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Structural Sustainability of Light Weight Sandwich Concrete Slabs

A Thesis

Submitted to the Civil Engineering Department /College of Engineering Kerbala University/ In Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering-Infrastructure Engineering

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

هَلْ أَتَىٰ عَلَى الْإِنْسَانِ حِينٌ مِنَ الدَّهْرِ لَمْ يَكُنْ شَيْئًا مَذْكُورًا
(1) إِنَّا خَلَقْنَا الْإِنْسَانَ مِنْ نُطْفَةٍ أَمْشَاجٍ نَبْتَلِيهِ فَجَعَلْنَاهُ سَمِيعًا
بَصِيرًا (2) إِنَّا هَدَيْنَاهُ السَّبِيلَ إِمَّا شَاكِرًا وَإِمَّا كَفُورًا (3)

صدق الله العظيم

سورة الانسان(من الاية 1-3)

Dedication

To the hope of the world's savior

My Sir Imam al-hujjah Muhammad ibn Hasan al-Mahdi

(Peace be upon him)

Acknowledgments

In the name of ***ALLAH,*** *who gave me the strength, the health and the ability to complete this work. Praise be to* ***ALLAH*** *and pray and peace be on his* ***prophet Mohammed*** *his relatives and companions and on all those who follow him.*

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Last, special thanks and gratitude to every person who tries to do wonderful work with immaculate intentions.

Suad Abbas Ali
2018

Supervisor Certificate

I certify that this thesis entitled “**Structural Sustainability of Light Weight Sandwich Concrete Slabs**”, which is prepared by " Suad Abbas Ali", is under my supervision at University of Kerbala in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Infrastructure Engineering).

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We certify that we have read the thesis entitled "**Structural Sustainability of Light Weight Sandwich Concrete Slabs**" and as an examining committee, we examined the student "Suad Abbas Ali" in its content and in what is connected with it, and that in our opinion it is adequate as a thesis for degree of Master of Science in Civil Engineering (Infrastructure Engineering).

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ABSTRACT

Concrete sandwich structure is rather modern and inventive construction system based on the best use of materials. The simplest type of sandwich slabs consists of two concrete layers confine low weight material. The two concrete layers are connected by steel shear connector trusses. The shear connectors are essential functions to transmit the shear and to ensure that when the panel is bent, the faces do not slide over each other and to connect the concrete layers so that they behave as a single one unit.

The present study involves experimental investigation on the behavior of one-way simply supported sandwich slabs and solid slab. The effect of using sandwich principle was studied. The concrete wythes were normal weight aggregate concrete or lightweight concrete; Therefore, the main variable of this study was; aggregate type that used to produce concrete. The other studied variable was the optimum position of shear connectors via using different shear connectors steel ratio at the two ends a fourth of span as compared with the middle section of the span. On the other hand, in this study, the effect of the inclined bent angle of shear connector truss was investigated by using two different bent angles (27˚and 45˚) with different shear connectors steel ratios. Moreover, the effect of using discrete W-shaped shear connector, as compared with continuous truss shear connector by using the same shear connectors steel ratio was examined.

In the present work, two types of lightweight aggregate (waste crushed bricks and Attapulgite which is natural stones are broken and burned at a specified temperature) were used to produce structural lightweight

aggregate concrete. Cylinders and cubes, for each type of concrete, were tested to observe the mechanical properties of concrete.

The results indicate that the structural lightweight aggregate concrete (SLWAC) of Attapulgite (as a coarse aggregate), with using natural sand and high performance superplasticizers (PC-200), produces an average cylinder compressive strength of about 21 MPa and air dry density of 1940 kg/m^3, which agree with the requirements of SLWAC according to ACI 213R-03 and ASTM 330-05.

When Attapulgite is replaced with the waste crushed bricks, with the same mix proportion, the average cylinder compressive strength and air dry density are 25.2 MPa and 1954 kg/m^3, respectively.

All sandwich slabs behave as one structural unit. Also, all sandwich slabs exhibit more ductility and toughness than solid slab. Additionally, they have low total weight by about (**42.75%- 31.21%**) of the weight of solid slab.

In sandwich slabs, using crushed bricks as aggregate in slabs shows increment in the deflection, ductility, and toughness by about **62.96%, 8.62%, 54.04%** when is compared with slab with normal coarse aggregate accompany with decreeing total weight by **11.70%.** On the other hand, when using Attapulgite as course aggregate in slab, the increment in the max deflection value, ductility index (μΔ), toughness was **73.48%, 38.75%, 43.82%**, respectively. Additionally, gaining another benefit which is decreasing the total weight by **14.31 %**.

