase with the increase of normal weight fine aggregate [15].

2.3.5 Coarse Aggregate

Differences are there between the properties of lightweight and normal weight coarse aggregate such as strength, absorption and density.

2.4 Lightweight Aggregates Properties

2.4.1 Unit Weight (bulk density)

At the same aggregate gradation, unit weight of the lightweight aggregate is much lower than the normal weight aggregates due to the cellular structure of the lightweight aggregate [36]. According to ASTM C 330-05 [37] the loose bulk density of lightweight aggregate is less than 880 kg/m^3.

2.4.2 Gradation

A well-graded aggregate will have a continuous distribution of particle size producing minimum void content and requiring a minimum amount of cement paste to fill the voids. This will result in the most economical use of cement and will provide maximum strength [38].

The mechanical properties of lightweight concrete such as strength and density can be affected by the gradation of aggregate. Where, the strength of lightweight aggregate concrete decreases with the increase of aggregate particle sizes, because of the aggregate strength decrease with the increase of aggregate particle sizes [(39)].

2.4.3 Surface Texture and Shape

The mechanical properties of lightweight aggregate concrete is affected by the shape of lightweight aggregate particles, where the compressive strength of concrete made with a rounded aggregate is more than that of concrete made with elongated aggregate (length/thickness ratio = 4.00)[(40)].

Also, the roughness of aggregate's surface can effect on the mechanical properties of lightweight concrete as the roughness of the aggregates surface can increase the bond between the aggregate particles and cement mortar [(41, 42)].

2.4.4 Strength of Aggregate Particles

The strength of lightweight aggregate particles depends mainly on the type and source of the aggregate [(23)]. Weaker lightweight aggregate particles may need higher contents of cement [(43)].

It is well known that the porosity has an important effect on the compressive strength of aggregate as higher porosity can lead to lower strength [(38)].

2.4.5 Absorption and Moisture Content

Lightweight aggregate absorbs water in higher rate than normal weight aggregate because of their cellular structure [(15)]. In the concrete mixing process, it is necessary to avoid water absorption by lightweight aggregate particles. Therefore, it is necessary to pre-wet the lightweight aggregate before casting [(44)].

2.5 Previous Studies on Mechanical Properties of LWC

The previous experimental works on lightweight aggregate concrete (LWC) were displayed as follow:

1- Previous studies on the mechanical properties of LWC with natural aggregate.

2- Previous studies on the mechanical properties of LWC with aggregate manufactured from natural materials.

3- Previous studies on the mechanical properties of LWC with aggregate manufactured from industrial by-products.

4- Previous studies on the mechanical properties of LWC with recycled aggregate.

- **Natural aggregate**

In 2006, Mesut [23] studied the effect of using perlite aggregate and perlite powder as a replacement of the cement on the mechanical properties of lightweight concrete. The results indicated that natural perlite aggregate can be used in the production of SLWC with 20-40 MPa cylindrical compressive strength. Also, the use of perlite powder can reduce dead weight and improve the performance of concrete.

In 2012, Al-Bayati [45] studied the using of Porcelanite lightweight aggregate as a coarse aggregate to produce lightweight concrete. This study presents empirical formulas to predict the cylindrical and cube compressive strength. The results indicated that it is possible to produce structural lightweight aggregate concrete by using Porcelanite aggregate with 1841 kg/m^3 concrete dry density and 17.5 MPa cylindrical compressive strength.

In 2012, Saleh [46] studied the using of Porcelanite lightweight aggregate as a coarse aggregate to produce lightweight concrete. The normal weight coarse aggregate was replaced by Porcelanite lightweight aggregate in percentages of 0%, 25%, 50%, 75, and 100% by weight. The results indicated that using Porcelanite in concrete mix can reduce the compressive strength, splitting strength, and density of concrete. Indeed, using Porcelanite aggregate caused a reduction in the dry density ranging between (8%-23%) of normal weight concrete. While the reductions in the cylindrical compressive strength ranged from (53% to 77.6%) of normal weight concrete.

In 2012, Hachim [47] studied the effect of using lightweight aggregate (Porcelanite or Thermostone) with 0.32 water-cement ratio on the mechanical properties of lightweight aggregate concrete. The results indicated that it is possible to produce a structural lightweight aggregate concrete by using Porcelanite or Thermostone as coarse lightweight aggregate. The compressive strength and air dry density of Porcelanite aggregate concrete were more than Thermostone aggregate concrete by about 14.8%, 7.9% respectively.

In 2014, Al-Attar et al [48] investigated the effect of internal curing by two ways on high-performance concrete. The first way was through the use of partial replacement of normal weight coarse aggregate (gravel), while, the second way by partially replacing the normal weight fine aggregate (sand) by crushed Porcelanite. The replacement for coarse material (crushed Porcelanite) was done with two percentages: 7.5% and 15% by volume, and for fine material (crushed Porcelanite) with two percentages: 5% and 10% by volume. The results indicated that using fine Porcelanite aggregate as internal curing material was more effective than coarse Porcelanite aggregate. The partial replacement by 5% and 10 % of fine crushed Porcelanite caused an increase in the compressive strength by about 4.4%-5%, the splitting tensile strength from 5.48%-6.85% and for flexural strength from 11.76%-12.74% respectively. From 28 days and above, the compressive strength of lightweight aggregate concrete increased insignificantly with the increase of replacement of fine crushed Porcelanite.

In 2018, Naser et al[49] studied the effect of using three types of lightweight coarse aggregate (Porcelanite, pumice, and composite aggregates(75% clay bricks and 25% themestone)) on the mechanical properties of structural lightweight concrete. The results indicated that the composite aggregate (25% themestone and 75% bricks) concrete gave the lowest hardened density (1869 Kg/m^3) and the lowest cylinder compressive strength (25.3 MPa). While, Pumice aggregate concrete had the highest cylinder compressive strength (38.5 MPa) with a hardened density of (1888 Kg/m^3). Indeed, the Porcelanite aggregate concrete had the highest density (1905 Kg/m^3) with a cylinder compressive strength equal to (28.5 MPa). The modulus of elasticity of pumice aggregate concrete was more than Porcelanite and composition aggregate concrete by about 20.4% and 22.2% respectively. Also, the splitting and flexural strengths of pumice aggregate concrete were more than Porcelanite aggregate concrete by about 37% and 37.2% and by about (49.5% and 65.3%) than composition aggregate concrete.

- **Manufactured aggregate from natural materials**

In1999, Alduaij et al [50] studied lightweight concrete in coastal areas by using crushed bricks lightweight aggregate, expanded clay lightweight aggregate (LECA) and normal weight aggregate with exclusion the natural fine aggregate (no-fines concrete). The results indicated that it is possible to produce structural lightweight concrete by using LECA with 29 MPa cube compressive strength and 1520 kg/m^3 dry unit weight at 28 days.

In 2014, JASIM[38] studied the effect of using Attapulgite lightweight coarse aggregate on the mechanical properties of lightweight aggregate concrete and compared the result with those of Porcelanite lightweight aggregates concrete with the same mixing proportions. The results indicated that it is possible to produce structural lightweight concrete by using Attapulgite lightweight coarse aggregate with 27.2 MPa cylinder compressive strength and 1824 kg/m^3 oven dry density at 28 days. The cylinder compressive strength, splitting tensile strength, flexural strength and static modulus of elasticity of Attapulgite lightweight concrete at 28 days were more than Porcelanite aggregates concrete having same mix proportions by about 59%, 41%, 183% and 81% respectively and the oven dry density of Attapulgite lightweight concrete less than Porcelanite aggregates concrete by nearly 1%.

In 2015, Nagashree(51) studied the use of combining two types of lightweight aggregates in which light expanded clay aggregate (LECA) and scoria aggregate were used to produce lightweight concrete. The two types of lightweight aggregate are mixed in different proportion. Fully replacing the normal weight coarse aggregate by the blend of lightweight aggregate. The results indicated that 40% replacement of LECA and 60% replacement of scoria aggregates instead of normal weight coarse aggregates gave better results, with 29.9 MPa cube compressive strength and 1837 kg/m^3 density.

In 2016, Frayyeh et al(52) studied the combined effects of using Attapulgite high reactive mineral admixture and superplasticizers on the properties of Attapulgite lightweight coarse aggregate concrete. The Attapulgite high reactive mineral admixture used as partial replacement of cement (6% of cement weight). The results indicated that it is possible to produce structural lightweight concrete by using Attapulgite lightweight coarse aggregate with 27.7 MPa cylindrical compressive strength and 1775 kg/m^3 oven dry density at 28 days.

When only the Attapulgite mineral admixture was used, the compressive strength increased by nearly 12.2%, 12.6% and 16.3% and the water absorption reduced by 4%, 4.85% and 4.9% in ages of 7, 28 and 56 respectively as well as the oven dry density decreased by about 0.56% at 28 days. While when the superplasticizers and Attapulgite high reactive mineral admixture were used, the compressive strength increased by about 19.3%, 15.5% and 25% and the water absorption reduced by about 2%, 3% and 2.6% in ages of 7, 28 and 56 days respectively and the oven dry density decrease by about 0.36% at 28 days.

- **Aggregate produced from industrial by-products.**

In 2014, Shafigh et al[(10)] studied the effect of using two waste materials from palm oil industry as coarse and fine aggregates. The normal weight fine aggregate is replaced with oil palm boiler clinker (OPBC) in volume percentages from 0, 12.5%, 25%, 37.5%, 50% in oil palm shell (OPS) lightweight coarse aggregate concrete. The results indicated that it is possible to produce structural lightweight concrete by using oil palm shell as coarse aggregate with 1900 kg/m^3 oven dry density, 37.8 MPa cube compressive strength, 2.64 MPa splitting tensile strength and 4.18 MPa flexural strength. The partial replacement (12.5%, 25%, 37.5% and 50%) of normal fine aggregate with oil palm boiler clinker caused a decrease in the density by about 21.7%, 22.2%, 26.2% and 27.4%, splitting tensile strength decrease by about 2.7%, 57%, 8.7% and16.7% and flexural strength decreased by about 0.7%, 8.1%, 10.8% and 23%. The compressive strength of OPS concrete containing oil palm boiler clinker fine aggregate up to 25% was approximately equal to the compressive strength of control OPS concrete (without oil palm boiler clinker). It has been recommended not to use oil palm boiler clinker fine aggregate with a percentage of more than 37.5%.

In 2017, Farahani et al[(53)] studied the use of oil palm shell as a coarse aggregate and the cement was replaced with fly ash and rice husk in weight percentages of 35% RHA,35%FA to produce structural lightweight concrete. The results indicated that it is possible to produce structural lightweight concrete by using oil palm shell as coarse aggregate with 1840 kg/m^3 oven dry density, 40 MPa cube compressive strength. Using blended of RHA-FA by about 70% (35% RHA + 35%FA) has caused a decrease in the oven dry density and the compressive strength of concrete by about 13.6% and 52% respectively.

- **Recycled Aggregate**

In 2002, AL-Soadi[54] studied the effect of using crushed clay brick as a fully or partially replacing to the natural coarse aggregate in different percentages (0, 25, 50, 75 and 100%) on the mechanical properties of lightweight concrete. The results indicated that the density and compressive strength of concrete made with crushed brick aggregate ranged from 1845 to 2408 kg/m^3 and 24.15 to 52.43 MPa respectively.

In 2011, Al-Baghdadi [55] studied the effect of cement content and crushed clay bricks as a lightweight coarse aggregate on the mechanical properties of high strength lightweight aggregate concrete in which the cement content ranged between 300-600 kg/m^3. The results indicated that it is possible to produce high strength lightweight concrete by using crushed clay bricks as a lightweight coarse aggregate with 27.2-49.6 MPa cube compressive strength, 3.1-4.0 MPa splitting tensile strength, 1900-1960 kg/m^3 oven dry density, and 4.5- 7.1 MPa flexural tensile strength at 28 days.

2.6 Previous Studies on Structural Behavior of LWC

In 2006, Teo et al[56] studied the flexural behavior of reinforced concrete beams produced from oil palm shell (OPS) lightweight coarse aggregates of deferent reinforcement ratios (0.52% to 3.90%). For singly reinforced beams, the oven dry density was 1965 Kg/m^3 and the cube compressive strength was 26.3 MPa, while the double reinforced beams produced on oven dry density of 1940 Kg/m^3 and a cube compressive strength of 25.3 MPa. All beams were simply supported and tested under two-point symmetric load. The results indicated that OPS concrete beams showed a good ductility behavior with an acceptable amount of deflection.

In 2008, Alengaram et al[57] studied the structural behavior of palm kernel shell concrete with 37 MPa cube compressive strength and 1888 kg/m^3

density at 28 days. The palm kernel shell lightweight coarse aggregate was a by-product waste from the production of palm oil. The cement content was 480 kg/m^3 for palm kernel shell lightweight concrete and 320 kg/m^3 for normal weight concrete. All beams were simply supported and tested under two-point symmetric load. The results indicated that the palm kernel shell lightweight concrete beams were more ductile than the normal weight concrete beams. Moment capacity of palm kernel shell lightweight concrete beams was higher than normal weight concrete beams by about 3%.

In 2013, Altun and Aktas[(58)] studied the effect of using steel fiber on the structural behaviors of lightweight reinforced concrete beams. In this study, pumice origin coarse and fine aggregate with 450 kg/m^3 cement content was used to produce concrete with 20 MPa cylinder compressive strength and 1532 kg/m^3 concrete density. Two different steel fiber proportions (30 and 60 kg/m^3) were used in the lightweight concrete mixes. The beams were tested using two concentrated symmetrical loads. The results indicated that the weights of lightweight aggregate reinforced concrete beams were lower than normal weight reinforced concrete beams by nearly 42%. Using 30 and 60 kg/m^3 of steel fiber caused an increase in the mid-span vertical deflection by about 100% and 79.2% and an increase in the ultimate load by about 51% and 63.5% respectivily.

In 2013, Vázquez-Herrero et al[(59)] studied the effect of using Arlita lightweight coarse aggregate on structural lightweight concrete prestressed girders with 1800-2000 kg/m^3 a dry density and 70-75 MPa cube compressive strength at 28 days. The beams were tested using two concentrated symmetrical loads. The results indicated that the flexural strength of lightweight and normal weight exceeded the designed flexural strengths and the ductility of lightweight concrete beams was lower than the normal weight concrete beams. Moreover, as expected, the immediate prestressed losses in the lightweight concrete beams were higher than normal weight concrete beams due to the high elastic shortening of lightweight concrete. Finally, lightweight concrete was not recommended to use in prestressed concrete bridge girders due to the splitting cracks observed in the lower face of the beams after releasing the prestress, which caused a reduction in the strand confinement and a reduction in their durability and bearing capacity.

In 2013, Carmo et al[60] studied the bending strength and ductility of reinforced lightweight aggregate concrete beams. Three types of lightweight aggregate (LECA) concrete were produced with density ranged between 1870 - 1900 kg/m^3; different compressive strength 35 MPa, 55 MPa and 70 MPa; five different ratios of longitudinal reinforcement varied between 0.55% and 2.96%, and three different ratios of transversal confinement stirrups (0%, 0.6%, and 1.68%). The results indicated that at the same concrete strength the deformation capacity of reinforced lightweight aggregate concrete beams decreased with the increase in the tensile reinforcement ratio. While the increase in concrete strength, particularly in beams with lower tensile reinforcement ratio caused an increase in the vertical displacement. As for the beams without transverse reinforcement in the central zone, a brittle failure was appeared.

In 2016, Thiyab[61] studied the use of crushed clay bricks as coarse aggregate to produce a structural lightweight aggregate concrete beam with cylindrical compressive strength ranged between 21.1-27.4 MPa and oven dry density ranged between 1869-1916 kg/m^3. The cylinder compressive strength and oven dry density of normal weight concrete were 18 Mpa and 2358 kg/m^3 respectively. The results indicated that using crushed clay bricks aggregate instead of normal weight aggregate caused a decrease in the weight of beams by nearly 20% and an increase in the ultimate flexural by about 1.84%-32.1%.

In 2016, Abtan and Jaber[62] studied the flexure behavior of hybrid reinforced concrete beams combining reactive powder concrete (RPC) (RPC was used in compression layer) and lightweight concrete (LWC) (LWC was used in tension layer). The main parameters were: The type of concrete (LWC and RPC), thicknesses of RPC layer (h_R) (0%, 25% and 50% of beam height). The lightweight aggregate concrete used in the study is Porcelanite aggregate concrete, polystyrene aggregate concrete and sawdust aggregate concrete). The results indicated that no slip between the two concrete layers was noticed. The increase of RPC layer thickness (25% and 50% of beam height) caused an increase in ultimate loads of beams by about 32% and 105% for Porcelanite aggregate concrete, 42% and 83% for polystyrene aggregate concrete and 40% and 133% for sawdust aggregate concrete. while the increase in the RPC layer thickness (25% and 50% of beam height) caused a decrease in the maximum deflection by about 2% and 5% for Porcelanite aggregate concrete, 3% and 13% for polystyrene aggregate concrete and 11% and 17% for sawdust aggregate concrete. For the same RPC thickness, the ultimate load of Porcelanite aggregate concrete beams was more than polystyrene aggregate concrete and sawdust aggregate concrete.

2.7 Summary

From the previous studies, number of remarks can be concluded about lightweight aggregate concrete as well as the structural behavior of lightweight and normal weight concrete as follows:

- Attapulgite aggregate belongs intimately to the family of manufactured aggregate from natural materials similar to expanded clay.

- Most of the available work in Iraq have studied the effect of various lightweight aggregate on the mechanical properties and structural behaviors of lightweight concrete. However, for Attapulgite aggregate, all the available work in Iraq have studied the effect of such aggregate on the mechanical properties only. Therefore, the present work try to study the effect of lightweight aggregate (Attapulgite and crushed clay brick) on the structural behavior of beams, as well as the mechanical properties of structural lightweight concrete.