It is clear that the presence of shear connectors in the ends one-fourth (1/4) of span has significant performance than in the center of the panel, therefore.

Also, the results indicate that using a continuous truss shear connector with 27˚ is better than using discrete W-shaped shear connectors with 45˚.

List of Content

Notation

The major symbols used in this thesis are listed below, the others are defined as they first appear.

Symbols:

Symbol	Description
$f_{c}`$	Concrete compressive strength of cylinder (150×300) mm, (MPa)
f_{cu}	Concrete compressive strength of cube (100) mm, (MPa)
P_u	Ultimate strength (kN)
P_{cr}	First cracking load of slabs (kN)
Ø	Diameter of steel bar (mm)

Abbreviations:

Abbreviation	Description
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard (BSI: British Standard Institute)
CSS	Concrete Sandwich Slab
LWA	Lightweight Aggregate
LWC	Lightweight Concrete
NWA	Normal Weight Aggregate
NWC	Normal Weight Concrete
ODD	Oven Dry Density
SA	Concrete Mix with Attapulgite
SB	Concrete Mix with Crushed Bricks
SN	Concrete Mix with Normal Aggregate
SLWC	Structural Lightweight Concrete
SLWA	Structural Lightweight Aggregate
SLWC	Structural Lightweight Concrete
SSD	Saturated Surface dry Density
R.D	Relative Density

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Chapter One

Introduction

Introduction

1.1 General

The slabs represent one of the basic elements of the structural elements. Slabs have a smaller thickness as compared with other member and they bear loads normal to their planes.

In all types of infrastructure, reinforced concrete is a combination of concrete and steel that have been successfully used for more than a century. As a structural material, the main demerit of reinforced concrete is its great self-weight. Normal weight concrete density varies between 2200 and 2600 kg/m^3, therefore, self-weight of traditional concrete parts could represent the main fraction of the loads on the foundations. So, use of the lightweight concrete LWC has significant benefits such as reduced the dimensions of foundations sections.

Reducing concrete self-weight of the structure elements was the main important reason to use Light Weight Concrete(LWC). Therefore, LWC was used successfully for several years in a variety of installations.

In infrastructure engineering, the purpose of using or choosing any material is to take the advantage to obtain the optimum performance for the structural elements. The benefits of any material are based on many agents such as availability, structural strength, durability, and workability. Since it is difficult to get a material that possesses all these desired good properties, therefore, the engineer’s challenge consists of finding new materials and improving them and developing new methods of construction. Improving materials utilization can be divided into two trends, the first trend is to identify the best materials mixed and the second is the distribution of these materials in such a way that the best use of their desired properties resulting a new product known as a composite element. In other words, different materials can be arranged in the best geometrical configuration to produce optimal structural member. Then this structure is known as a composite structure and the method of the building known as a composite construction [1].

1.2 Structural Lightweight Concrete (SLWC)

Density and compressive strength are the two important factors affecting the properties of SLWC. SLWC is defined as the concrete that having an Oven-Dry Density (ODD) less than 2000 kg/m^3. ***(Li***) [2] defined SLWC as concrete which has a bulk density lower than 1950 kg/m^3 and a cylinder compressive strength *fc*` more than 17 MPa. Whereas, SLWC is defined by the **ACI 213R-03** [3] as a concrete owning a minimum 28 days compressive strength of 17 MPa and having density ranged between 1120 and 1920 kg/m^3. It is declared that this definition includes both the concrete composed entirely of LWA or combination of LWA and of Normal Weight Concrete (NWA).

According to compressive strength, ***(Nilson et al, 1986****)[4]* classified SLWC into three groups: -

1. Low Strength Concrete; Structural lightweight concrete having a compressive strength *fc*` ranged (17 – 27) MPa.

2. Medium Strength Concrete, Structural lightweight concrete with a compressive strength *fc*` ranged (27 – 41) MPa.
3. High Strength Concrete, Structural lightweight concrete that has a compressive strength *fc*` more than 41 MPa.

Whilst (**ACI213R-03**)[3] organized structural lightweight concrete as a high strength concrete when it has 40 MPa or more of compressive strength *fc*` at 28 days.