Chapter Three

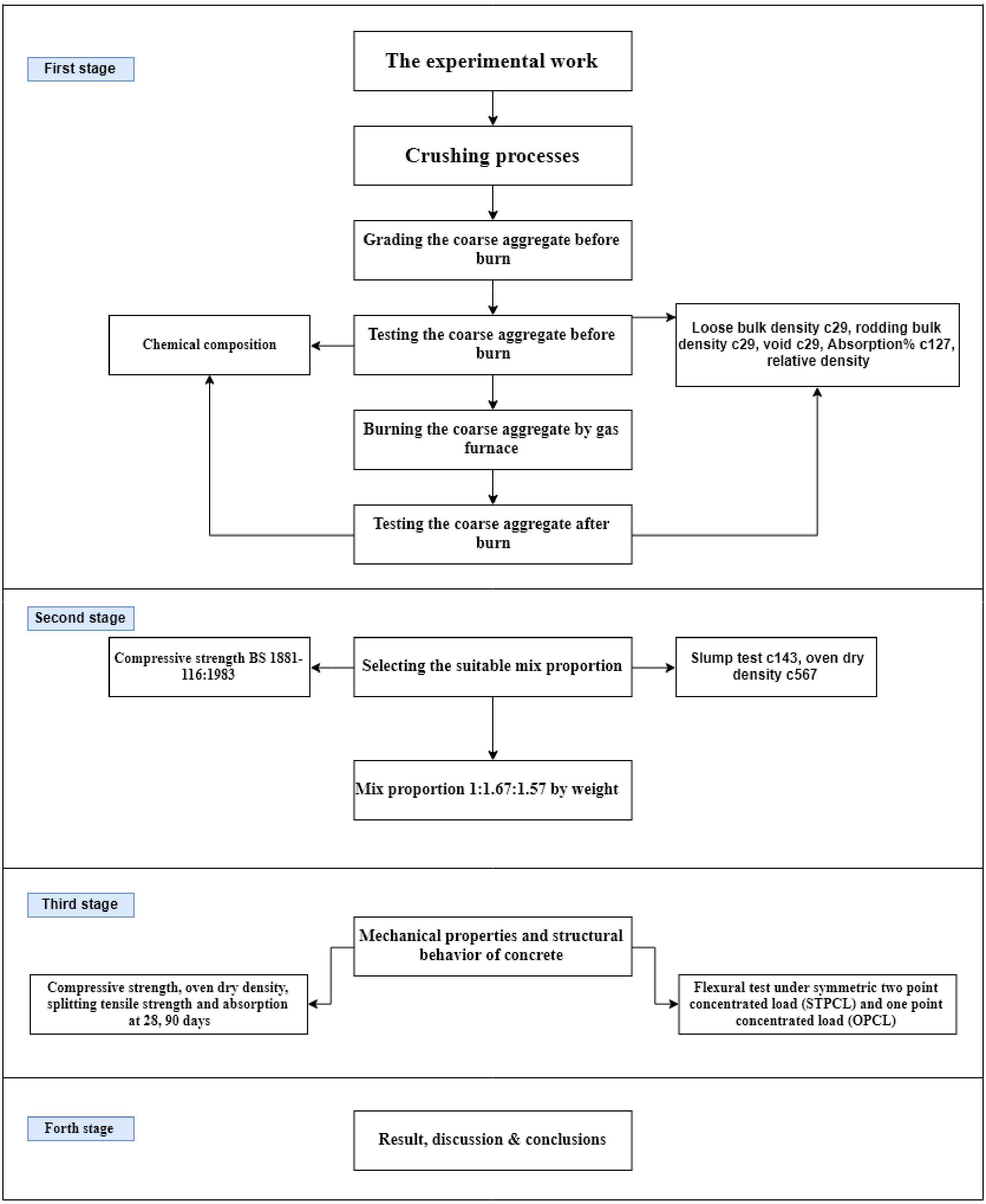
Experimental Work

Experimental Work

3.1 General

Producing structural lightweight aggregate concrete is the primary purpose of the current work, where Attapulgite aggregate and crushed clay bricks aggregate was used as a lightweight coarse aggregate and natural sand as a fine aggregate. Another purpose of the current work is to investigate the flexural behavior of lightweight aggregate concrete beam and normal weight concrete beam. In this chapter, the process of producing lightweight aggregate, material properties which are used in the experimental work and the standard tests of the materials and concrete which have been implemented according to the Iraqi and American standards were mentioned. Also, this chapter includes the mixing procedures for lightweight concrete and normal weight concrete, trial mixes, fresh concrete tests and hardened concrete tests such as density, absorption, cube compressive strength, cylindrical compressive strength, splitting tensile strength.

The details of beam specimens such as beam dimensions, casting procedure of beams and test setups of beams were also mentioned. Plate (3-1) shows the details of the experimental program.



Flow chart 3-1: Experimental program of the current work

3.2 Materials

3.2.1 Cement

Resistant Portland cement, manufactured by AL-JESR / Lafarge Cement Factory, was used in all mixes. The compliance of the cement was carried out according to the Iraqi Standard No.5/1984[63]. The physical and chemical properties of cement used are presented in Tables (3.1) and (3.2) respectively.

Table 3-1: Physical Requirements of cement*

Physical properties		Unit	Result	IQS 5/1984[63]
Initial setting time		Min.	61	≥45
Final setting time		Min.	233	≤ 600
Compressive strength	3days	MPa	15.7	≥15
	7days	MPa	24.9	≥23

*These tests were made at Kerbala University, College of Engineering, Civil Department Laboratories.

Table 3-2: Chemical composition and main compounds of ordinary Portland cement*

Oxide	% by weight	Limits of IQS No.5/1984[63]
SiO_2	20.7	-
CaO	61	-
Al_2O_3	4.1	-
Fe_2O_3	5.5	-
Lime Saturation Factor	0.89	0.66-1.02
MgO	3.1	≤ 5%
SO_3	2.3	≤ 2.5%
Loss on Ignition	3.5	≤ 4%
Insoluble Residue	0.4	≤ 1.5

(C_3S)	49.04	-
(C_2S)	22.35	-
(C_3A)	1.56	≤ 3.5
(C_4AF)	16.74	-
Al_2O_3 / Fe_2O_3	0.75	-
Free lime	0.78	-

* These tests were made at Kerbala University, College of Engineering, and Civil Department Laboratories.

The test results indicates that the used cement conforms to the Iraqi Specification No. 5/1984[63].

3.2.2 Fine Aggregate

Al-Ekhaider natural sand was used as fine aggregate. The sieve analysis of natural fine aggregate is shown in Table (3-3) and Figure (3-1). The fine aggregate was speared out and left in air to dry before use. Results indicate that fine aggregate grading was within the requirements of the Iraqi Specification No.45/1984[64]. Table (3-4) shows the relative density, sulphate content, absorption of fine aggregate. The test results also indicate that the fine aggregate conforms to the Iraqi Specification No. 45/1984[64], ASTM C29[65] and ASTM C128[66]

Table 3-3: Sieve analysis of fine aggregate*

Sieve Size (mm)	Passing%	IQS 45/1984 Zone (2)[64]
10	100	100
4.75	96	90-100
2.36	78	75-100
1.18	61	55-90
0.60	45	35-55
0.30	20	8-30

0.15	3	0-10

*This test was made at al-kafeel laboratory

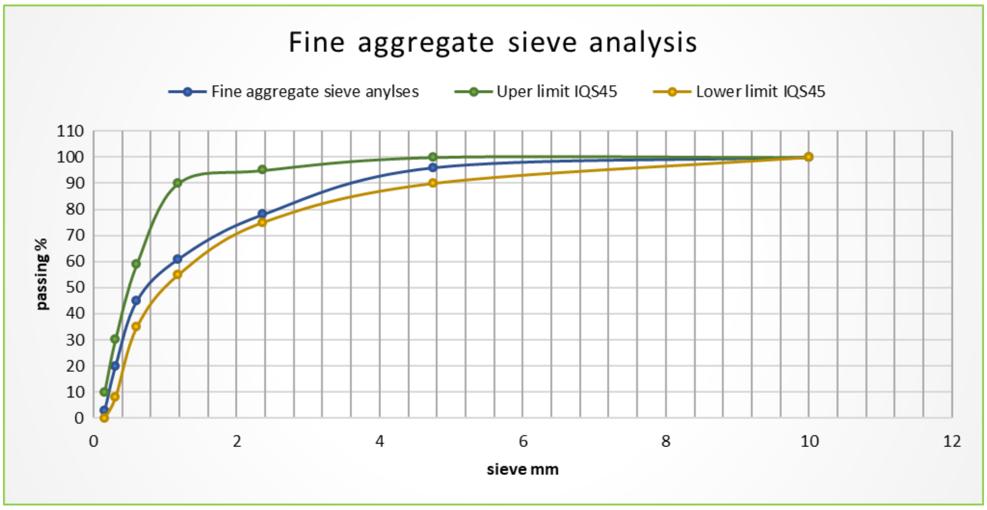


Figure 3-1: Sieve analysis of fine aggregate

Table 3-4: Physical and chemical properties of fine aggregate*

Tests	Test results	Specification	Limits of Specification
Relative density (OD) (Kg/m^3)	2.3	ASTM C128[(66)]	-
Dry loose unit weight (kg/m3)	1671.0	ASTM C29[(65)]	-
Dry rodding unit weight (kg/m3)	1822.0	ASTM C29	-
Absorption %	2	ASTM C128	-
Materials finer than75 μ m %	4.5	IQS 45/1984[(64)]	≤5
Fineness modules	2.96	IQS 45/1984	-
SO_3 content%	0.27	IQS 45/1984	≤0.5

*The first three tests were carried out in Kerbala University, College of Engineering, Civil Department Laboratories, while the remaining tests were carried out in al-kafeel Laboratory.

3.2.3 Water

Tap water was used for preparing and curing samples.

3.2.4 Attapulgite aggregate and the production method

Attapulgite or Palygoriskite are two names for one mineral. The name of Attapulgite was introduced by Bradley in 1940 for the same mineral Attapulgus, Georgia (USA)(67). Attapulgite is a fibrous silicate with a relatively large surface area and acidic properties that make the clay most useful as an adsorbent and catalyst. Attapulgite form at the surface of the earth with a low temperature of clay environments, hence they are classified as clays (58). The chemical form of Attapulgite was introduced by Carrol in1970 as:(68)

$$Si_8\,Mg_5\,O_{20}\,(OH)_2\,(OH_2)_4 .\,4H_2O$$

The raw material for producing lightweight aggregate is Attapulgite clays. Attapulgite clay is found in Al-Najaf region (Tar Al-Najaf) and Karbala region as bluish green and gray clay lump as shown in plate (3-2).

Plate 3-1: Attapulgite lumps in Tar AL-Najaf region

Attapulgite was brought from Tar AL-Najaf region. The lumps were manually crushed into smaller sizes by means of a hammer hand to give a finished product of about 19mm maximum aggregate size as shown in plate (3-3).

The sieve analysis of Attapulgite aggregate was implemented according to ASTM C330-05[37] as shown in Table (3-5). Figure (3-2) show the Attapulgite selected grading sample used for mixing.

Plate 3-2: Crushing Attapulgite lumps by handy hammer

Table 3-5: Sieve analysis of coarse lightweight aggregate

Sieve size	Passing % ASTM C330-05[37]	Selected %passing	%Retained
25	100	100	0
19	90-100	95	5
9.5	10-50	30	65
4.75	0-15	0	30

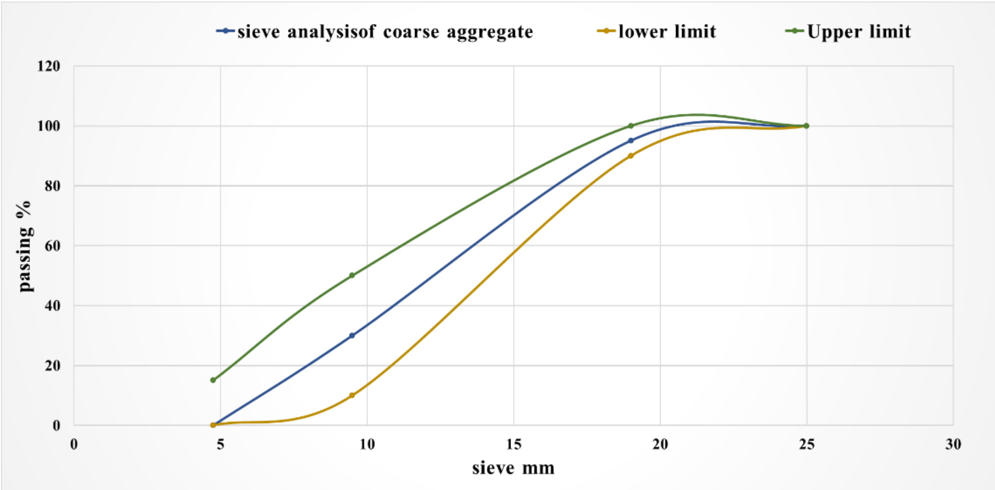


Figure 3-2: Sieve analysis of coarse lightweight aggregate

The prepared raw material was placed in the burning furnace powered by gas, in loose layers approximately 100–125 mm thick(38), on a special bed consist of (carbon silicate) materials. The burning furnace, which was made from fiber glass material and ceramic fiber plates, has an internal dimension of (64×64×100 cm), and contains special plates made of carbon silicate to undertake high temperature up to (1400 Cº) and weights up to (100 kg) with dimensions of (45×45cm) as shown in plate (3-4). The temperature inside the burning furnace was controlled manually and it was measured by using thermal cable type K up to (1100 Cº) and digital screen as shown in plate (3-5).

Plate 3-3: Burning furnace and carbon silicate plates

Plate 3-4: Thermal cable type K and digital screen

The raw material was reduced to the desired size before heating in a burning furnace to incipient fusion (temperature of 1000 to 1100ºC), the cellular structure of aggregate results from the fusion of the fine particles of the raw material. This porous structure is retained on cooling so that the apparent specific gravity of the expanded material is much lower than before heating[38].

Attapulgite sample was burned at a temperature ranged between (1000-1100) ˚C, the temperature was increased gradually with a burn rate of 5ºC/minute until reaching to (1000-1100) ˚C and left for a period 30 minute. Then, the cooling phase of the model starts gradually by opening the oven door very slightly to allow heat exchange with the laboratory temperature to the next day[38]. Plate (3-6) show Attapulgite burns at (1000-1100) ºC.

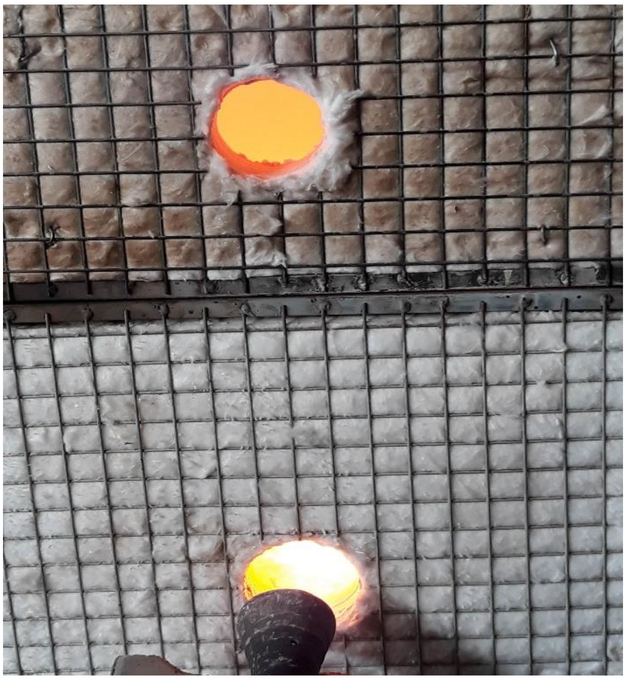


Plate 3-5: Attapulgite burns at (1000-1100) ºC

The effect of burning in 1100ºC and soaking 30 minute on the chemical and physical properties of Attapulgite aggregate was tabulated in Tables (3-6) and (3-7) respectively.

Table 3-6: Chemical analysis of Attapulgite*

Oxide Composition	Oxide content (%) before burning	Oxide content (%) after burning
SiO_2	37.8	44.3
Al_2O_3	2.85	5.22
Fe_2O_3	2.45	6.3
CaO	9.56	12
SO_3	1.23	1.13

* These tests were made at Kerbala University, College of Engineering, and Civil Department Laboratories.

Table 3-7: Physical properties of Attapulgite*

Tests	Results		Specifications	Limits
	before	After		
Loose unit weight dry(Kg/m^3)	952	755	ASTM C29[65]	≤880
Rodding unit weight dry (kg/m^3)	1018	795	ASTM C29	-
Loose unit weight SSD (kg/m^3)	1280	1015	ASTM C29	-
Rodding unit weight SSD (kg/m^3)	1369	1069	ASTM C29	-
Density (OD) (kg/m^3)	1662	1359	ASTM C127[69]	-
Density (SSD) (kg/m^3)	2016	1828	ASTM C127	-
Apparent density (kg/m^3)	2576	2566	ASTM C127	-
Relative density (specific gravity OD)(kg/m^3)	1.66	1.36	ASTM C127	≤2.6
Relative density (specific gravity SSD)(kg/m^3)	2.02	1.83	ASTM C127	-
Apparent specific gravity (kg/m^3)	2.58	2.57	ASTM C127	-
Absorption %	21.3	34.5	ASTM C127	5-30

* These tests were made at Kerbala University, College of Engineering, Civil Department Laboratories.

3.2.5 Crushed clay bricks aggregate and production method

Crushed clay bricks were used as coarse lightweight aggregate to produce lightweight concrete, which is obtained from building demolition. The brick samples were firstly crushed into smaller sizes by handy hammer to have a final product of nearly 19mm maximum aggregate size. The sieve analysis of crushed clay bricks aggregate was implemented according to ASTM C330-05[37], as shown previously in Table (3-5) and Figure (3-2). Table (3-8) show the physical properties of crushed clay bricks

Table 3-8: Physical properties of crushed clay bricks*

Tests	Results	Specifications	Limits
Loose unit weight dry (kg/m³)	839	ASTM C29[65]	≤880
Rodding unit weight dry (kg/m³)	918	ASTM C29	------
Loose unit weight SSD (kg/m³)	1035	ASTM C29	------
Rodding unit weight SSD (kg/m³)	1133	ASTM C29	------
Density (OD) (kg/m³)	1654	ASTM C127[69]	------
Density (SSD) (kg/m³)	2041	ASTM C127	------
Apparent density (kg/m³)	2703	ASTM C127	------
Relative density (specific gravity OD)(kg/m³)	1.66	ASTM C127	≤2.6
Relative density (specific gravity SSD)(kg/m³)	2.05	ASTM C127	------
Apparent specific gravity (kg/m³)	2.71	ASTM C127	------
Absorption %	23.4	ASTM C127	5-30

* All tests were carried out at Kerbala University, College of Engineering, Civil Department Laboratories.

3.2.6 Normal Weight Aggregate

Normal weight coarse aggregate used through this work with a maximum size of 19 mm was used to produce normal weight concrete. The normal weight coarse aggregate was screened on a standard sieve series with the same grading of Attapulgite and crushed clay bricks aggregate.

Table 3-9: Physical and chemical properties of normal weight coarse aggregate*

Tests	Results	Specifications	limits
Loose unit weight dry (kg/m^3)	1514	ASTM C29(65)	≤880
Rodding unit weight dry (kg/m^3)	1607	ASTM C29	------
Loose unit weight SSD (kg/m^3)	1547	ASTM C29	------
Rodding unit weight SSD (kg/m^3)	1642	ASTM C29	------
Density (OD) (kg/m^3)	2562	ASTM C127(69)	------
Density (SSD) (kg/m^3)	2617	ASTM C127	------
Apparent density (kg/m^3)	2712	ASTM C127	------
Relative density (specific gravity OD)(kg/m^3)	2.56	ASTM C127	≤2.6
Relative density (specific gravity SSD)(kg/m^3)	2.62	ASTM C127	------
apparent specific gravity (kg/m^3)	2.72	ASTM C127	------
Absorption %	2.15	ASTM C127	5-30
Materials finer than 75μ m %	0.9	IQS 45/1984(64)	≤3
So_3 content%	0.08	IQS 45/1984	≤0.1

* All tests were carried out in Karbala University, College of Engineering, and Civil Department Laboratories. Except (Materials finer than75μm and So_3) tests that were carried out in AL-Kafeel Laboratory.

3.2.7 Chemical Admixture (Hyperplast PC200)

Hyperplast PC200 is a high performance super plasticizing admixture. Hyperplast PC200 complies with ASTM C494(70), Type A and G, depending on the dosage used.

Table 3-10: Main properties of Hyperplast PC200*

Property	Description
Specific gravity	1.05 ± 0.02
Freezing point	≈ -3°c
Hazardous decomposition products (hazardous reactions)	Hyperplast pc200 is not classified as a hazardous material
Dosage	0.50 - 2.50 % of cementitious materials
Color	Light yellow liquid
Storage	Hyperplast pc200 has a shelf life of 12 months from the date of manufacture if stored at temperatures between 2°c and 50°c
Compatibility	Hyperplast pc200 can be used with all types of Portland cement and cement replacement materials
Fire	Hyperplast pc200 is nonflammable

*These properties were taken from manufacturer data sheet.

3.2.8 Steel bar reinforcement

Deformed steel bars of 12mm, 6mm and 5mm as nominal diameter were used in this study as tensile reinforcement, compression reinforcement and shear reinforcement respectively. The steel bar reinforcement tests have been implemented in the Laboratory of the Mechanical Engineering College at Kerbala University by using a computerized testing machine as shown in plate (3-7). The tested specimens were conformed with ASTM A615M – 05a[71]. The steel reinforcement Ø 12 mm conforming to the technical specifications required for steel grade 60. While the steel reinforcement of nominal Ø 6 & 5 mm was conformed to the technical specifications required for steel grade 40. The results of testing steel reinforcement are summarized in Table (3-11).

Plate 3-6: Testing machine of steel reinforcement

Table 3-11: Properties of steel reinforcement

Property	**Results**			**Tensile requirement ASTM 615M – 05a[71] Minimum**	
	Ø 12	Ø 6	Ø 5	Grade 40	Grade 60
Nominal diameter (mm)	12	6	5	-	-
Measured diameter (mm)	11.75	5.65	4.92	-	-
Actual Weight (kg/m)	0.856	0.238	0.143	-	-
Yield strength, f_y (MPa)	576	510	533	≥280	≥420
Ultimate strength f_u (MPa)	710	540	583	≥500	≥620

Elongation %	17	-	-	12%	9%

* All tests were carried out in the Laboratory of the Mechanical Engineering College at Kerbala University.

3.3 Mix Design

As mentioned previously, the structural lightweight aggregate concrete is a concrete with an oven dry density less than 2000 kg/m^3 and a cylinder compressive strength more than 17 MPa at 28 days. These mixes were designed in accordance with ACI committee 211.2-98[(72)]

After many trials, one reference mix proportion was used in this study for Attapulgite coarse aggregate. Selected Mix (A5) has the proportions of (1:1.67:1.57) by weight of cement, with 328 kg/m^3 cement content, 549.5 kg/m^3 dry fine aggregate content, 515.6 kg/m3 dry Attapulgite coarse aggregate content. The w/c ratio was 0.315 while the superplasticizer content was 1.51% of cement content to give a slump of 90 mm.

For comparison purposes, the mix proportion was used through this study for crushed clay bricks coarse aggregate and normal weight coarse aggregate as well as for Attapulgite coarse aggregate mix except the superplasticizer content was changed to achieve the same workability. Table (3.12) shows the details of the trial mixes used throughout this investigation.

Table 3-12: Trial mixes proportions

Mix	A1	A2	A3	A4	A5 Selected	B1	N1
Cement kg/m^3	450	328	328	328	328	328	328
Fine aggregate kg/m^3	650	549.5	549.5	549.5	549.5	549.5	549.5
Coarse aggregate kg/m^3	446	515.6	515.6	515.6	515.6	515.6	515.6
W/C %	31.8	57	40	34	31.5	31.5	31.5
Superplasticizer %	0	0	0	0.7	1.51	1.27	0.7
Slump, mm	200	190	30	40	90	90	90
Cube compressive strength, MPa	19	21	24	27	28	37	48
Oven dry density, kg/m^3	1700	1797	1761	1753	1745	1861	2331

A: Attapulgite aggregate concrete, B: Crushed clay bricks aggregate concrete, N: normal weight concrete

3.4 Mixing procedure

Mixing was performed by using 0.1 m^3 rotary mixer as shown in plate (3-8). The interior surface of the pan was cleaned and moistened before placing the materials. The components were mixed according to ASTM C 192/C 192M-05[(73)]. The coarse aggregate is added in the mixer with some of mixing water and chemical admixture. The chemical admixture is preferred to be mixed with some of mixing water before adding it to the mixer. After A few seconds of mixing, the fine aggregate is added with some of mixing water in the mixer. Finally, the cement and the remaining mixing water are added in the mixer. After the addition of all the concrete component, the mixture is mixed for another three minutes then rest for three minutes then mixed for two minutes. To prevent the absorption of concrete mixing water by lightweight aggregates, lightweight aggregate and normal weight aggregate should be soaked in water for 24 hours. To achieve the saturated surface dry (SSD) condition of the aggregate particles, it was exposed to air, then aggregate particles surface was dried by using blower and clothes, as recommended by ACI 211.2-98 [72] as shown in plate (3-9).

Plate 3-7: Concrete mixer

Plate 3-8: Attapulgite saturated surface dry (SSD) condition

3.5 Preparation, Casting and Curing of Test Specimens

The internal surfaces of cubes, cylinders and the constructed molds of beam models were well cleaned and oiled to avoid adhesion with concrete after hardening. Steel molds were used for casting cube and cylinder specimens. After the concrete had been mixed by a rotary mixer, the fresh concrete was placed inside molds, two equal layers for cubic and cylinder molds with 25 strokes for each layer [73, 74].

The beams were cast in two layers[75], each layers compacted by using vibrating table as shown in plate (3-10). The duration of vibration for each layer was limited to the removal of entrapped air and the concrete surface became relatively smooth and had a glazed appearance and this is within 5 seconds[73]. After the top layer had been compacted, it was smoothed, leveled with the top of the mold by using a steel trowel. After 24 hours, the specimens immersed in tap water until the time of testing as shown in plate (3-11).

Plate 3-9: Vibrating table

Plate 3-10: Curing of concrete

The molds and test specimens used in this research are:

- Rectangular molds (140×180×1200) mm to determine the flexural strength of concrete.
- Cubic molds (100×100×100) mm to determine the compressive strength of concrete.
- Cylindrical molds (100×200) mm to determine the splitting tensile strength of concrete, oven dry density, water absorption and the static modulus of elasticity**.**

3.6 Fresh Concrete Tests

3.6.1 Slump test

The workability of all concrete mixes was measured immediately after mixing using slump test according to the procedure described in ASTM C143–03[76] as shown in plate (3-12). For comparison purposes, the superplasticizer content was changed with the type of aggregate to achieve a constant workability.

Plate 3-11: Slump test

3.7 Hardened Concrete test

3.7.1 Oven Dry Density

This test was conducted according to ASTM C567-05a[77] on 100×200 mm cylinders. The test was conducted at ages of 28 and 90 days, and three specimens were tested at each age. The oven-dry density was determined from Eq. (3.1).

$$\mathbf{O_m\ Density(kg/m^3) = (D\times 997)/(F-G)} \qquad (3\text{-}1)$$

Where:

$\mathbf{O_m}$ = Measured oven-dry density, kg/m^3

D = Mass of oven-dry cylinder, kg.

F = Mass of the saturated surface-dry cylinder, kg.

G = Apparent mass of suspended-immersed cylinder, kg

3.7.2 Compressive Strength

This test was conducted on 100 mm cube according to B.S. 1881: part 116:1989[78] and 100×200 mm cylinder according to ASTM C 39/C 39M – 05[79] by using a digital compression testing machine of 2000 kN capacity as shown in plate (3-12) The test was conducted at ages 28 and 90 days, and three specimens were tested at each age.

Plate 3-12: Compressive machine test

3.7.3 Splitting Tensile Strength

The splitting tensile strength test was performed according to ASTM C496-04[80]. 100×200 mm cylindrical concrete specimens were used. The specimens were tested using an electrical testing machine with a capacity of 2000 kN as shown in plate (3-13). This test was conducted at ages of 28 and 90 days.

For splitting tensile strength test of lightweight aggregate concrete, at least eight cylindrical specimens were required at each age. While three-cylindrical specimens were required for normal weight concrete[37].

The experimental splitting tensile strength of cylinders was calculated by using the ASTM C496-04[80] equation:

$$f_{sp} = 2P/\pi\, d\, L \qquad (3\text{-}2)$$

Where

f_{sp}= Splitting tensile strength, (MPa).

P =Maximum applied load, (N).

d = Diameter of the specimen, (mm). **L**= length of the specimen, (mm)

Plate 3-13: Splitting tensile strength test of concrete

The ACI 318-14[13] provide an equation to predict splitting tensile strength of concrete based on concrete compression strength.

$$f_{sp} = \lambda * 0.56 * f'_c{}^{1/2} \qquad (3\text{-}3)$$

Where

λ = A reduction factor

λ = 1 for normal weight concrete

λ = 0.85 for sand LWC

λ = 0.75 for all lightweight concrete

Linear interpolation between 0.75 and 0.85 shall be permitted, on the basis of volumetric fractions, when a portion of the lightweight fine aggregate is replaced with normal weight fine aggregate. Linear interpolation between 0.85 and 1.0 shall be permitted, on the basis of volumetric fractions, for concrete containing normal weight fine aggregate and a blend of lightweight and normal weight coarse aggregates[13].

f_{sp}= Splitting tensile strength, MPa

f'_c = Cylinder compressive strength, MPa

3.7.4 Static Modulus of Elasticity

Usually, the elastic modulus was obtained by using the uniaxial compression tests. Due to the unavailability of the compressometer in the laboratory, the compressometer was manufactured in a workshops as shown in plate

(3-14). Because the test results were inaccurate, the ACI 318-14[13] formula was used to find the elastic modulus of concrete.

$$E_c = W_c^{1.5} * 0.043 * (f_c')^{1/2} \qquad (3\text{-}4)$$

Where

E_c = Modulus of elasticity, MPa

W_c = Equilibrium density of lightweight concrete between 1440 and 2560 kg/m^3

f_c' = Cylinder compressive strength, MPa

Plate 3-14: Static modulus of elasticity test

3.7.5 Water Absorption

The test was carried out according to ASTM C642-97[81] on 100×200 mm cylinder specimens. Absorption of each specimen was calculated as the increase in weight resulting from the immersion, expressed as a percentage of the specimen dry weight. The test was conducted at age of 28, and 90 days. The average of three specimens was adopted at each test. The absorption was calculated using ASTM C642-97[81] formula:

$$A = [(W_s - W_d)/ W_d] \times 100 \qquad (3\text{-}5)$$

Where:

A = Absorption value (%).

W_s = Mass of the surface-dry sample in air, kg

W_d = Mass of the oven-dried sample in air, kg

3.8 Beam Molds Description

3.8.1 Molds Preparation

The beam was cast in plywood molds to achieve a beams with clear dimensions of (140×180×1200) mm as shown in plate (3-15).

Plate 3-15: Plywood molds for beam

3.8.2 Details of Reinforced Concrete Beam Models

The experimental program consisted of testing eight reinforced concrete rectangular cross-section beams. Five of these beams were tested under symmetric two-point concentrated load (STPCL) as shown in plate (3-16) and the others were tested under one point concentrated load (OPCL) as shown in plate (3-17). The cross-section of beam and reinforced details are illustrated in plate (3-18)

All beams have the same dimensions; 140 mm width, 180 mm depth and 1200 mm length with 10 mm clear bottom cover and side covers. The reinforcement bars were cut to the desired length. After oiling the molds of the beam sample, reinforcement bars are held carefully in their position inside the molds. The distribution of tensile reinforcement and shear reinforcement is constant for all types of beams. In order to achieve the concrete cover, spacers of 10 mm height were used.

The beam specimens were simply supported. The ends of all beams extended 75 mm beyond the support’s centerlines to prevent splitting (crushing) failure and any local failure. Therefore, the effective span of beams was 1050 mm.

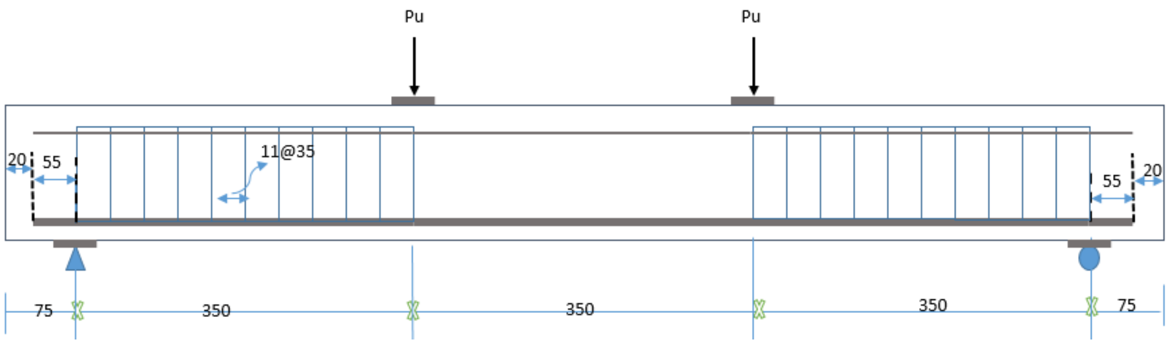


Plate 3-16: The longitudinal section of the beam with symmetric two-point concentrated load

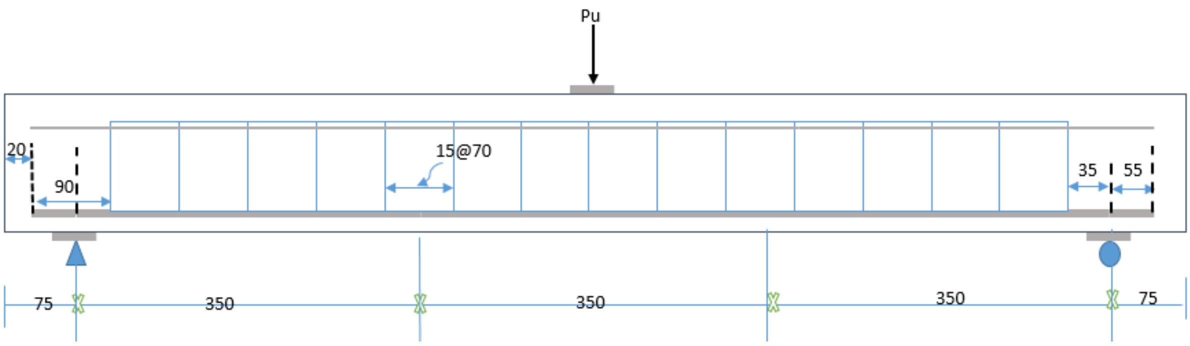


Plate 3-17: The longitudinal section of the beam with one point concentrated load

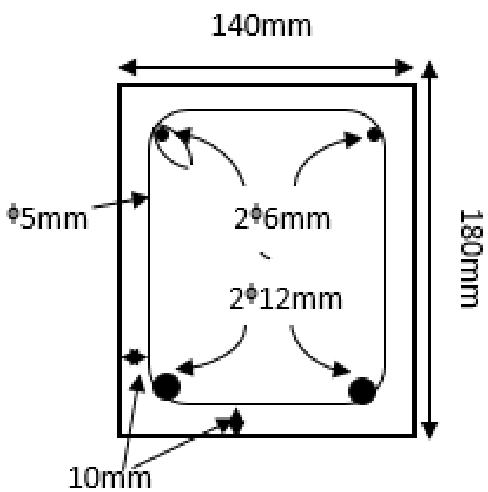


Plate 3-18: The cross section of the beam

3.8.3 Beam Specimens Identification

In order to identify the test of normal weight concrete and lightweight concrete beam specimens, the following designation system is used:

1. Type of coarse aggregate: (A) for Attapulgite coarse aggregate, (B) for crushed clay bricks coarse aggregate and (N) for normal weight coarse aggregate.
2. Type of loading: (2) symmetric two-point concentrated load (STPCL) and (1) one point concentrated load (OPCL).
3. Age of test: (28) for test at 28 days and (90) for test at 90 days.

3.9 Instruments and Testing Procedure of Beam Specimens

3.9.1 Supporting and Loading Condition

Two rigid steel W-sections were designed as a supporting system were used and placed on the top face of the testing machine base. To achieve a simply supported condition for the beam, steel bar of 30 mm diameter was welded on the upper face of one of the supports and a moveable steel bar was used on the other support with an effective span of 1050 mm, as shown in plate (3-19). The supports were located at 75 mm from the beam edges. Five of the beam specimens were tested under symmetric two-point concentrated load (STPCL) and the others were tested under one point concentrated load (OPCL).

Plate 3-19: Supporting system

The symmetric two-point concentrated load system and the one point concentrated load system shown in plate (3-20) and (3-21) respectively.

Plate 3-20: Symmetric two point concentrated load system

Plate 3-21: One point concentrated load system

3.9.2 Test Setup and Equipment's

All beam specimens were tested by using a testing machine with a capacity of 2000 KN at the concrete Laboratory of Civil Engineering Department in Kerbala University, as shown in plate (3-22).

Plate 3-22: Flexural testing machine

The strain of concrete was measured by using a linear variable differential transformer (LVDT) of 10 mm capacity. Two LVDT were used to monitor the strain concrete at 10 mm near the tension face for all reinforced concrete beam models as shown in plate (3-23). The test results were neglected because the test results were inaccurate.

Plate 3-23: LVDT used to measure the longitudinal strain

The deflection was measured by using linear variable differential transformer (LVDT) of 100 mm capacity. One LVDT was used at the center point of the beam specimens. The LVDT contacts the lower surface of the specimen as shown in plate (3-24). The LVDT reads the deflection every 1 second.

Plate 3-24: LVDT used to measure the vertical deflection

3.9.3 Testing Procedure

Before starting the flexural test, the beam specimens were painted in a white color to ensure the clear appearance of crack growth during testing. Before loading, the reading of LVDT was obtained and the load was approximately increased by 8 KN. The first cracking load and its location were recorded. At each load increment, observations of crack development on the concrete beams were traced by marker pen. The deflections and strains were measured for each step and the loading process was continued until the ultimate load is reached. The failure of the beam specimen was declared when no further increase of the loading readings was recorded with a noticeable large deflection in addition to large flexure cracking.

Chapter Four

Experimental Results and Discussion

Experimental Results and Discussion

4.1 General

This chapter includes the results of the experimental work described in chapter three as well as discussions for these results. The experimental results were displayed by using tabulated and graphical form.

At first, the results of the mechanical properties of concrete, which obtained from the tests of lightweight aggregate concrete and normal weight concrete such as oven-dry density, cylinders and cubes compressive strength, splitting tensile strength, water absorption and predicted modulus of elasticity are described and discussed. Then, the experimental results of eight beam specimens were given in which five of these beams were tested under symmetric two-point concentrated load (STPCL) and the others were tested under one-point concentrated load (OPCL).

The first cracking load, ultimate load, failure mode and the deflection at the center of the beam were generally presented.

4.2 Mechanical Properties of Concrete

Two various criteria were used in discussing the results of concrete tests which are as follows:

Criterion No.1: Investigating the effect of coarse aggregate used on the mechanical properties of concrete.

Criterion No.2: Investigating the effect of curing age on the mechanical properties of concrete.

The mechanical properties of lightweight concrete and normal weight concrete specimens were tested at 28 and 90 days, the results listed in Tables (4-1) and (4-2) respectively.

Table 4-1: Mechanical properties of various concrete mixes at 28 days

Mix type	Oven dry density, Kg/m³	Absorption, %	Compressive strength, MPa			Splitting strength f_{sp}, MPa	Modulus of elasticity, MPa
			f'_c	f_{cu}	$\frac{f'c}{fcu}$		
Attapulgite concrete	1805	16.8	18.5	25	0.74	2.38	14955
crushed clay bricks concrete	1977	11.8	31.5	43.7	0.72	3.88	22012
Normal weight concrete	2317	4.5	40.4	50.5	0.8	4.22	31201

Table 4-2: Mechanical properties of various concrete mixes at 90 days

Mix type	Oven dry density, Kg/m³	Absorption, %	Compressive strength, MPa			Splitting strength f_{sp}, MPa	Modulus of elasticity, MPa
			f'_c	f_{cu}	$\frac{f'c}{fcu}$		
Attapulgite concrete	1850	15.7	18.7	29.1	0.64	2.60	15225
crushed clay bricks concrete	1991	12.7	32	45	0.71	3.95	22421
Normal weight concrete	2318	4.4	42	54.3	0.77	4.47	32113

4.2.1 Oven Dry Density

The oven dry densities of concrete are presented in Figure (4-1).