1.2.1 Advantages of Structural Lightweight Concrete

LWC represents an important and multi-purpose material, which offers a range of practical, economic, and develops the environmental and preserving many advantages. The main advantages of using structural lightweight concrete instead of normal weight concrete NWC in a similar form of a facility might be summarized as follows: -

- ***Lower Dead-Load [5] :***

1- Reduction in the area of the cross-section of elements such as; columns, beams, slab plates and foundations.

2- longer spans could be produced and decreasing the required supports number.

3- Materials handling is easier such as precast sections transference, etc.

- ***Enhanced Physical Properties***:

1- Including less micro cracks due to the congruence between cement mortar and aggregate particles in elastic modulus and in thermal expansion coefficient which are result in less heterogeneous concrete and more cohesive material.

2- Lowering thermal expansion coefficient that leads to less thermal movements.

3- Lower elastic modulus leads to decrease the differential settlements effects in the continues bridges.

4- Improving nailing characteristics more than ordinary normal weight concrete.

5- Improving thermal and acoustic insulations than ordinary concrete.

6- Owing to the higher capacity of tensile strain and lower elastic modulus. Thus, good impact resistance can be obtained [6].

- ***Improved Durability[5]:***

1-Likelihood of early thermal cracking and shrinkage is low.

2- Lowering permeability.

3- Good bond between aggregate and cement paste.

4- Because of the internal curing of LWA, the urgent need for external curing is lower.

5- better resistance to the free-thaw cycles of the LWAC.

6- Lowering coefficient of thermal conductivity that leads to reduce damages and construction dangers resulting from fires [6].

- ***Environmental Problems [5]:***

The benefits to the environment can be important when using manufacturing waste products to construction the LWAC. So no need to stock or disposed of large quantities of waste.

- ***Demolition[5]:***

Because it has a lower density, demolition a reinforced LWC is easier process by shattering the concrete. And the recycled material could be used to produce new concrete or as the filling material.

1.2.2 Disadvantages of Structural lightweight concrete.

There are some demerits of LWC as following :[6]

1. Lower strength and lower resistance to abrasion in most cases.
2. It's need more attention in the control of mixing, water cement ratio, and supervision to control the requirements of workability and strength.
3. Lightweight aggregate concrete might need more amount of cement based on the aggregate selected.
4. Due to higher hydration-heat, the temperature is rising.
5. LWAC has lower ductility due to the strength of cement paste is high.
6. Low resistance to concentrated loads which led to the need greater reinforcement for confining at bearings or anchorages of prestressing.
7. Cellular lightweight aggregates required specific procedures for the concrete pumpable.
8. LWAC needs longer time for mix process than NWC to produce adequate mixing
9. Sometimes, floating occurs in the concrete mix by aggregate separating to the surface because the LWA particles are angularity and voided structure.

1.2.3 Applications and Uses of SLWC

SLWC has become an important structural material and the demand for it is rising, because of the functional advantages which it owns. It has different applications including frames and floors building of multistory, folded plates, bridges, curtain walls, rigs of offshore oil, shell roofs and the precast or the prestressed of all kinds. Many engineers, architects realize the attached economies and advantage obtained by these materials, as can be seen by the appreciation SLWC structures established [3].

1.3 Concrete Sandwich Slab (CSS)

The principle of sandwich structures offers an effective structural system suitable for a set of applications, including floors and roof panels, bridge decks and cladding walls for buildings [7]. For more than 50 years ago, CSS first appearing in North America [8].

Concrete sandwich slab CSS is a somewhat modern and developed system of construction, it consists of two reinforced concrete wythes (layers) confine between them core layer, the concrete wythes are connecting by shear connectors [9-11] [as illustrated in Fig 1-1]. Generally, this type of units is considered as a composite structure.

The major benefit of this system is its high stiffness, high strength over weight ratio, useful insulations panels, high ductility, easier to handle, due to its light weight material**,** decrease material and labor cost [12]. Other significant merits of this CSS are the low self-weight and the high thermo-acoustic adequacy that favorite in their applications in residential, commercial and industrial buildings [13].

The essential role of the shear connectors is connecting the layers (three layers or more) together and also they play as shear reinforcement. Various types of the connector can be used to improve composite behavior, these shear connectors convey shear force across the weak, low density, insulation core layer. The resulted degree of composite action is influenced by number and properties of shear connectors, that leads to a wide range of tolerable behavior (from non-composite to fully composite) [14].