Study No.1: The oven dry density of structural lightweight aggregate concrete, produced from local naturally occurring Attapulgite aggregate, found to be conformed to the requirement of ACI 213R -14[(15)], However, the oven dry of Attapulgite lightweight aggregate concrete and crushed clay bricks lightweight aggregate concrete and at all age were conformed to the requirements of unified European standard (CEN ENV 1992-1-4, 1994)[(17)] and RILEM[(18)] which limits the maximum density to 2000 kg/m³.

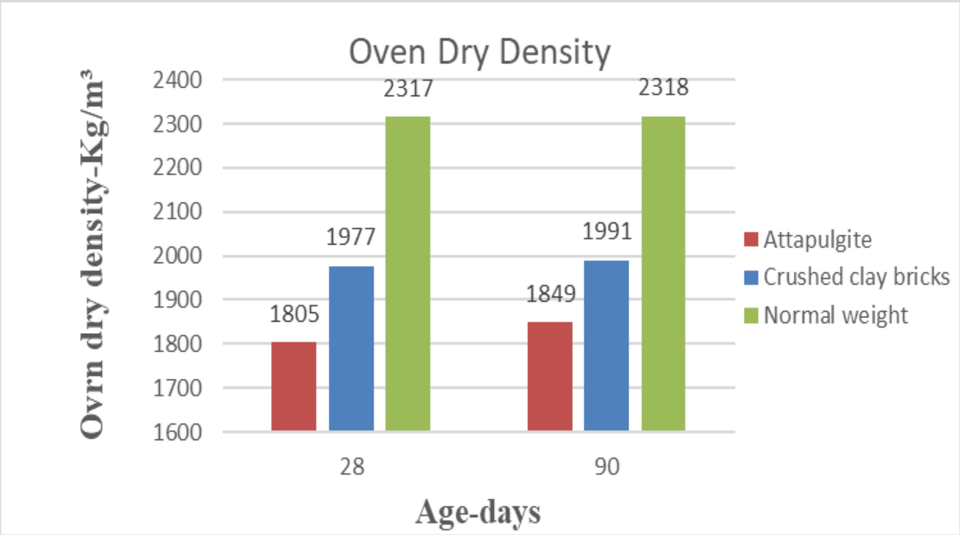


Figure 4-1: Oven dry density at 28 and 90 days

The oven dry density of Attapulgite aggregate concrete were lower than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete as shown in Figure (4-2). This is because the oven dry densities of Attapulgite aggregate were lower than that of crushed clay bricks aggregate and normal weight aggregate by about 17.8% and 46.9% respectively.

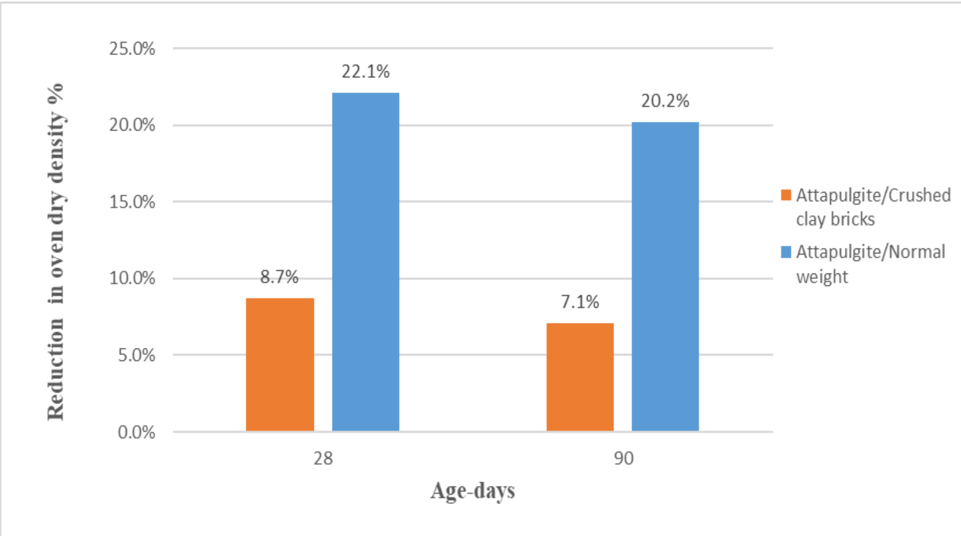


Figure 4-2: Reduction in oven dry density

Study No.2: The development of oven dry density with age of Attapulgite aggregate concrete was more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete as shown in Figure (4-3), because the water absorption of Attapulgite aggregate was more than that of crushed clay bricks and normal weight aggregate. This has led to more effective hydration process. However, Attapulgite aggregate concrete remains in conformity to the requirement of ACI 213R -14[15]

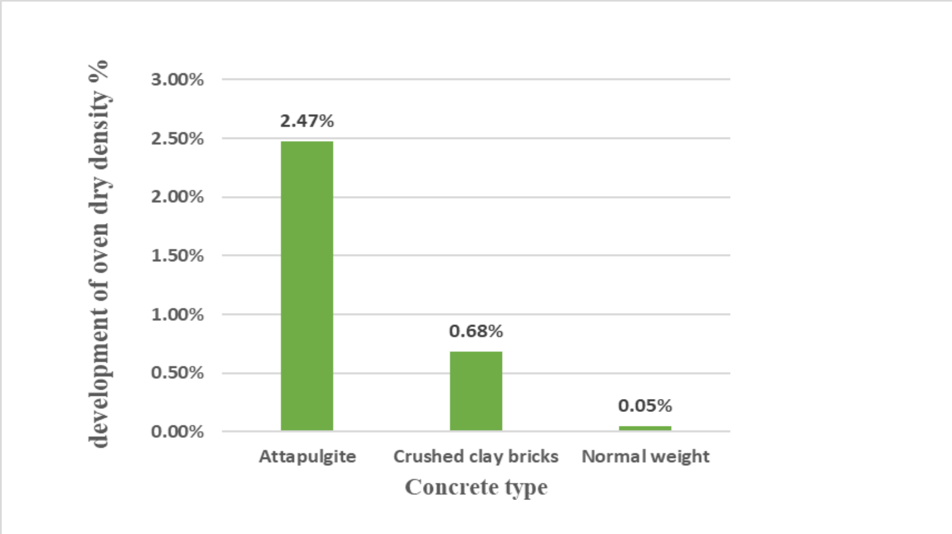


Figure 4-3: Development of oven dry density from 28 to 90 days

4.2.2 Cylinder and Cube Compressive Strength

The cylinder compressive strength (f_c') and cube compressive strength (f_{cu}) for lightweight aggregate concrete and normal weight concrete are tabulated in Tables (4-1) and (4-2) and shown in Figures (4-4) and (4-5) respectively.

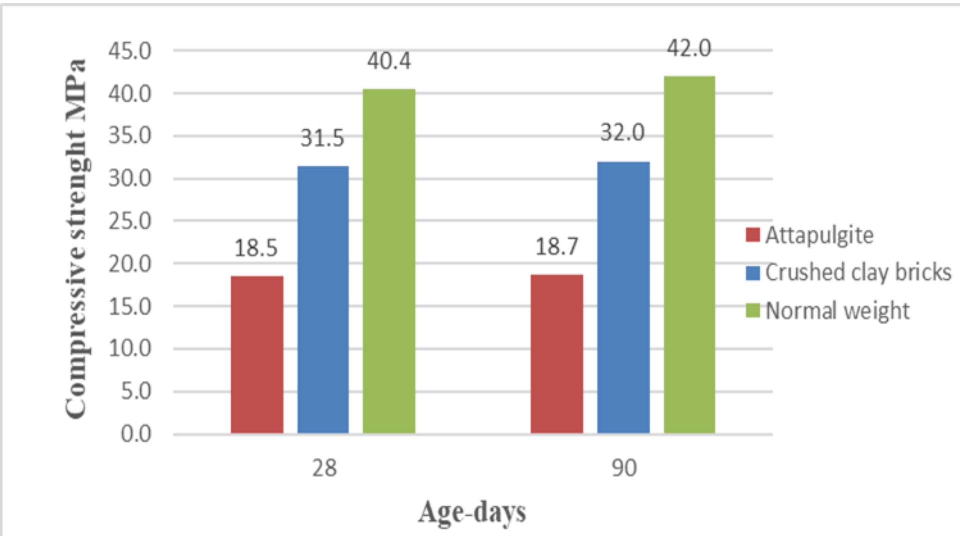


Figure 4-4: Cylinder compressive strength

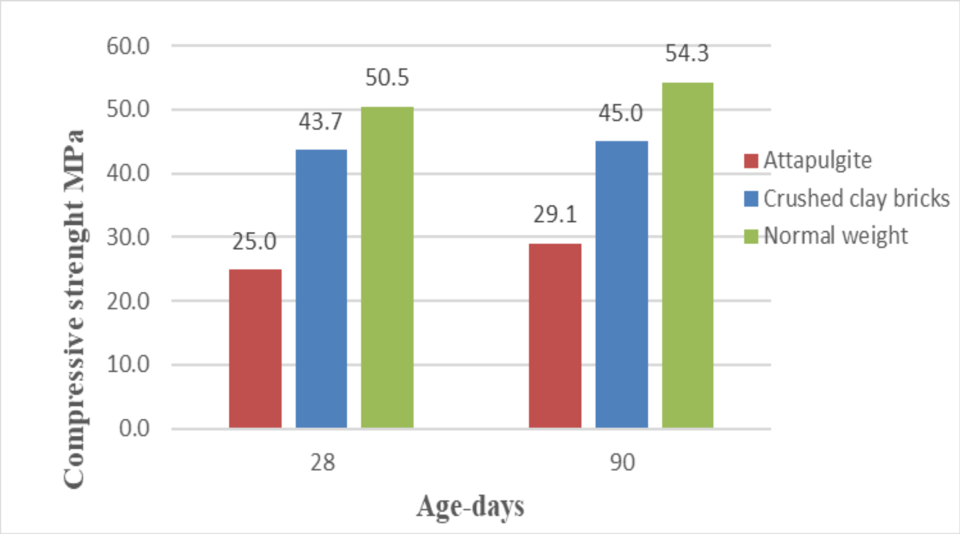


Figure 4-5: Cube compressive strength

Study No.1: The results indicated that the cylinder compressive strength of Attapulgite aggregate concrete was lower than crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 41.2% and 54.2% at 28 days respectively. Also, the cubic compressive strength of Attapulgite aggregate concrete was lower than crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 42.8% and 50.5% at 28 days respectively. This is due to the weakness of the Attapulgite aggregate compared to crushed clay bricks aggregate and normal weight aggregate.

Study No.2: The results indicate that, the development in Attapulgite aggregate concrete compressive strength was more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete as shown in figure (4-6), because the water absorption of Attapulgite aggregate more than that of crushed clay bricks and normal weight aggregate and this led to more effective hydration process.

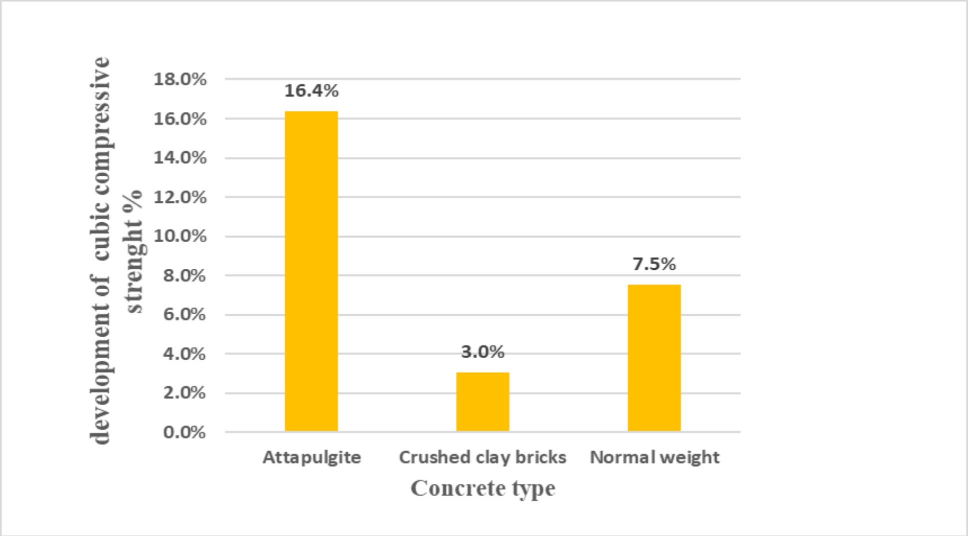


Figure 4-6: Development of cube compressive strength

The average ratios between cylinder and cube compressive strength (f_c', f_{cu}) for lightweight concrete and normal weight concrete are presented in figure (4-7).

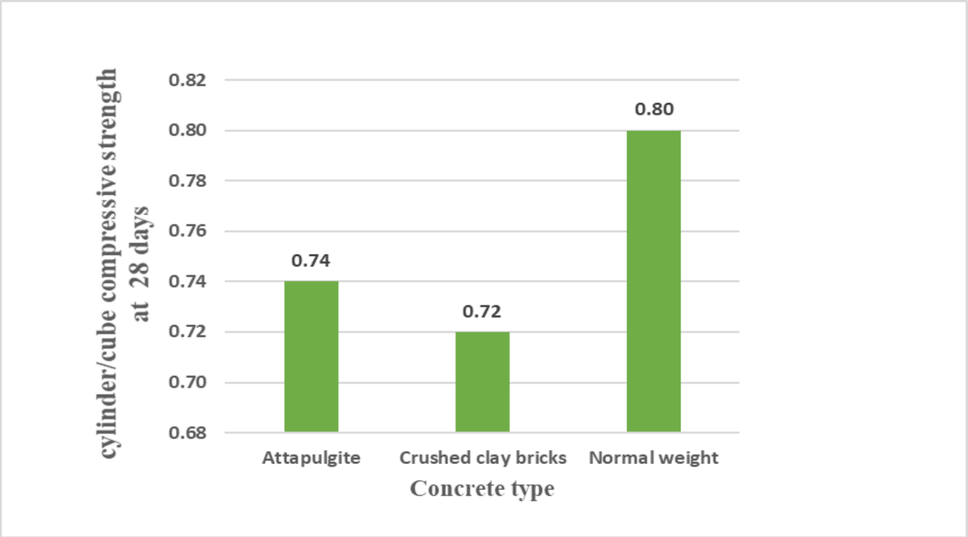


Figure 4-7: Cylinder/cube compressive strength at 28 days

4.2.3 Splitting Tensile Strength

The splitting tensile strength results for Attapulgite aggregate concrete, crushed clay bricks aggregate concrete and normal weight aggregate concrete were tabulated in Table (4-1), (4-2) and graphed in Figure (4-8).

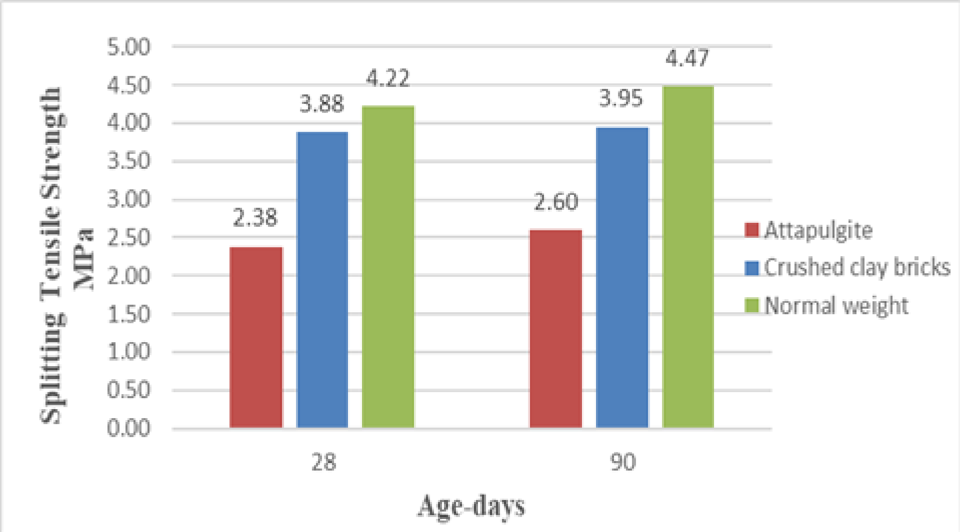


Figure 4-8: Splitting Tensile Strength

Study No.1: The results indicated that, the splitting tensile strength of Attapulgite aggregate concrete was lower than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 38.7% and 43.6% at 28 days and 34.2% and 41.8% at 90 days respectively. This is due to the weakness in Attapulgite aggregate compared to crushed clay bricks aggregate and normal weight aggregate.

Study No.2: The results indicated that the development in Attapulgite aggregate concrete splitting tensile strength was more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete as shown in figure (4-9). This shows that the hydration process of Attapulgite aggregate concrete is more effective than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete, because the water absorption of Attapulgite aggregate more than that of crushed clay bricks and normal weight aggregate.

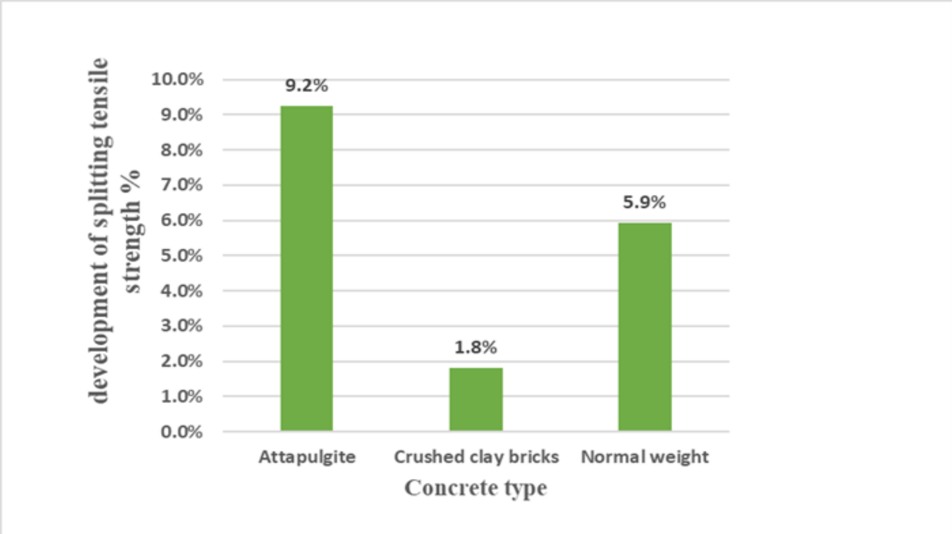


Figure 4-9: Development of splitting tensile strength

The splitting tensile strength test indicated that the fracture path travels through Attapulgite lightweight aggregate particles, is same as crushed clay bricks aggregate particles and normal weight normal aggregate particles as shown in plate (4-1)

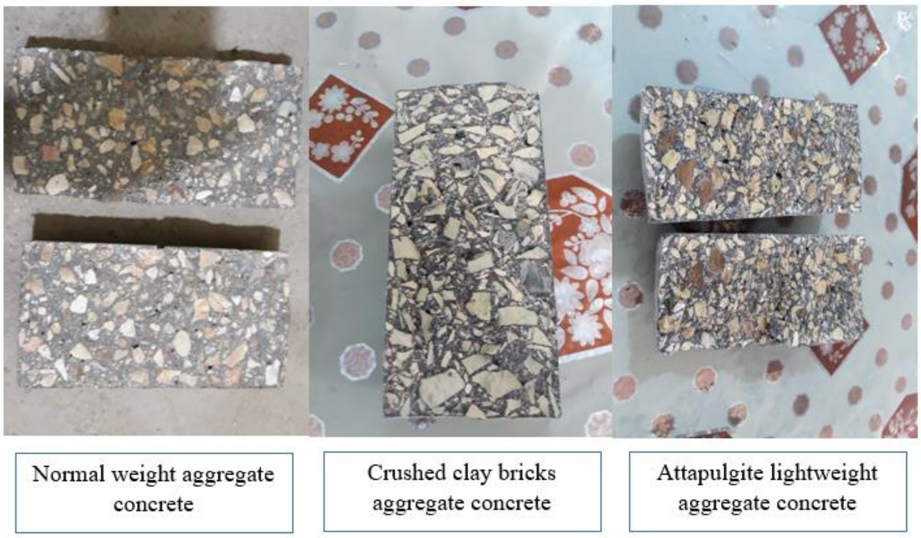


Plate 4-1: Fracture path

The average value of experimental splitting tensile strength was more than the predicted splitting tensile strength which adopted by ACI Code 318-2014[13] as shown in Figure (4-10).

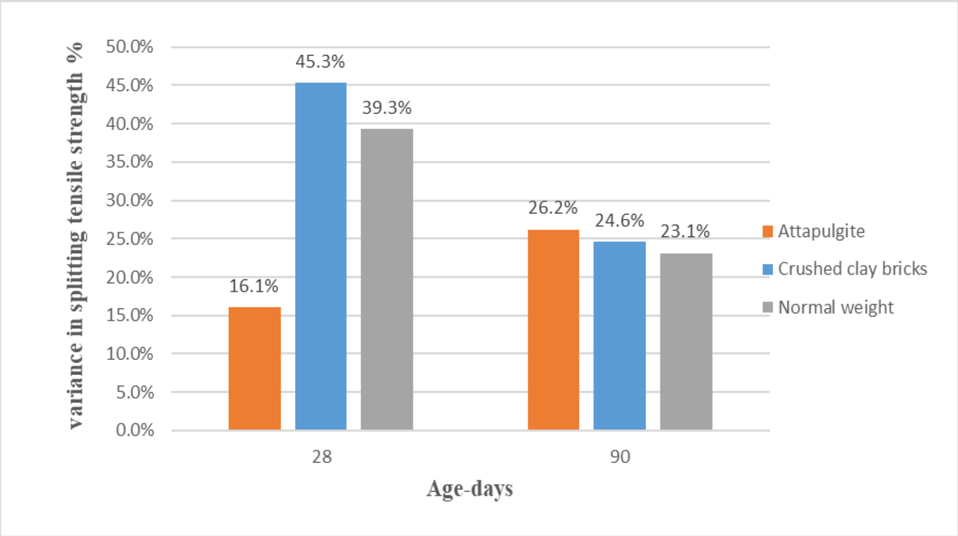


Figure 4-10: Variance between calculated and predicted splitting tensile strength

4.2.4 Water Absorption

The values of water absorption of lightweight aggregate concrete and normal weight concrete are presented in Figure (4-11).

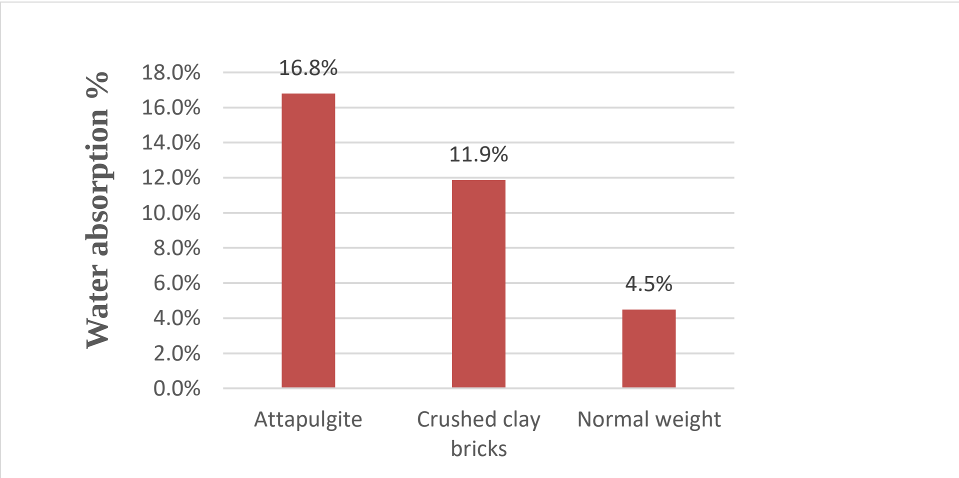


Figure 4-11: Water absorption at 28 days

Results indicated that the water absorption of Attapulgite aggregate concrete was more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 41.2% and 273.3% respectively, and this led to the develop the strength of Attapulgite aggregate concrete more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete.

4.2.5 Static Modulus of Elasticity

The predicted static modulus of elasticity according to ACI 318-14(13) for lightweight and normal weight concrete presented in Figure (4-12).

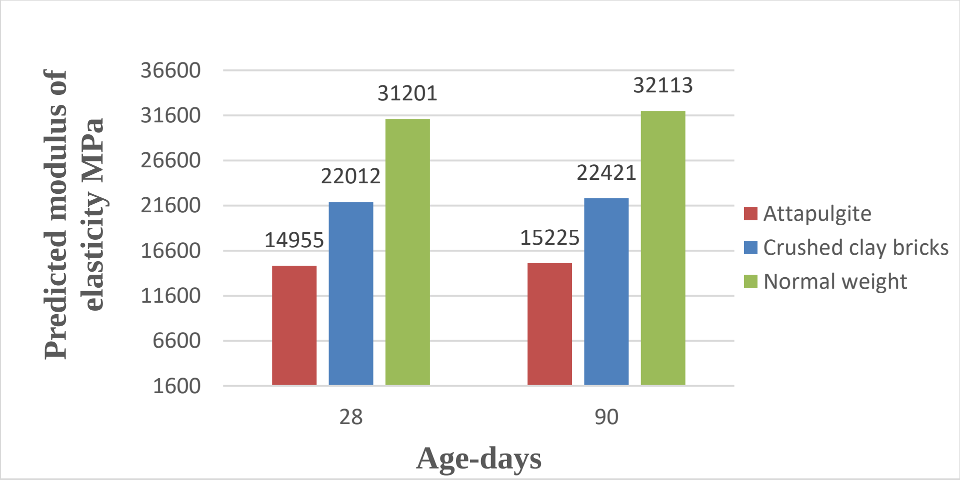


Figure 4-12: Predicted modulus of elasticity of LWC and NWC

Results indicated that the predicted modulus of elasticity of Attapulgite aggregate concrete was less than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 32.05% and 52.0% at 28 days and 32.09% and 52.5% at 90 days respectively. This is because the compressive strength and the density of Attapulgite aggregate concrete were less than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete.

4.3 Experimental Results of Beam specimens

The results are based on eight beam specimens tested in the civil engineering laboratories of Kerbala University. Five of these beams were tested under symmetric two-point concentrated load (STPCL) and the others were tested under one-point concentrated load (OPCL). There are three criteria for discussing the results of concrete tests ,which are as follows:

Criterion No.1: Investigating the effect of coarse aggregate used on the structural behavior of beam model.

Criterion No.2: Investigating the effect of curing age on the structural behavior of beam model.

Criterion No.3: Investigating the effect of loading type whether STPCL and OPCL on the structural behavior of beam model.

The results of the test were discussed depended on hardened density of concrete, saturated surface dry density**,** cracking behavior, first cracking load, ultimate load, the vertical deflection and failure mode of beam specimens.

4.3.1 General Behavior

All concrete beams were tested under the same conditions. The deformations of beams were within the elastic ranges at an early stage of loading. When the applied load increase, the cracks start to appear at the tension face of the beams, the number of cracks increases and the cracks become wider and moved upwards. Table (4-5) listed the first cracking load, the ultimate failure load, reserve strength of the beams (ratio of the ultimate load (W_u) to the first cracking load (W_{cr}))[82] and failure mode for beam specimens tested under (STPCL) and (OPCL). As expected, the failure of all beams was a flexural failure as shown in plates (4-2) to (4-9). For the beams tested under STPCL, the concrete crushing in compression face at final stage of loading. The load-deflection curves for all beams are presented in Figures (4-13) to (4-20).

Table 4-3: Results of beam specimens tested under (STPCL) and (OPCL)

Beam model symbol	Ultimate load Pu (KN)	First crack load Pcr (KN)	$\frac{Pu}{Pcr}$ %	maximum deflection Δu (mm)	failure mode
A-1-28	77.4	27	2.87	8.093	Flexural failure
A-2-28	119.6	41	2.92	7.364	Flexural failure+ Crushing
A-2-90	102.5	34	3.01	9.253	Flexural failure+ Crushing
B-1-28	86.3	27	3.20	9.329	Flexural failure
B-2-28	125.7	42	2.99	14.374	Flexural failure+ Crushing
B-2-90	119.4	52	2.30	11.673	Flexural failure+ Crushing
N-1-28	86.5	25	3.46	10.020	Flexural failure
N-2-28	125.9	32	3.93	17.137	Flexural failure+ Crushing