The structural behavior of CSS varies depending on the strength and stiffness of the shear connectors, while shear connector's arrangement and spacing differ according to the applied loads, wanted composite action degree, the length of span, and the materials of shear connectors[15]. Though, no specific rules, guidelines or design codes that can be used to determine the number or arrangements of the required connectors so it was needed to investigate their effect experimentally [16]. Reportedly, bonding layer between the insulation core and concrete wythes could provide shear transfer, but its capability is reduced over time and will not preserve the strength of the shear connector over the lifespan of the panel [10, 17].

However, the complicated behavior of CSS owing to its material non linearity. Therefore, the inexact design roles of the shear connector and the interaction between many components should be studied and proved by experimental and analytical investigations via finite element analysis (FEA) [18].

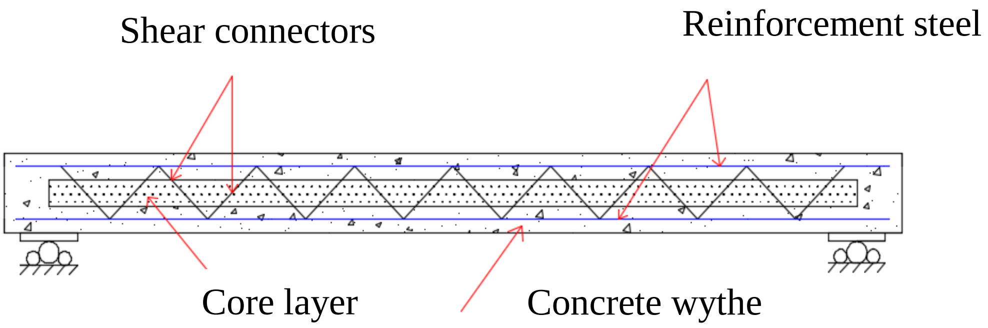


Figure (1- 1): Typical concrete sandwich panel

Current research investigates the behavior of sandwich slabs with lightweight concrete in the wythes with different type of lightweight coarse aggregate. The aim of this work is to achieve structural lightweight construction with high stiffness and high strength over weight ratio and reduce the total weight to the minimum extent. Reducing the total weight of the structures minimizes the risks of earthquake damages, also reduce the load applied on the foundation of the structure, so the dimensions of the foundation will reduce. In addition to these advantages, its increases thermal and acoustic insulation.

1.4 Objectives and Scope of Study

The main objects of the present work are: -

- Investigating experimentally the effect of using Attapulgite and crushed bricks as a coarse aggregate to produce SLWC.
- Studying, experimentally the behavior of concrete sandwich slabs (CSS), with two LWC wythes and polystyrene core, subjected to two lines loading.
- Investigating the effect of location, orientation and ratio of shear connectors in the CSS.

1.5 Layout of Thesis

The present study consists of five chapters, as the following:

Chapter one: presents a general introduction regarding the use of lightweight concrete LWC, its advantages and disadvantages, sandwich concrete slabs and objective and scope of study

Chapter two: reviews of previous literature related to the topics of current research, including Light Weight Aggregate Concrete (LWAC), its physical and mechanical properties, and the previous researches on the concrete sandwich panels and CSS components.

Chapter three: deals with reporting the experimental program carried out at the Structural Laboratory of the Civil Engineering Department of Kerbala University. It includes the producing Lightweight Aggregate from Attapulgite or crushed bricks to produce lightweight concrete**,** also it includes sandwich specimens' details, the properties of materials, casting procedures, and test setup. Additionally, exhibition the equipment's were used during the experiments.

Chapter four: deals with the results of the experimental tests, the graphical representation of the results and results' discussion. the results for hardened concrete obtained from the tests were presented in chapter four.

Chapter Five: presents the conclusions and suggestions for further studies in future.

Chapter Two

Literature Review

Literature Review

2.1 General

Previous work of literature has been reviewed to gain more knowledge about the structure lightweight aggregate concrete being used in sandwich slabs. Where both lightweight aggregate concrete and sandwich technique are not a new invention in concrete technology, but studying their combined effect was limited.

This chapter includes three brief reviews: The first one is about structural LWAC, its definitions, types of lightweight aggregates, and a review of the previous studies on mechanical properties of lightweight aggregates and its use in Iraq. The second part presents the details of Concrete Sandwich Slabs (CSS), its components, definitions of each part. The third part deals with the previous studies on using crushed clay bricks and Attapulgite as a lightweight coarse aggregate, as well as, a summary about literature reviews on reinforced concrete sandwich slabs.

2.2 Lightweight Aggregate

2.2.1 Types of Lightweight Aggregate

High porosity is the main property of lightweight aggregate, which results in low specific gravity. There are two types of LWA:

- **The natural aggregates**

These types aggregates are found naturally in many regions in the world and these aggregates need only a mechanical treatment (crushing and sieving) before using. When comparing their properties to artificial lightweight aggregate, they are generally not satisfactory [19]. Diatomite, pumice, scoria, volcanic, cinders and tuff are the main aggregates classified in this category [19].

- **Manufactured aggregates**

There are different types of artificial LWA which vary in their raw material, chemical and mineral composition, specific gravity, water absorption, strength, physical and chemical stability and the process of manufacturing. Despite these differences, their properties can be predicted with simple formulas, which in general depend on the particle density[19].

2.2.2 Definition of Lightweight Aggregate Concrete

Lightweight aggregate concrete LWAC is defined based on its density[20]. ACI 213R-03 describes this material as, structural concrete made with lightweight aggregate; at 28 days, the air dried unit weight is generally in the range of 1440 to 1850 kg/m^3 and the lower compressive strength is 17.2 MPa. The unified European standard defines structural lightweight concrete as concrete having an oven-dry density ODD not more than 2000 kg/m^3 [19, 20]. LWAC is defined in several codes as a concrete having an oven-dry density ODD of less than 2000 kg/m^3. Classification of lightweight concrete is illustrated in Table (2-1), while Table (2-2) shows density classes for lightweight aggregate concrete.

Table (2-1): Classification of lightweight concretes[20].

Property	Class and Type		
	I	II	III
	Structural	Structural/ Insulating	Insulatin g
Compressive strength fc\` (MPa)	> 15.0	> 3.5	> 0.5
Coefficient of thermal conductivity (W/mK)	-	< 0.75	< 0.30
Approximate density range (kg/m^3)	1600-2000	< 1600	< 1450

Table (2-2): Density classes for lightweight aggregate concrete[20].

Density Class	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**
Oven dry density (kg/m^3)	**901-1000**	**1001-1200**	**1201-1400**	**1401-1600**	**1601-1800**	**1801-2000**

2.2.3 Properties of Lightweight Aggregate

There is a wide range of different lightweight aggregate LWA, which vary in the raw material, density, shape, outer skin and water absorption and the procedure of manufacturing. Despite this fact, the properties can be expected with simple formulas, which in general depend on the particle density [21].The ASTMC330-03 specified the required properties of LWA for structural concrete[22]. The aggregates properties affect the concrete properties as follows:

2.2.3.1 Surface Texture and Particle Shape

Natural and artificial LWA particles vary in shape and surface texture. The LWA particles might have a different shape such: cubical, rounded, or irregular, reasonable regular or angular, while texture could differ from relatively soft that having small pores to rough which have large pores [23]. The surface roughness of the aggregate particles provides high bonding between the component of concrete [24]. The compressive strength of LWAC varies depending on the particles shape of LWA. When the length/thickness ratio for the particles increases the compressive strength of LWAC decreases. The shape of lightweight aggregate influence the stress condensation in concrete and this may be the reason of variation in compressive strength value between the concrete prepared with different aggregate particles shapes[25].

Swamy and Lambert [26] observed a good bond between the LWA and the cement paste when using particles with a spherical shape and soft surface. For the same workability, the mortar content of the concrete can be lower than with angular, flat or elongated aggregate particles shapes. When using crushed angular LWA, with coarse open surface pores, the interlocking of the sharp - edged particles restrain the compaction of the concrete. In this case, a very high mortar content is required because a portion of the mortar permeate into the open surface pores.

2.2.3.2 S*trength*

Some of LWA particles could be weak or could be hard and strong according to the type and the source of LWA particles. The weaker of LWA particles required greater contents of cement and even stronger mortars[27]. The crack path moves through the aggregate particles in the

LWAC, while in the normal concrete failure may occur at the aggregate-mortar interface because the aggregate is considerably stronger than the mortar [28].

Because of lower strength of LWA particles, LWAC has less capacity of local bearing and lower energy to fracture and tensile strength at the same compressive strength [3].

2.2.3.3 Unit Weight and Bulk Relative Density.

Relative Density (R.D) of LWA is lower than normal weight aggregates owing to their cellular structure The bulk R.D of LWA also varies with specific gravity for the same particle shape and with particle size, being fine particles is higher than the coarse particles. Due to a different percentage of voids, LWA of different particle shape that having the same specific gravity could have clearly different unit weight [29]. For a variety of fractions size, the bulk specific gravity of lightweight aggregate usually increases since particle size decreases [6].