Plate 4-2: Cracks Patterns at Failure for A-1-28 beam specimen

Plate 4-3: Cracks Patterns at Failure for A-2-28 beam specimen

Plate 4-4: Cracks Patterns at Failure for A-2-90 beam specimen

Plate 4-5: Cracks Patterns at Failure for B-1-28 beam specimen**s**

Plate 4-6: Cracks Patterns at Failure for B-2-28 beam specimen

Plate 4-7: Cracks Patterns at Failure for B-2-90 beam specimen

Plate 4-8: Cracks Patterns at Failure for N-1-28 beam specimen

Plate 4-9: Cracks Patterns at Failure for N-2-28 beam specimen

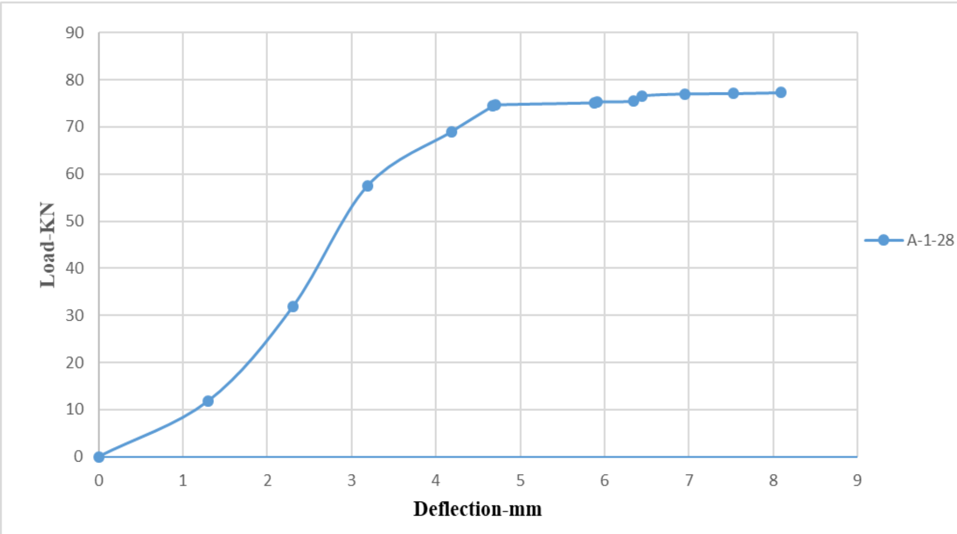


Figure 4-13: Load-deflection curve for A-1-28 beam specimen

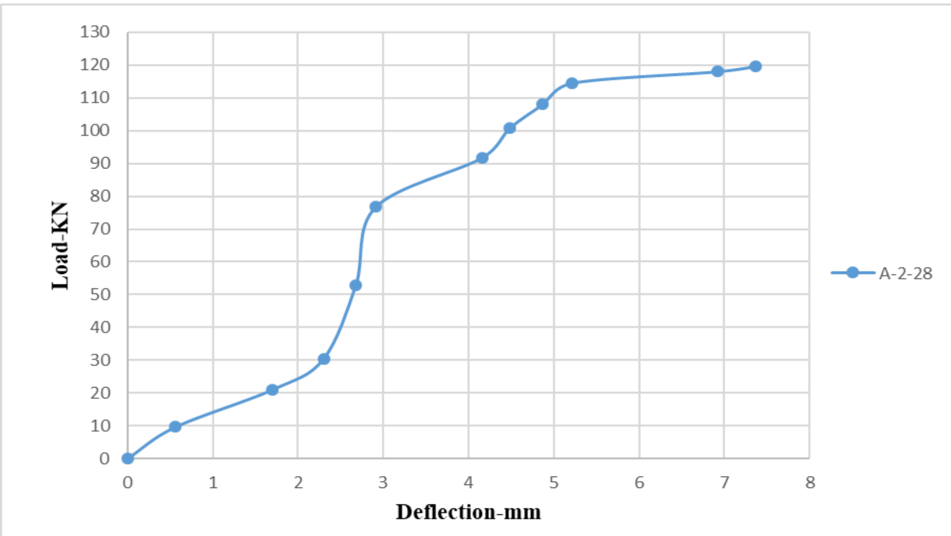


Figure 4-14: Load-deflection curve for A-2-28 beam specimen

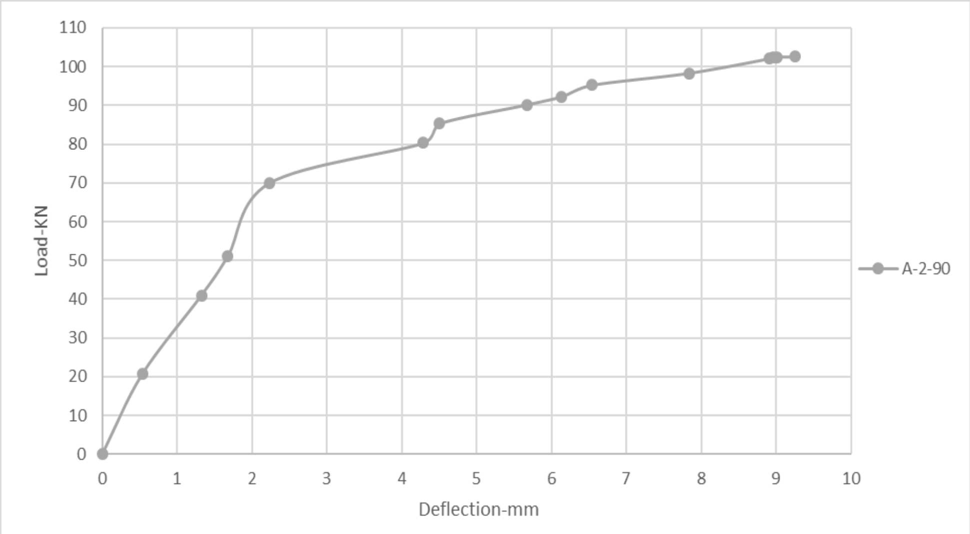


Figure 4-15: Load-deflection curve for A-2-90 beam specimen

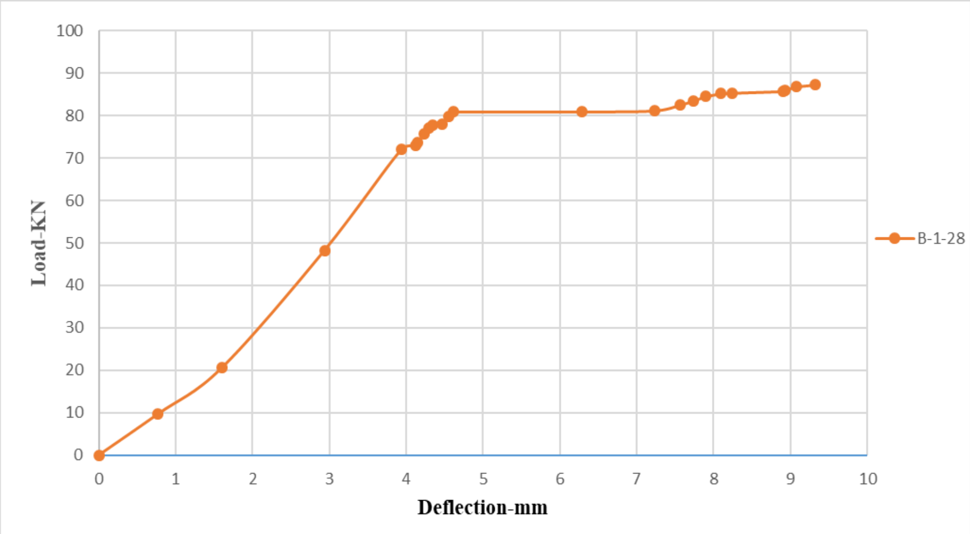


Figure 4-16: Load-deflection curve for B-1-28 beam specimen

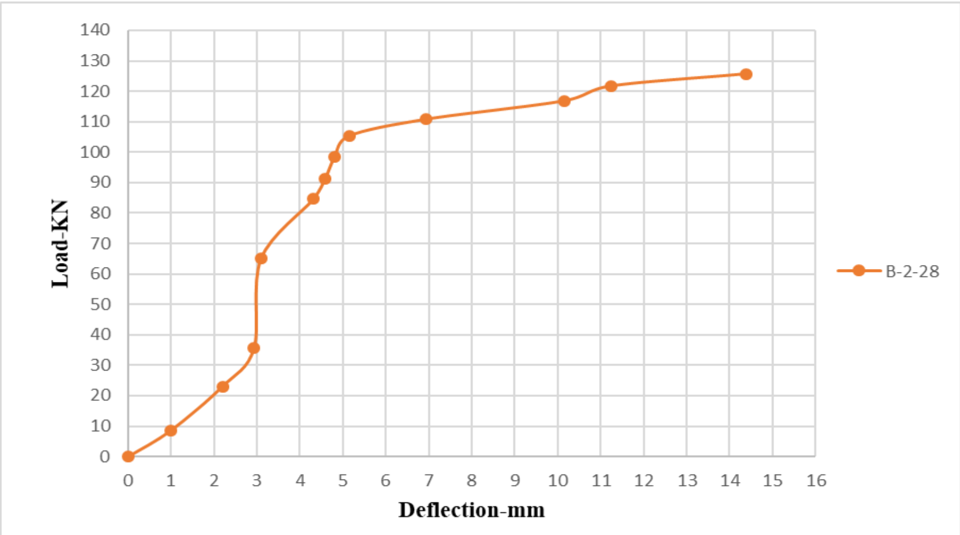


Figure 4-17: Load-deflection curve for B-2-28 beam specimen

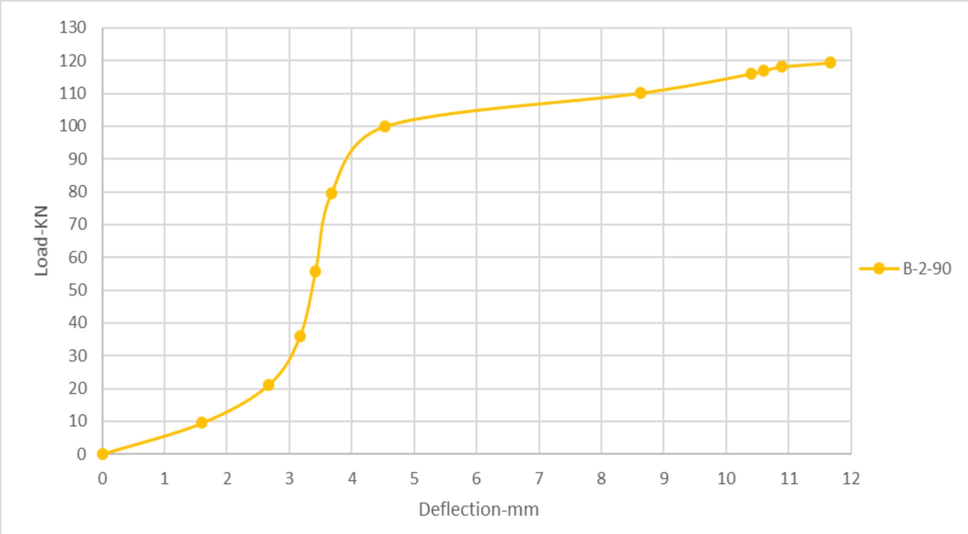


Figure 4-18: Load-deflection curve for B-2-90 beam specimen

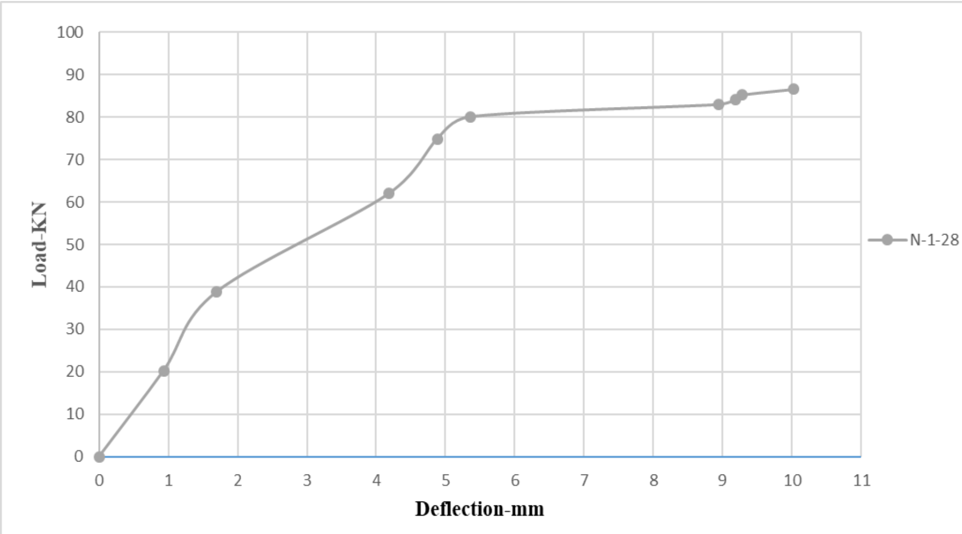


Figure 4-19: Load-deflection curve for N-1-28 beam specimen

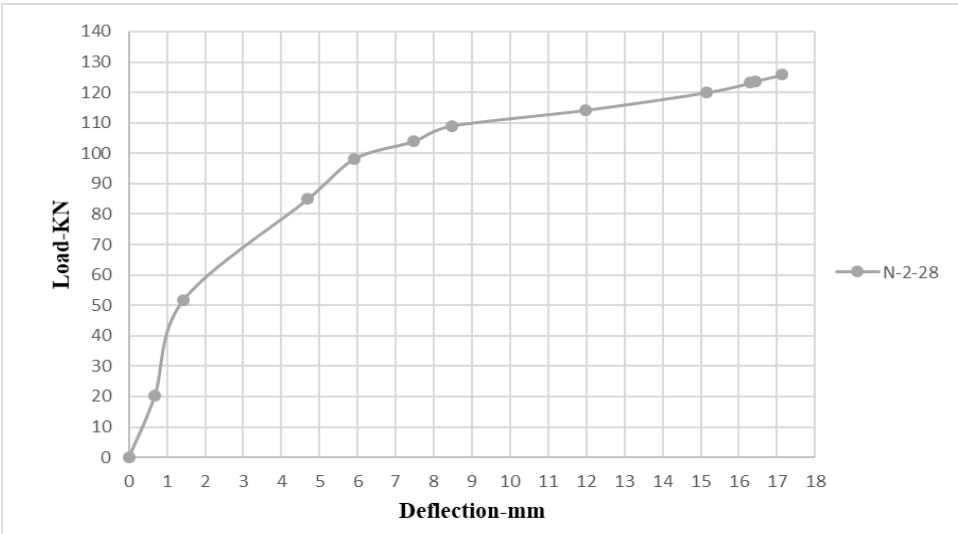


Figure 4-20: Load-deflection curve for N-2-28 beam specimen

4.3.2 Ultimate Load

The ultimate failure load for beam specimens tested under (STPCL) and (OPCL) exceed the design load.

Study No.1: It is observed that using Attapulgite aggregate concrete instead of crushed clay bricks aggregate concrete and normal weight aggregate concrete causes a reduction in the ultimate load as shown in Figure (4-21).

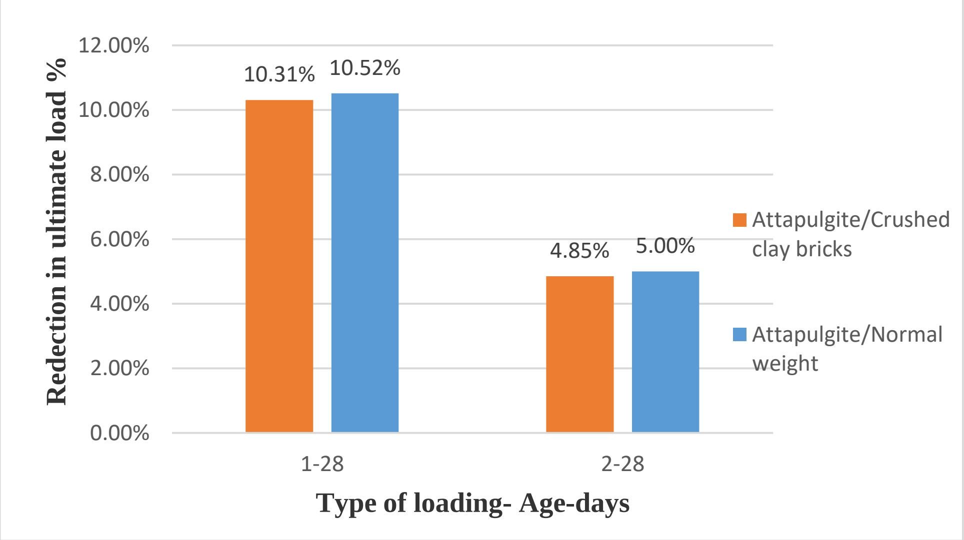


Figure 4-21: Reduction in ultimate load

Study No.2: It was observed that for Attapulgite aggregate concrete and crushed clay bricks aggregate concrete, the ultimate load decreases with age as shown in Figure (4-22).

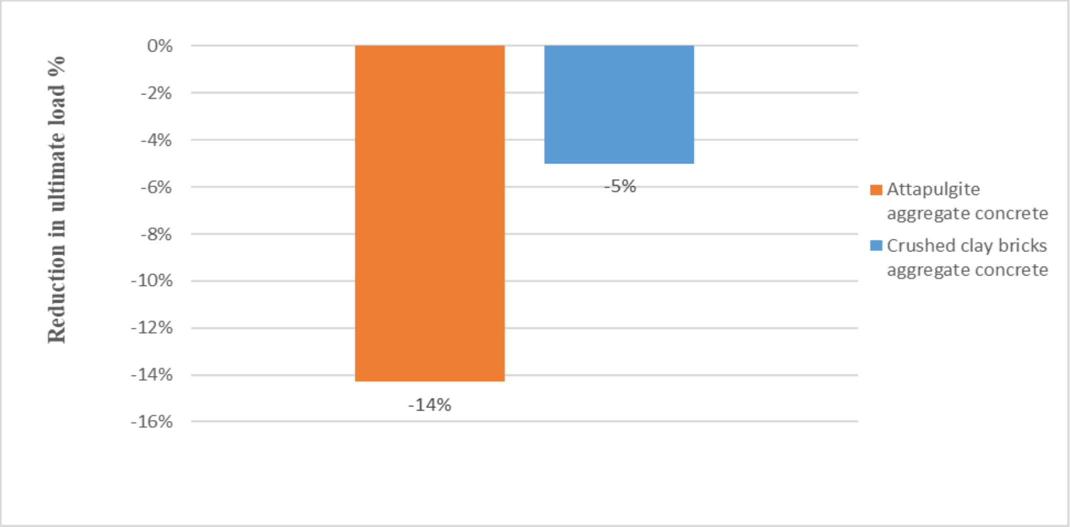


Figure 4-22: Reduction in ultimate load with age for beam tested under STPCL

4.3.3 Load–Deflection Curve

To measure the deflection of the beams, one dial gage was placed under the center of the beam in both X and Z-directions. The ultimate deflection for beam specimens tested under (STPCL) and (OPCL) exceed the design deflection.

➢ **Load–deflection curve for beam specimens tested under STPCL**

Study No.1: It was observed that using Attapulgite aggregate concrete instead of crushed clay bricks aggregate concrete and normal weight aggregate concrete causes a decrease in the ultimate mid-span vertical deflection as shown in Figure (4-23).

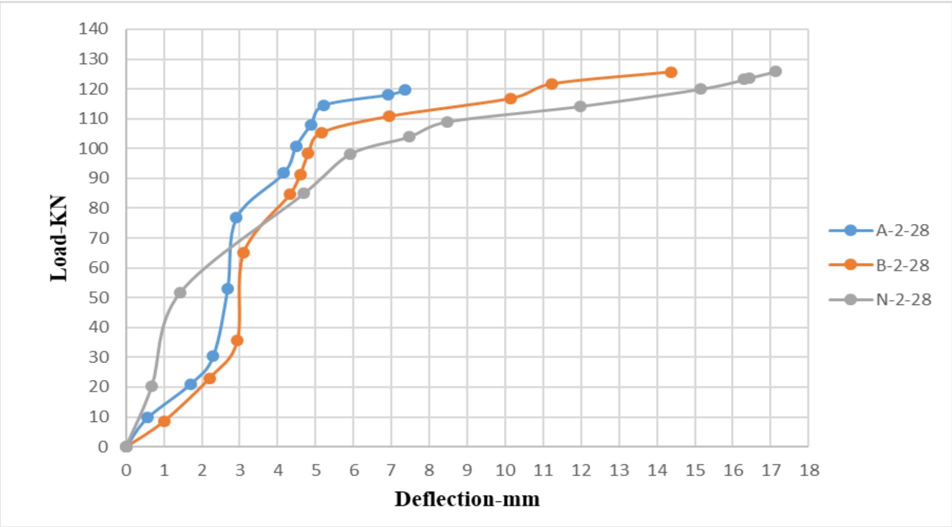


Figure 4-23: Load-deflection curve for beam specimens tested under STPCL at 28 days

Study No.2: It was observed that for Attapulgite aggregate concrete and crushed clay bricks aggregate concrete, the ultimate load decreases with age, while the ultimate vertical deflection increases with age for Attapulgite aggregate concrete and decreases for crushed clay bricks aggregate concrete as shown in Figure (4-24).

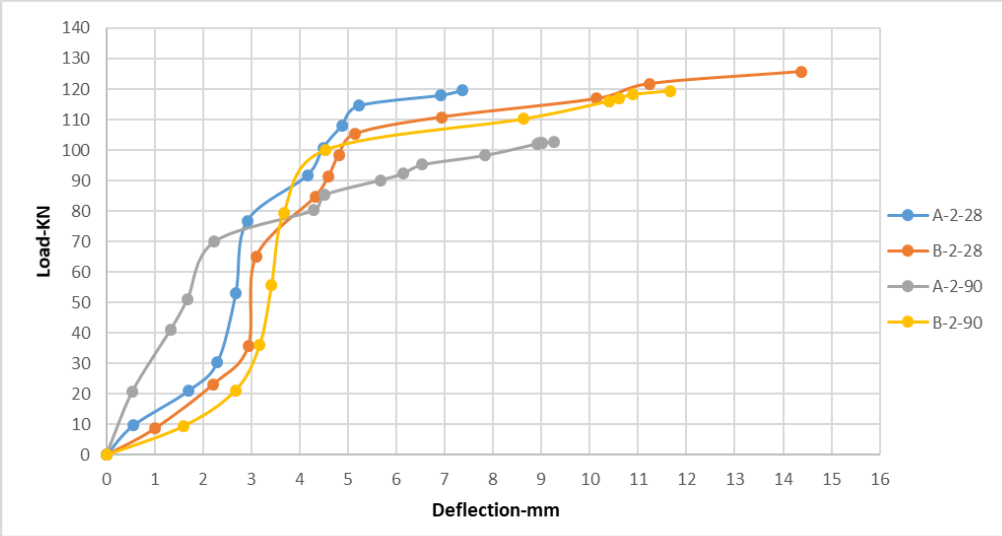


Figure 4-24: Load-deflection curve for beam specimens tested under STPCL at 28 and 90 days

➢ **Load–deflection curve for beam models tested under OPCL**

Study No.1: It was observed that using Attapulgite aggregate concrete instead of crushed clay bricks aggregate concrete and normal weight aggregate concrete causes a decrease in the ultimate mid span vertical deflection as shown in Figure (4-25).

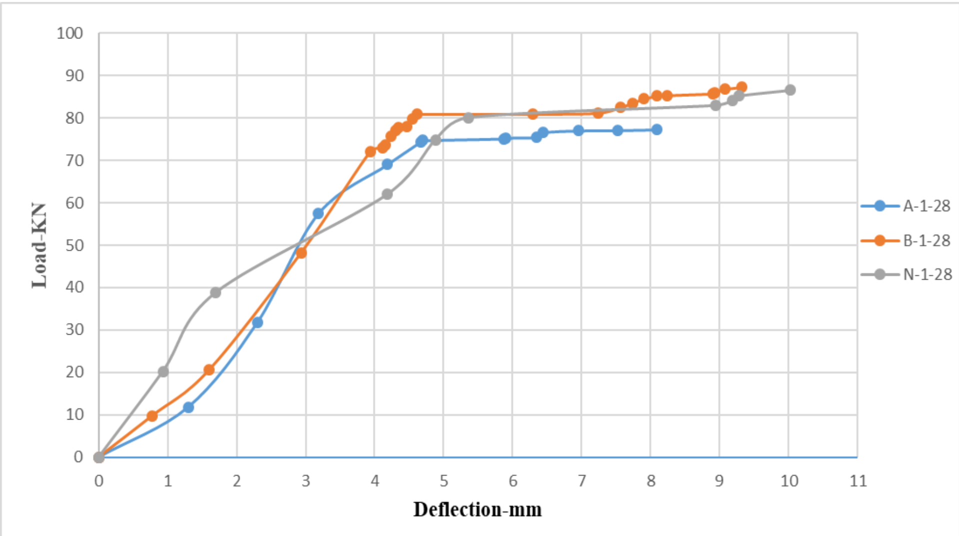


Figure 4-25: Load-deflection curve for beam specimens tested under OPCL at 28 days

4.3.4 Ductility

Ductility is the ability of the structural member to undergo large deflections prior to failure which ensures ample amount of warning to its failure(75). The ductility of reinforced concrete can be assessed based on ductility index, where ductility index is the ratio of the deflection at the ultimate load to the deflection when steel yields. Structural member can undergo large deflections before failure if ductility index is high(83).

Study No.1: Attapulgite aggregate concrete and crushed clay brick aggregate concrete beams showed good ductility behavior. All beams exhibited considerable amount of deflection, which provided ample warning to the imminence of failure as shown previously in Figures (4-23) and (4-25).

Study No.2: It was observed that the ductility of Attapulgite aggregate concrete increases with age. While for crushed clay bricks aggregate concrete the ductility decreases with age as shown previously in Figure (4-24).

4.3.5 Flexural toughness

Flexural toughness is the energy absorbed in deflecting a beam a specified amount, being the area under a load–deflection curve(84).

Study No.1 It was observed that the toughness of Attapulgite aggregate concrete and crushed clay brick aggregate concrete beams was lower than that of normal weight concrete beam, but they are still providing good toughness as shown previously in Figures (4-23) and (4-25).

Study No.2: It was observed that the toughness of Attapulgite aggregate concrete increases with age. While for crushed clay bricks aggregate concrete the toughness decreases with age as shown previously in figure (4-24).

4.3.6 Hardened Density of Concrete

The equilibrium density for lightweight aggregate concrete and normal weight concrete of beam specimens are presented in Table (4-4). The equilibrium density of concrete was considered as a reference density for the calculation of the permanent load of the structure member[36]. For most structural lightweight concretes, equilibrium density is approached at about 90 days, while for high-strength lightweight concretes, equilibrium density is approached at about 180 days. Extensive tests demonstrated that the equilibrium density will be approximately greater by 50 kg/m^3 than the oven-dry density[77].

The hardened density of beam specimen calculated as follows and the results were tabulated and graphed in Table (4-4) and Figure (4-26) respectively.

1- Calculate the weight of concrete in the beam specimen

Weight of concrete (kg) = equilibrium density of concrete (kg/m^3) ×volume of beam (m^3)

2- Calculate the weight of reinforcement in the beam specimen

Weight of reinforcement (kg) = weight of reinforcement (kg/m) ×total length used in beam (m)

3- Find total weight (concrete and reinforcement) of beam

Total weight (kg) = weight of concrete (kg) + weight of reinforcement (kg)

4- Calculating total density of beam (kg/m^3) = total weight(kg)/volume of beam (m^3).