2.2.3.4 Gradation.

For larger particle sizes of LWA, the modulus of elasticity, strength, and density is decreased. In LWC, the usage of bigger lightweight aggregate particles will cause weakness in the concrete because aggregate have lower strength and because of weakness in the matrix network covering the aggregate particles. For the same W/C ratio, the upper limit of strength can also be increased when the maximum particle size was smaller, limiting it to 9.5 mm for high-strength concrete [6].

2.2.3.5 Moisture Content and Absorption.

Based on the absorption test of ASTM C 127 [30] and due to the pore system of aggregate, LWA is able to absorb water more than normal weight aggregates. Depending on the pore system of the aggregate, LWAs generally absorb water by mass within the range of (0.05 - 0.25) of mass dry aggregate based on 24hr absorption test [3]. In lightweight aggregates, the moisture content is largely absorbed into the interior of the particles while it is mostly surface moisture in normal weight aggregates. During the mixing of concrete, it is essential to avoid absorption water by LWA particles, therefore LWA submerges in water for 24hr before using it.

2.3 Concrete Sandwich Panels Components

Concrete Sandwich slabs patterns are comprised of two reinforced concrete layers splitting up by a core layer of lightweight insulating material. The concrete layers are usually held together by using steel connectors, concrete webs, steel glass fiber reinforced polymer (SGFRP), or Fiber Reinforced Polymer (FRP) connectors [31].

Concrete sandwich panel system has been commonly used for building wrappers of some conventional structures owing to its efficiency in thermal and sound insulation, such as residential, commercial, and warehouse infra-structures[32]. The outer wythe carries the loads and transfers it to inner one through the shear connectors.

Concrete sandwich panel systems are organized as fully composite, partially composite or non-composite panels based on the degree of composite action of the inner and outer concrete wythes[10]. Fully-composite panels provide maximum shear transformation between the concrete layers and both layers work together as one unit to support the applied load. This behavior becomes clearer by observation the strain distribution along the depth of panel thickness of full-composite slab as shown in Figure (2-1) (a). While in the non-composite sandwich panel, shear connectors don’t convey any shear force between the two concrete layers, and it is stressed individually. The outer concrete layer’s weight is entirely supported by the inner concrete layer; therefore, the inner layer is larger thickness than the outer. The distribution of strain, that represents non-composite slabs, is presented in Figure (2-1) (c). CSS was considered partially composite panels if the connectors can transfer only a portion of the longitudinal shear. The bending strain distribution in such a case is shown Figure (2-1) (b).

Adhesion between the concrete layer and the insulation core layer as well as the material and shape of the used shear in the system impacts on the degree of composite action. A continuous steel truss-shaped shear connector transferred the full shear forces most effectively and achieved high composite action [10].

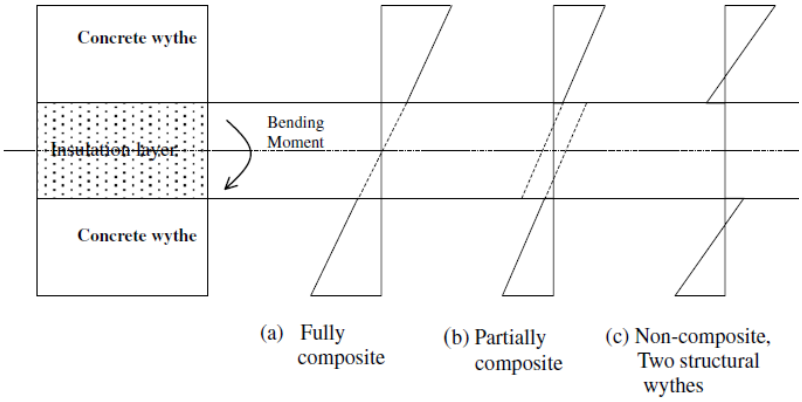


Figure (2-1): Strain Distribution in CSS Under Flexure [33]

2.3.1 Wythes and Flexural Reinforcement

Wythe can be made of a thin concrete layer with an architectural treatment. The outer wythe helps in protection the insulation core layer from damaging. In some cases, might be designed to work with the inner layer as one unit, this depending on the shear connection system (PCI 1997). The inner wythe is generally named the structural layer.

Often, the inner layer has more thickness than the outer layer, particularly in non-composite panels because the inner layer will support the entire loads. In spite of two concrete layers, slabs are very popular, three layers slabs also can be used [34]. Popular reinforcement of concrete layers is steel welded wire. Except the slab supports large degrees of eccentric axial load.

2.3.2 Core Layer

The Basic principle of the sandwich structure is a separating concrete layers by a low density core. This separating leads to increase the moment of inertia of the element with little increase in weight[35]. Polystyrene has been utilized as an insulating material due to its role in thermal insulation. Polystyrene foam is regularly used in insulation lightweight concrete forms. There are two types of Polystyrene: Expanded polystyrene foam (EPS) and Extruded polystyrene foam (XPS)[36]. The Expanded Polystyrene foam is a lightweight, small closed-cell, hydrophobic, and thermoplastic polymer[37]. Biologically, it is inert and nontoxic.

Scheirs and **Priddy** (2003) stated that the usage of expanded polystyrene (EPS) vary between acoustic and thermal insulation as well as in renovation work. Also, the isolated structural members are varying, they may be walls, slabs, floors as well as ceilings.

Also in the slabs, **Dawood (2011)** [12] used a different types of core material. He used lightweight concrete with different coarse aggregates (polystyrene, sawdust, poricelinite)

2.3.3 Shear Connectors

Composite construction involves two or more materials joined together in one structural unit, so that it can exploit their best advantage. Concrete sandwich panels can be considered as a composite element and the method of connecting the two components is an essential parameter to establish the required composite behavior. The economic and structural benefit is generally achieved when the two materials (lightweight concrete and core material) work as full composite action. The main element influencing the level of composite action is shear connectors [12].

Theoretically, full composite action can be only achieved if there is no slip at the interface of the core and concrete layers. In practice, the shear force is mainly transferred by mechanical shear connectors, owing to its deformable nature, some slips usually occur. The amount of this slip is clearly related to the magnitude of the shear forces and the strength and load-deformation characteristics of the shear connectors. Typical types of shear connectors may be classified as either rigid or flexible. Rigid connectors deform very little under load, while flexible connectors may exhibit significant deformation [12].

2.7 Application Lightweight Aggregate Concrete in Iraq

The lightweight concrete in Iraq has not been used extensively in the structural members, such as foundations, columns, slabs, beams, etc. because the LWA is imported. For example, In the Martyr monument dome in Baghdad the expanded clay type of LWA was used, and in the telephone exchanges flooring. In 1980, Polystyrene was used in product LWAC that was used in Baghdad University building which is yet in good working condition [38].

In 1977, Munir was tried to build a research center in the central and southern parts of Iraq to manufacture clay aggregates. In a factory of clay-bricks, the experiments were occurred. However this stilled within research context [39].

Quite recently, many researchers have used some different materials to produce lightweight concrete; such as polystyrene, crushed-thermos tone, waste of plastic materials. Specific stone from Najaf desert has also been utilized.

2.8 Previous Studies on Using Attapulgite

Since the past few decades there has been increasing interest in the alternative materials which can be used as an alternative for traditional materials. Consequently, research on feasibility of using Attapulgite in concrete is advantageous, and if it is compatible with the valid engineering properties as the LWAs in concrete which in continuous rising desire, primarily because of economic and practical considerations.

AL-Amedi 2012 [40] investigate Attapulgite as a local clay mineral .In Iraq , The idea of research was raised by the production of the mineral admixture from the raw materials that collected from Tar Al-Najaf Desert .Attapulgite lump was crushed by the means of storming and converted to a powder with high fineness. Then the second step was determination of burning temperature at which the material converts to an active pozzolanic material. The suitable temperature required for treating Attapulgite by heat was 750˚C for calcination time 30 minutes'. The optimuum percent of replacement from the weight of cement was very important for the investigation greatly when used high reactive water reducer, thus Attapulgite added in percentages of (3% to 11%) to a mix with proportion of (1:1.45:1.75) by weight, and the results indicated that (6%) of adding by weight of cement was the preferred as it was achieved the higher strength of 79.7 MPa. At 60 days, the absorption of water decreased with 36%, and the results for the main mixes of the study showed significant increasing for compressive strength, density, splitting tensile strength and flexural strength, the increasing percentages were (57.7%, 3.73%, 46.44%, 44.26%) respectively. At the age of 90 days the results exhibited an increase of 59 % in compressive strength.