Table 4-4: Equilibrium density and hardened density of concrete beam specimens

Beam model symbol	Concrete oven dry density (Kg/m^3)	Concrete equilibrium density (Kg/m^3)	Weight of hardened concrete beam (kg)	Weight of reinforcement in beam (kg)	Total weight (kg)	Hardened density of reinforced beam (Kg/m^3)
A-1	1805	1855	56.10	3.71	59.81	1978
A-2-28	1805	1855	56.10	4.23	60.33	1995
A-2-90	1849	1899	57.43	4.23	61.66	2039
B-1	1977	2027	61.30	3.71	65.01	2150
B-2-28	1977	2027	61.30	4.23	65.53	2167
B-2-90	1991	2041	61.72	4.23	65.95	2181
N-1	2317	2367	71.58	3.71	75.29	2490

N-2	2317	2367	71.58	4.23	75.81	2507

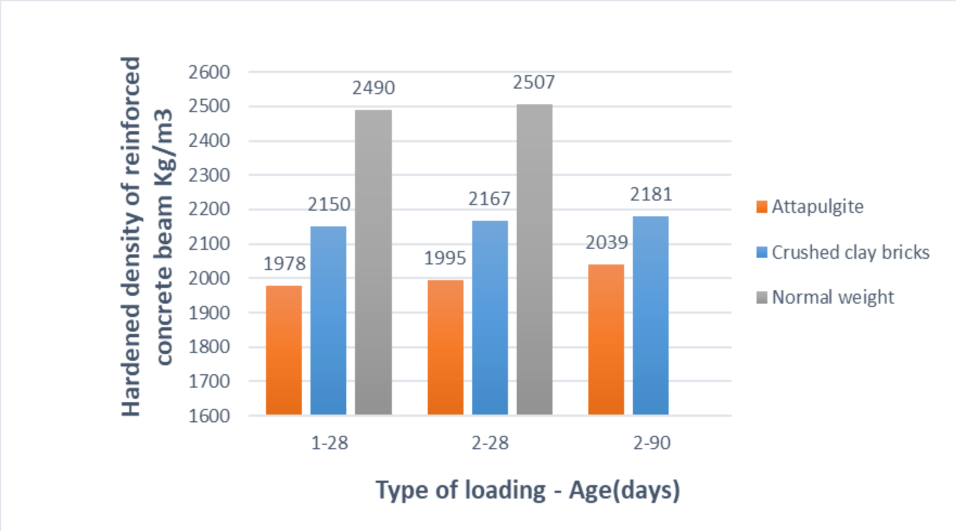


Figure 4-26: Hardened density of beam specimens

Study No.1: The average values of hardened density of Attapulgite aggregate concrete beam specimens was lower than crushed clay bricks aggregate concrete and normal weight aggregate concrete beam specimens as shown in Figure (4-27)

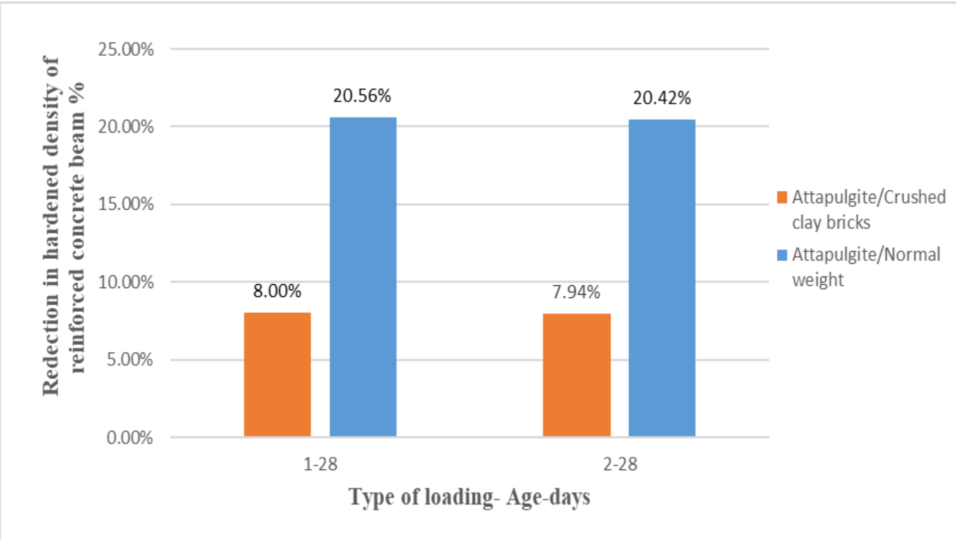


Figure 4-27: Reduction in hardened density of beam specimens

4.3.7 Saturated Surface Dry Density

The saturated surface dry density of concrete beam is calculated by determining the weight of the beam after taking it out of the curing tank and dry the surface of beam. The results of the saturated surface dry density of concrete beam are tabulated and graphed in Table (4-5) and Figure (4-28) respectively.

Table 4-5: Saturated surface dry density of reinforced beam specimens

Beam specimen	Saturated surface dry density of reinforced beam Kg/m^3
A-1-28	2108
A-2-28	2143
A-2-90	2257
B-1-28	2232
B-2-28	2252
B-2-90	2325
N-1-28	2470
N-2-28	2490

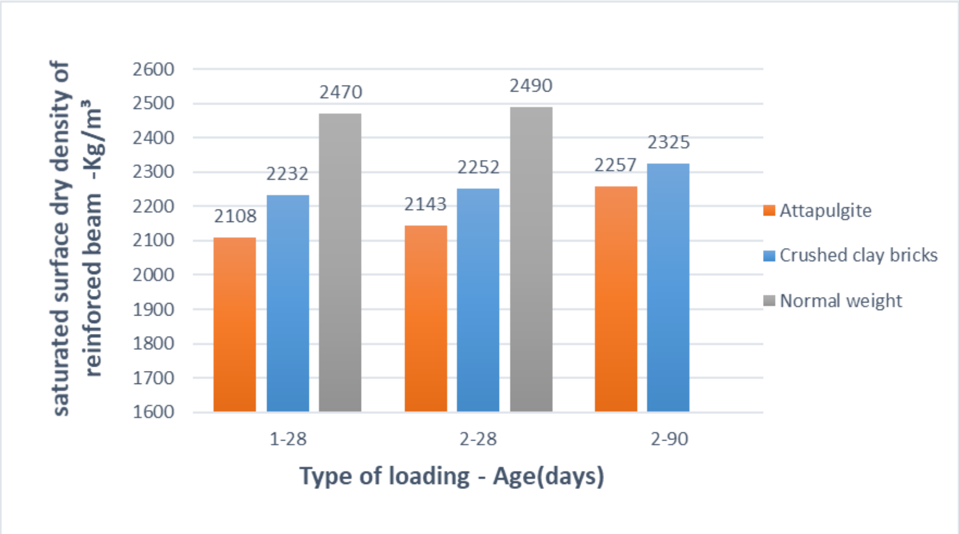


Figure 4-28: Saturated surface dry density of reinforced beam specimens

Study No.1: The average values of saturated surface dry density of Attapulgite aggregate concrete beam specimens was lower than crushed clay bricks aggregate concrete and normal weight concrete beam specimens as shown in Figure (4-29).

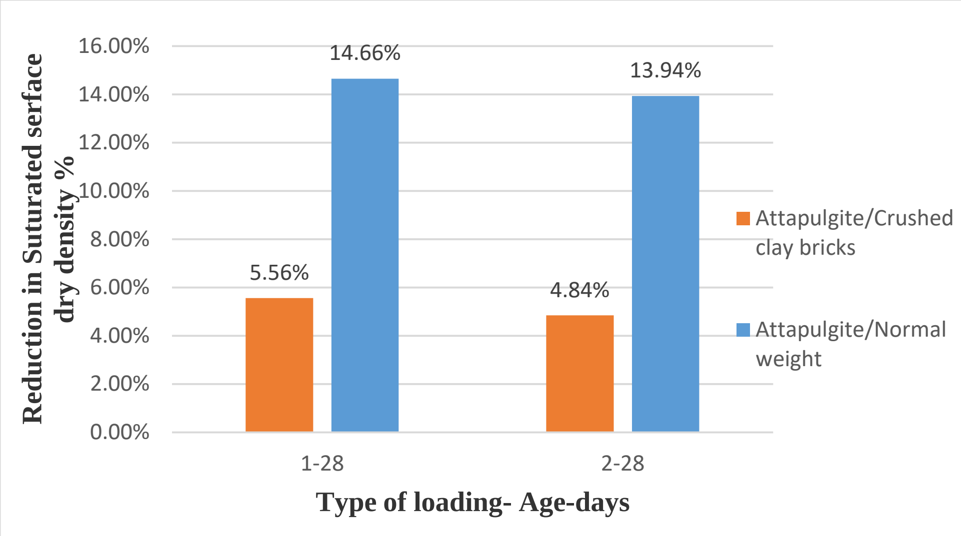


Figure 4-29: Reduction in saturated surface dry density

Study No.2: The development of Attapulgite aggregate concrete saturated surface dry density with age was more than that of crushed clay bricks aggregate concrete and normal weight concrete as shown in Figure (4-30). This is because the water absorption of Attapulgite aggregate is more than that of crushed clay bricks and normal weight aggregate. which led to more effective hydration process. However, the saturated surface dry density of Attapulgite aggregate concrete beam at 90 days remained less than that of crushed clay bricks aggregate concrete beam and normal weight concrete beam as shown previously in Figure (4-28).

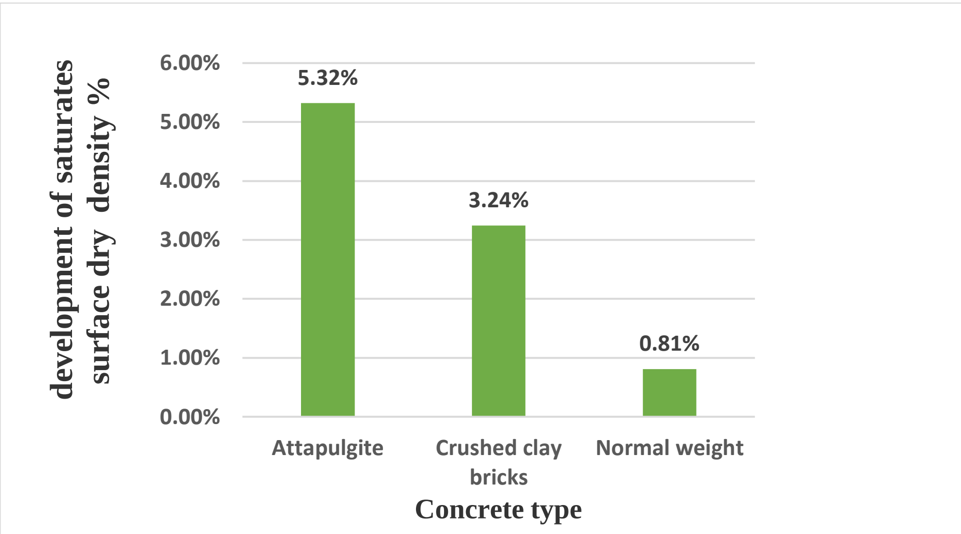


Figure 4-30: Development of saturated surface dry density from 28 to 90 days

Chapter Five

Conclusions and Recommendations For Future Work

Conclusions and Recommendations for Future Work

5.1 General

Two parts of conclusions were covered in this chapter; the first part concentrates on the materials properties. It is related to the results obtained from the standard test specimens. The second part relates to the structural behavior of (8) simply supported reinforced beams with various type of concrete, age of test and type of loading.

5.2 Material Properties Conclusions

The following conclusions were concluded based on the overall results of the experimental work:

1- Structural lightweight coarse aggregate can be prepared by burning Attapulgite at a temperature of 1100˚C for 30 minute. The Attapulgite aggregate and crushed clay bricks aggregate conforms to the requirements ASTM C330-05[37] with dry loose bulk density about 755 kg/m^3.

2- Structural lightweight aggregate concrete produced from Attapulgite aggregate conforms to the requirements of structural lightweight concrete according to ACI 213R-14[15] with an average cylinder compressive strength of 18.5 MPa and average oven dry density of 1805 kg/m^3.

3- Structural lightweight aggregate concrete produced from crushed clay bricks aggregate conforms to the requirements of structural lightweight concrete of most codes except the requirements of structural lightweight concrete of ACI 213R-14[15] with an average cylinder compressive strength of 31.5 MPa and average oven dry density of 1977 kg/m^3.

4- The oven-dry density decrease when using Attapulgite aggregate concrete instead of crushed clay bricks aggregate concrete and normal weight aggregate concrete. Where at age of 28 days, the oven-dry density of Attapulgite aggregate concrete was less than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 8.7% and 22.1 % respectively.

5- The compressive strength of Attapulgite aggregate concrete was lower than crushed clay bricks aggregate concrete and normal weight aggregate concrete. Where at age of 28 days, the cylinder compressive strength of Attapulgite aggregate concrete was less than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 41.2 % and 54.2 % respectively.

6- The splitting tensile strength of Attapulgite aggregate concrete was lower than crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 38.7 % and 43.6 % respectively at 28 days.

7- All types of concrete exhibited a continuous increase in splitting tensile strength and compressive strength with time of curing, but the strength development of Attapulgite aggregate concrete was more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete.

8- The experimental values of splitting tensile strength more than the splitting tensile strength predicted by ACI Code 318-2011[(13)] by about 16.1% for Attapulgite aggregate concrete, 45.3 % for crushed clay bricks aggregate concrete and 39.3 % for normal weight aggregate concrete at 28 days.

9- The predicted modulus of elasticity of Attapulgite aggregate concrete was less than that of crushed clay bricks aggregate concrete and normal weight concrete by about 32.05% and 52%.

10- The water absorption of Attapulgite aggregate concrete was more than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete by about 41.2% and 273.3% respectively.

5.3 Structural Behavior Conclusions

Based on the overall results obtained from the experimental work, the following conclusions can be drawn:

1- For all beams, as was expected, the failure of all beams was a flexural failure.

2- The hardened density of Attapulgite aggregate concrete beam specimens was lower than crushed clay bricks aggregate concrete and normal weight concrete beam specimens by about 8% and 20.56% respectively at 28 days.

3- The reserve strength of Attapulgite aggregate concrete beam tested under STPCL was lower than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete beam specimens by about 2.3% and 25.7% respectively. While the reserve strength of Attapulgite aggregate concrete beam tested under OPCL was less than that of crushed clay bricks aggregate concrete and normal weight aggregate concrete beam specimens by about 10.3% and 17.1% respectively.

4- The ultimate load capacity of Attapulgite aggregate concrete beams tested under STPCL was lower than that of crushed clay bricks aggregate concrete beams and normal weight aggregate concrete beams by about 4.85% and 5% respectively at 28 days. While the ultimate load capacity of reinforced Attapulgite concrete beams tested under OPCL was lower than that of reinforced crushed clay bricks aggregate concrete beams and reinforced normal weight aggregate concrete beams by about 10.3% and 10.5% respectively at 28 days.

5- The ultimate deflection for beam specimens tested under (STPCL) and (OPCL) exceed the design deflection. Where the ultimate deflection of Attapulgite aggregate concrete beams tested under STPCL was lower than that of crushed clay bricks aggregate concrete beams and normal weight aggregate concrete beams by about 48.7% and 57% respectively. While the ultimate deflection of Attapulgite aggregate concrete beams tested under OPCL was lower than that of crushed clay bricks aggregate concrete beams and normal weight aggregate concrete beams by about 13.2% and 19.2% respectively.

6- Normal weight aggregate concrete showed higher ductility and toughness than that of crushed clay bricks aggregate concrete and Attapulgite aggregate concrete.

5.4 Recommendations for Further Research

The following suggestions could be considered as an extension for the present study

1- Production of structural lightweight aggregate concrete by replacing natural fine sand by lightweight aggregate in full or partial replacement.
2- Investigate the structural behavior of high performance lightweight aggregate concrete.
3- Investigate the structural behavior of lightweight aggregate concrete with carbon fibers reinforced polymer (CFRP) bars reinforcement.
4- Investigate the structural behavior of continuous lightweight aggregate concrete beam.
5- Investigate the structural behavior of prestressed lightweight aggregate concrete beam.
6- Investigate the shear failure of structural lightweight aggregate concrete beams.
7- Investigate the effect of using steel fibers on the behavior of reinforced lightweight aggregate concrete beams to improve concrete shear strength.
8- Investigate the effect of dynamic load on the behavior of reinforced normal weight and lightweight aggregate concrete beam.

Reference

References

1. Winter G. "Design of Concrete Structures". McGraw-Hill Book Company. 2004;Thirteen Edition.

2. Neville A. M. "Properties of Concrete". Longman Group Limited. 2011;Fifth Edition.

3. Mefteh H, Kebaïli O, Oucief H, Berredjem L, Arabi N. "Influence of moisture conditioning of recycled aggregates on the properties of fresh and hardened concrete". Journal of cleaner production. 2013;54.

4. Tu T-Y, Chen Y-Y, Hwang C-L. "Properties of HPC with recycled aggregates". Cement and concrete research. 2006;36(5):943-950;.

5. Tam, Vivian WY. "Comparing the implementation of concrete recycling in the Australian and Japanese construction industries". Journal of Cleaner production. 2009;17(7):688-702.

6. Pelisser F, Barcelos A, Santos D, Peterson M, Bernardin AM. "Lightweight concrete production with low Portland cement consumption". Journal of Cleaner Production. 2012;23(1):68-74.

7. Pelisser F, Zavarise N, Longo TA, Bernardin AM. "Concrete made with recycled tire rubber: effect of alkaline activation and silica fume addition". Journal of Cleaner Production. 2011;19(6-7):757-763.

8. Swamy R, "Design for sustainable development of concrete construction". Proceedings of the Fourth International Structural Engineering and Construction Conference (ISEC 4), Taylor & Francis Ltd England; 2007.

9. Bremner T, Eng P, "Environmental aspects of concrete: problems and solutions". All-Russian Conference on Concrete and Reinforced Concrete; 2001.

10. Shafigh P, Mahmud HB, Jumaat MZB, Ahmmad R, Bahri S. "Structural lightweight aggregate concrete using two types of waste from the palm oil industry as aggregate". Journal of Cleaner Production. 2014;80:187-196.

11. Kivrak S., Tuncan M., Onur M. I., Arslan G., and Arioz O. "An Economic Perspective of Advantages of Using Lightweight Concrete in Construction". 31st Conference on OUR WORLD IN CONCRETE & STRUCTURES. 2006.

12. Newman J., and Owen P. "Properties of Lightweight Concrete, Advanced Concrete Technology". Butterworth-Heinemann. 2003.

13. ACI Committee 318, " Building Code Requirements for Structural Concrete and Commentary (ACI 318-14)", American Concrete Institute; 2014.

14.Owens P.L. "Lightweight Aggregates for Structural Concrete. Structural Lightweight Aggregate Concrete". Chapman & Hall. 1993.

15. ACI Committee 213, "Guide for structural lightweight aggregate concrete (ACI 213R-14)", American Concrete Institute; 2014.

16. NS 3473 E 1992. "Design of Concrete Structure". Norwegian Standard, English version.

17.CEN ENV 1992-1-4. "Design of Concrete Structures - General Rules - Lightweight Aggregate Concrete with Closed Structures". 1994.

18.RILEM, "Terminology and Definitions of Lightweight Concrete". Recommendation LCI 1st edition, 1975,.

19. BS EN1992-1-1. "Eurocode 2 (EC2): Design of Concrete Structures (Part 1-1: General Rules and Rules for Buildings)", Nottingham Trent University.

20. Chandra S, Berntsson L "Lightweight aggregate concrete": Elsevier; 2002.

21. Jallab A.K. "Flexural Behavior of Reinforced Self Compacting Concrete Beams", PhD Thesis, University of Technology, Iraq. 2008.

22. Ismail H.K.M., Fathi M.S., and Manaf N.B. "Study of Lightweight Concrete Behavior". United Kingdom and Sweden,2004.

23. Mesut A. "Structural Lightweight Concrete with Natural Perlite Aggregate and Perlite Powder". MSc Thesis, The Graduate School of Natural and Applied Sciences of Middle East Technical University, 2006.

24.Tommy YL, and Cui HZ. "Properties of Green Lightweight Aggregate Concrete". International Workshop on Sustainable Development and Concrete Technology, City University of Hong Kong,2015.

25.Expanded Shale, Clay and Slate Institute (ESCSI). "Building Bridges and Marine Structures". Salt Lake City, Utah. 2001.

26.El-Kordy A.A., and Safouh A.M. "Lightweight Concrete". Alexandria University Faculty of Engineering. 2003.

27.Transportation Research Record. "Recycling Materials for Highways". No 54 National Academy Press Washington. 1976.

28.Mindess S, Young JF, and Darwin D. "Concrete". 2nd ed, Prentice-Hall, New Jersey. 2003.

29.Spartt BH. "An Introduction to Lightweight Concrete". 1975;Fifth Edition.

30.Al-Musawi, J., "Flexural Behavior of Porcelinite Reinforced Concrete Beams". PhD Thesis, University of Technology, 2004.

31.Al-Dhaher B., "The Use of Local Porcelinite for the Production of Lightweight Concrete Units". MSc Thesis, University of Technology, 2001.

32.Al-Kass RM, and Al-Khaliss FQ. "Production of Lightweight Expanded Clay Aggregates from Some Iraqi Soil". Building Research Center, Rep No 61179, 1979.

33.Clarke JL. "Structural Lightweight Aggregate Concrete",First Edition, Chapman & Hall, London. 2005.

34.ACI Committee 523. ACI 523.3R-93, "Guide for Cellular Concretes Above 50 pcf, and for Aggregate Concretes Above 50 pcf with Compressive Strengths Less Than 2500 psi". American Concrete Institute, Detroit, USA. 1993.

35.FIP Manual. "FIP Manual of Lightweight Aggregate Concrete", 2nd. Edition. Surrey University Press. 1983.

36.Naser F., "Structural Behavior of Light Weight Concrete Slab Panels Reinforced with CFRP Bars " ,PhD Thesis. University of Babylon. 2015.

37.ASTM Designation C330–05. "Lightweight Aggregates for Structural Concrete". nnual Book of ASTM Standards, American Society for Testing and Materials & Design. 2005.
38. Jassim H.M., "Some Properties of Lightweight Concrete Containing Attapulgite ". MSc Thesis, University of Technology, 2014.
39.CEB/FIP Manual of design and technology. "Lightweight Aggregate Concrete". The Construction Press, Lancaster, 1st Publishing, 169 pp. 1977.
40.Alexander M., and Mindess S. "Aggregate In Concrete". Taylor and Francis, London and New York. 2010.
41.Clarke J.L. "Structural Lightweight Aggregate Concrete". First Edition, Chapman & Hall, London pp 1-161. 2005.
42.Bin Shamsuri M.K. "Development Of Lightweight Concrete By Using Polystyrene Beads". BSc, Graduation Project, University of Malaysia. 2011.
43.ACI 213R-87. "Guide for Structural Lightweight Concrete". ACI Manual of Concrete Practice, Part 1: Materials and General Properties of Concrete, Detroit, Michigan, 27 PP. 1994.
44.Berge O, "Reinforced Structures in Lightweight Concrete". PhD Thesis, Chalmers University of Technology, Division of Concrete Structures Publ. 81:3, Goteborg. 1981.
45.Al-Bayati N, "Behavior of Porcelanite Reinforced Concrete Deep Beams" Ph.D. Thesis, University of Technology, 2012.
46. Saleh H., "Using of Porcelinite as Coarse Aggregate in Concrete". Tikrit Journal of Engineering Sciences. 2012;19(3):33-40.
47.Fawzi N, Hachim Q, "The Effect of Different Types of Aggregate and Additives on the Properties of Self-Compacting Lightweight Concrete". Journal of Engineering. 2012;18(8):875-88.
48.Al-Attar TS, Abdullatif AM, Al-Saad AJ, "Effect of Internal Curing on Strength Development of High Performance Concrete by Using Crushed Lightweight

Porcelinite". Engineering and Technology Journal. 2014;32(11 Part (A) Engineering):2803-14.
49.Naser F, Naser M, Najim W, "Production of Structural Light-Weight Aggregate Concrete Using Different Types of Iraqi Local Crushed Materials as Coarse Aggregate"2018.
50.Alduaij J, Alshaleh K, Haque MN, EL- Laithy K. "Lightweight Concrete in Hot Coastal Areas". Cement and Concrete Composites, pp 453- 458. 1999.
51. Balasubramanya N. "Experimental Investigation on Development of Light Weight Concrete by Blending with LECA and Cinder", MSc. thesis. Visvesvaraya Technological University. 2015.
52.Frayyeh Q, Abbas W, Hassan A, "The Combined Effect of Attapulgite High Reactive Mineral Admixture and Superplastisizer on Compressive Strength of Attapulgite Lightweight Aggregate Concrete". Engineering and Technology Journal. 2016;34(12 Part (A) Engineering):2181-2192.
53.Farahani J, Shafigh P, Mahmud H, "Production of A Green Lightweight Aggregate Concrete by Incorporating High Volume Locally Available Waste Materials". Procedia Engineering. 2017;184:778-783.
54.Al-Soadi, E.N, "A Study on Using Crushed Brick in the Production of Concrete and Lightweight Concrete Bricks", M.Sc. Thesis. Technology University. 2002.
55.Al-Baghdadi HM, "Using Local Materials Wastes For Development Of High Strength Lightweight Concrete". 2011.
56.Teo DC, Mannan MA, Kurian JV. "Flexural behaviour of reinforced lightweight concrete beams made with oil palm shell (OPS)". Journal of advanced concrete technology. 2006;4(3):459-468.
57.Alengaram UJ, Jumaat MZ, Mahmud H. "Ductility behaviour of reinforced palm kernel shell concrete beams". European Journal of Scientific Research. 2008;23(3):406-420.

58.Altun F, Aktaş B, "Investigation of reinforced concrete beams behavior of steel fiber added lightweight concrete". Construction and Building Materials. 2013;38:575-581.

59.Vázquez-Herrero C, Martínez-Lage I, Vázquez-Vázquez H, Martínez-Abella F, "Comparative study of the flexural behavior of lightweight and normal weight prestressed concrete beams". Engineering Structures. 2013;56:1868-1879.

60.Carmo R, Costa H, Simões T, Lourenço C, Andrade D, "Influence of both concrete strength and transverse confinement on bending behavior of reinforced LWAC beams". Engineering Structures. 2013;48:329-341.

61.Thiyab HM, "Experimental Study of Reinforced Light Weight Concrete Beams". Journal of University of Babylon, 2016;24(4):1086-1098.

62.Abtan Y, Jaber H, "Behavior of hybrid reinforced concrete beams combining reactive powder concrete and varying types of lightweight concrete". Journal of Engineering and Sustainable Development. 2016;20(2):204-223.

63.المواصفة القياسية العراقية رقم 5 لسنة1984، "السمنت البورتلاندي"، الجهازالمركزي للتقييس المواصفة القياسية العراقية والسيطرة النوعية، بغداد.

64.المواصفة القياسية العراقية رقم45 لسنة1984، "ركام المصادر الطبيعية المستعمل في الخرسانة والبناء" الجهاز المركزي للتقييس والسيطرة النوعية، بغداد.

65.ASTM C29/C29M-97, (Re-approved 2003). "Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate". Annual Book of ASTM Standards, Vol. 04-02, Concrete and Aggregates, West Conshohocken, PA, United States, 2003,.

66. ASTM C128–04. "Standard Test Method for Density,Relative Density (Specific Gravity), and Absorption of Fine Aggregate". Annual Book of ASTM Standards, Vol. 04-02, Concrete and Aggregates, West Conshohocken, PA, United States, 2004,.

67.Bradley WF, "The Structure Scheme of Attapulgite", Am. Mineral, Vol. 25(6), 1940, pp. 405- 410.

68.Carroll H, "Clay Minerals A Guide to Their X-ray Identification", The Geological Society of America 1970, Colorado.

69.ASTM C127–04. "Standard Test method for Density Relative Density (Specific Gravity) and Adsorption of Coarse Aggregate". Annual Book of ASTM Standards Vol. 04-02 Concrete and Aggregates, West Conshohocken, PA, United States, 2004.

70.ASTM C 494/C 494M-05. "Standard Specification for ChemicalAdmixtures for Concrete". Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04-02, 2005.

71.ASTM A 615/A615M-05a, “Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys, West Conshohocken; PA 19428-2959; United States; 2005; 5 pp.

72.ACI Committee 211, "Standard Practice for Selecting Proportion for Structural Lightweight Concrete", (ACI 211-2-98), ACI Manual of Concrete Practice, Part 1, 2004.

73.ASTM C 192/C 192M-05, 2005 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory , Annual Book of ASTM Standards, American Society for Testing and Materials, pp. 1-8.

74. BS 1881-Part 108:1983, "Testing Concrete" British Standards Institution BSI.

75.Alhassan M, Al-Rousan R, Ababneh A. "Flexural behavior of lightweight concrete beams encompassing various dosages of macro synthetic fibers and steel ratios". Case Studies in Construction Materials. 2017;7:280-293.

76.ASTM C143-03. "Standard Test Method for Slump of Hydraulic-Cement Concrete". ASTM International, Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04-02, United States, 2004.

77.ASTM C567–05a. "Standard Test Methods for Determination Density of Structural Lightweight Concrete". ASTM International, Annual Book of ASTM

Standards, American Society for Testing and Materials, Vol. 04-02, United States, 2006,.

78.BS 1881, Part 116: 1989. "Method for Determination of Compressive Strength of Concrete Cubes", British Standards Institution, 1881.

79.ASTM C 39/C 39M-05. "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens". Annual Book of ASTM Standards, Vol. 04-02 Concrete and Aggregates, West Conshohocken, PA, United States, 7 pp.

80. ASTM C496-04. "Standard Test Method for Splitting Tensile of Cylindrical Concrete Specimens". Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04-02, 2004,.

81. ASTM C642-97. "Standard Test Method of Specific Gravity, Absorption and Voids in Hardened Concrete". Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04-02, 1997,.

82. Yang K-H, Chung H-S, Lee E-T, Eun H-C "Shear characteristics of high-strength concrete deep beams without shear reinforcements" Engineering Structures. 2003;25(10):1343-1352.

83. Huda MN, Jumat MZB, Islam ABMS. "Flexural performance of reinforced oil palm shell & palm oil clinker concrete (PSCC) beam". Construction and Building Materials. 2016;127:18-25.

84. Song P, Hwang S. "Mechanical properties of high-strength steel fiber-reinforced concrete". Construction and Building Materials. 2004;18(9):669-673.

Appendix A

Analysis of Lightweight Reinforced Concrete Beam

(According to ACI 318M-14 [13])

A simply supported Attapulgite aggregate concrete beam tested under symmetric two-point concentrated load (STPCL) has the following details as shown previously in plates 3-17 and 3-19.

-Dimensions:

Total span = 1200 mm, span length (center to center) (L)= 1050 mm, h = 180 mm, d = 159 mm, b = 140 mm, bottom and top cover 10 mm, side cover 10 mm.

- Material Properties:

From Table 4-4:

The equilibrium density of Attapulgite lightweight aggregte concrete Wc =1855 kg/m3

From Table 4-1:

The cylinder compressive strength (f_c') of Attapulgite lightweight aggregte concrete = 18.5 MPa

Two deformed steel bars Ø 12 mm were used as tensile reinforcement, two deformed steel bars of Ø 6 mm were used as compression reinforcement and deformed steel bars Ø 5 mm were used shear reinforcement.

From Table 3-11:

The nominal diameter and yield strenght of Ø 12 mm steel bars is 11.75 mm and 420 MPa respectively.

The nominal diameter and yield strenght of Ø 5 mm steel bars is 4.92 mm and 280 MPa respectively.

- Min. Reinforcment Ratio:

$$\rho_{act.} = \frac{As}{b \times d} = 0.0$$

$\rho_{min.} =$ → $\frac{1.4}{fy} = 0.0033$ (10.5.1)

→ $0.25 \times \frac{\sqrt{f'c}}{fy} = 0.0025$ (10.5.1)

$\rho_{min.} = 0.0033$

$\rho_b = 0.85 \times \beta_1 \times \frac{f'c}{fy} \times \frac{600}{600+fy}$ (B.8.4.1)

$\because f'c < 28$ MPa $\therefore \beta_1 = 0.85$ (10.2.7.1)

$\rho_b = 0.0187$

$\rho_{max.} = 0.75 \times \rho_b = 0.014$

$\rho_{min.} \leq \rho_{act.} \leq \rho_{max.}$

- Min. Thickness of Beam:

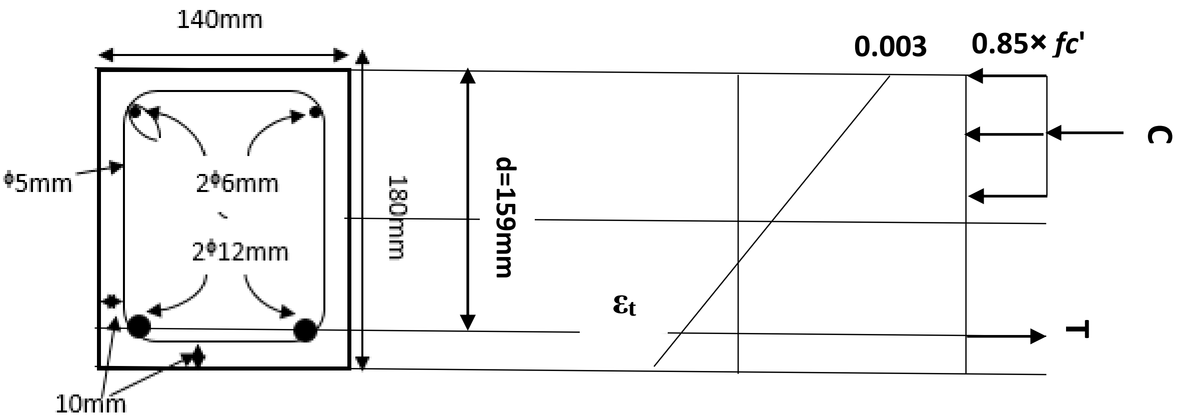
$h_{min.} = \frac{L}{16} \times (1.65 - 0.003 \times Wc)$ (9.5.2.2)

L= 1050 mm

$h_{min.} = 71.7$ mm < ($h_{act.}$ =140 mm) $\therefore$ O.K.

- Flexural Calculations:

$As = 2 \times \frac{\pi}{4} \times (d)^2 = 2 \times \frac{\pi}{4} \times (11.75)^2 = 215$ mm



T = C

$As \times fy = 0.85 \times f'c \times a \times b$

$a = \frac{As \times fy}{0.85 \times f'c \times b} = 41$

$C = \frac{a}{\beta 1} = 48.2$ mm

From strain daigram (ΔΔ)

$\frac{0.003}{C} = \frac{0.003 + \varepsilon t}{d}$

$\varepsilon_t = 0.0068$ Ø =0.9   (R.9.3.2.2)

$M_u = Ø \times M_n = Ø \times T \times (d - 0.5 \times a) = 11.25$ KN.m

- Shear Calculations:

Mu =035× Pu   From bending moment diagram

$P_u = 32.14$ KN

$V_u = P_u = 32.14$ From shear force diagram at (d) from the face of support

To achieve the flexural failure, the ultimate shear force increased by about 25 %.

$V_u = 1.25 \times P_u = 40.17$ KN

$V_c = (0.16 \times \lambda \times \sqrt{f'c} + 17 \times \rho_{act.} \times \frac{Vu \times d}{Mu}) \times b \times d$ (11.2.2.1)

$\frac{Vu \times d}{Mu} = 0.56 < 1$ O.K.   (11.2.2.1)

$\sqrt{f'c} = 4.3 < 8.3$ O.K.   (11.1.2)

$\lambda = 0.85$ (8.6.1)

$V_c = 15.08$ KN < $(0.29 \times \lambda \times \sqrt{f'c} \times b \times d = 23KN)$ O.K. (11.2.2.1)

$V_u = Ø\times V_c + Ø\times V_s$

$Ø = 0.75$ (9.3.2.3)

$V_s = 38.48$ KN < $(0.66 \sqrt{f'c} \times b \times d = 63.8$ KN$)$ O.K.   (11.4.7.9)

$S = \frac{Av \times fy \times d}{Vs}$

$A_v = 2 \times \frac{\pi}{4} \times d^2 = 2 \times \frac{\pi}{4} \times 4.92^2 = 38.02$ mm²

$fy = 280$ MPa

S = 44mm

Find $S_{max.}$

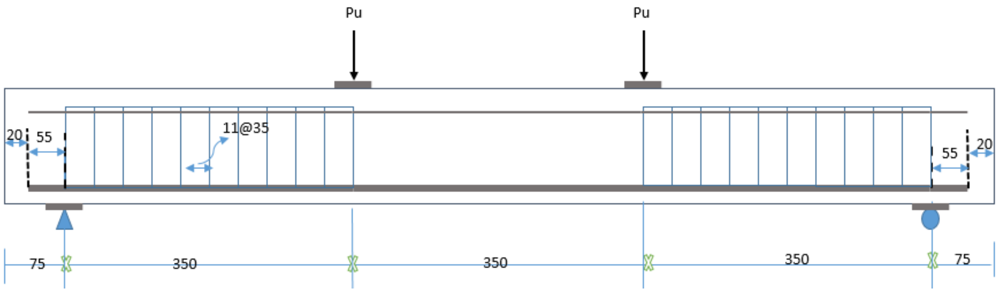
$\because V_s > (0.33 \times \sqrt{f'c} \times b \times d = 31.59\ KN)$

$\therefore S_{max.} =$ → $d/4 = 39.7\ mm$ (11.4.5.3)

→ 300 mm (11.4.5.3)

$\because S > S_{max.}$

$\therefore$ Use $S_{max.} = 35\ mm$



The first stirps located at S/2 from the face of support

$S/2 = 17.5\ mm \approx 15\ mm$

$$\text{No. of bars} = \frac{350-15}{35} + 1 = 10.57\ \text{bars} \approx 11\ \text{bars}$$

الخلاصة

نتيجة لمحدودية المواد الطبيعية المستخدمة في انتاج الخرسانة، فان استخدام المواد الفائضة في الطبيعة في انتاج الخرسانة يؤدي إلى تقليل التأثير السلبي للخرسانة على البيئة. لذلك تم استخدام الاتبولكايت وكسر الطابوق الطيني كركام خشن خفيف الوزن لانتاج خرسانة انشائية مستدامة خفيفة الوزن. تتضمن الدراسة الحالية التحري العملي لسلوك العتبات الخرسانية المسندة باسناد بسيط. يتكون البرنامج العملي من صب ٨ نماذج من العتبات الخرسانية المسلحة المستطيلة المقطع وبذات الأبعاد لجميع النماذج (1200*180*140) ملم . تم فحص خمسة نماذج تحت تأثير حملين مركزين متناظرين وبقية النماذج تم فحصها تحت تأثير حمل مركز في نقطة واحدة. اهم المتغيرات التي اخذت بنظر الاعتبار في هذه الدراسة هي نوع الركام (الاتبولكايت, كسر الطابوق الطيني والركام الاعتيادي الوزن), نظام تسليط الحمل وكذلك فترة الانضاج. تم اجراء اختبارات على عينات خرسانية اسطوانية ومكعبة لايجاد الخواص الميكانيكية للخرسانة. النتائج التي تم الحصول عليها من الاختبارات توضح امكانية انتاج خرسانة انشائية خفيفة الوزن بأستخدام ركام الاتبولكايت بمقاومة انضغاط 25 ميكاباسكال وكثافة جافة 1805 كغم/م^{3} وكذلك امكانية انتاج خرسانة انشائية خفيفة الوزن بأستخدام ركام كسر الطابوق الطيني بمقاومة انضغاط 43.7 ميكاباسكال وكثافة جافة 1977 كغم/م^{3}. وزن العتبات الخرسانية الخفيفة الوزن الحاوية على ركام الاتبولكايت او ركام كسر الطابق الطيني اقل من وزن العتبات الخرسانية الحاوية على الركام الاعتيادي الوزن بمقدار 20.56% و 13.56 % على التوالي بعمر 28 يوم. اما بالنسبة للتحمل الاقصى للعتبات فان العتبات الخرسانية المفحوصة تحت تأثر حملين مركزين متناظرين فان تحملها الاقصى يقل عند استخدام ركام الاتبولكايت بدل ركام كسر الطابق الطيني او الركام الاعيتادي الوزن بنسبة 4.85 % و 5 % على التوالي. في حين العتبات الخرسانية المفحوصة تحت تأثر حمل مركز في نقطة واحدة فان تحملها الاقصى يقل عند استخدام ركام الاتبولكايت بدل ركام كسر الطابق الطيني او الركام الاعيتادي الوزن بنسبة 10.3 % و 10.5 % على التوالي. كذلك اوضحت نتائج الاختبارت ان الخرسانة الخفيفة الوزن الحاوية على ركام الاتبولكايت او ركام كسر الطابوق الطيني اظهرت مرونة و متانة اقل من الخرسانة الاعتيادية الوزن.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة كربلاء
كلية الهندسة
قسم الهندسة المدنية

الأستدامة الأنشائية للأعتاب الخرسانية خفيفة الوزن

رسالة
مقدمة الى كلية الهندسة في جامعة كربلاء
كجزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية
(بنى تحتية)

من قبل

سجاد عبد الامير بدر

بكلوريوس هندسة مدنية 2015

اشراف

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