After two years, **(Kais et al 2014) [41]** study the possibility of using the Attapulgite clay as a pozzolan to improve some properties of concrete, many experimental work required to be made to find the more suitable conditions of temperature and time of calcinations. To investigate the influence of burring temperature, different samples of Attapulgite were prepared.

The Attapulgite lump was floured to fineness 2109 m^2/kg, the next step was burned the samples to (550, 600 650, 700, 750, 775 and 800) ˚C for 30 minutes, respectively. The strength activity index was conducted on the cubic specimens with dimensions (50 * 50 * 50) mm. The results showed that the optimum burning temperature was 750 ˚C. Then the Attapulgite samples were prepared at different burning time, (30, 60, 90,

120) minutes, respectively and the temperature was 750 ˚C, then conduct the strength activity index. The results showed that the optimum burning time was 30 minutes.

In the same year **Al-Aridhee 2014 [42]** investigated the adequacy of using a Attapulgite , from the south-west of Iraq , as a coarse aggregate in production LWAC. The study was divided into two parts, part one describes manufacturing of the lightweight coarse aggregate (LWA) and discovered the adequate burning temperature, convenient with the ASTM C330-03, while producing lightweight coarse aggregate concrete (LWAC) from the manufactured aggregate was researched in the second part. The results showed that the Attapulgite can be used as lightweight coarse aggregate with (808 km/m^3) bulk density and (1.45) specific gravity, at a treatment burning temperature of (1100 C) for a duration of (1/2 hour). The mechanical properties of (LWAC) which produced from Attapulgite (LWA) was investigated for some of its at curing ages of (7, 28 and 56) days, those mechanical properties were compressive strength, flexural strength, splitting strength, water absorption, the static modulus of elasticity, and some non-destructive tests.

The compressive strength was (27.7 MPa) for a density of 1824 kg/m^3 with W/C ratio of (0.4). Percentage of increase in splitting strength, flexure strength and modulus of elasticity (41%,28.3%,81%), respectively. These results were compatible within the requirements of **ACI 213R -03.**

(Qais et al., 2016)[43] studied the integrated influence of utilizing both Attapulgite as a high-reactive mineral admixture and superplasticizer on the compressive strength of Attapulgite lightweight aggregate concrete. Attapulgite particles had maximum size of 19 mm was used as a lightweight coarse aggregate. The percentages of addition were 6% by weight of cement for Attapulgite mineral admixture and 0.5 L/100 kg cement for the superplasticizer. The obtained percentages of increase in compressive strength were (12.2%,12.6% and 16.3%) for ages of 7, 28 and 56; respectively, when compared with the referenced mixture when only the Attapulgite mineral admixture be used, but when compared to the referenced mix, the combined impact of both admixtures was obvious by the percentages of (19.3%, 15.5% and 25%) for ages 7, 28 and 56 days; respectively. For a concrete mixture containing the two admixtures, the density achieved for Attapulgite LWAC was 1818 kg/m^3. The using of Attapulgite mineral admixture in the Attapulgite LWAC caused reduce in absorption by (4%, 4.85% and 4.9%) at 7, 28 and 56 days' ages; respectively, while the water absorption was increased by the addition of superplasticizer and the percentages of absorption above became (2%, 3% and 2.6%) at the curing ages of 7, 28 and 56 days.

2.9 Previous Studies on Using Clay Bricks in Production SLWAC

The environmental problem of the aggregate as construction material can be summarized in two problems, excessive consumption of natural resources and inactive construction's waste management. Therefore, researchers have resorted to studying the possibility of using crushed brick as a coarse aggregate in producing desirable concrete.

Fakher, 1998[44] conducted a study on the concrete mixtures when using crushed clay bricks as coarse aggregate. He showed that the compressive strength and tensile strength will decrease in the concrete which containing crushed bricks in comparing with conventional concrete. Also, he investigated the properties of crushed bricks such as: absorption, relative density, specific gravity. oven dry density, bulk density as well as compacted unit weight, the results were (29.33%, 1.47, 1.91 ,735 kg/m³, and 834 kg/m³) respectively.

After two years, crushed clay bricks was organized for being between LWA and the NWA. etc. Several other properties, like: absorption and porosity, would be classified as LWA.

Majid [45] studied the efficiency of using crushed brick, waste concrete, and crushed cast stone for full replacement of traditional coarse aggregate. She investigated the influence of utilizing superplasticizer on the properties of concrete that containing these types of aggregate. She indicated that concrete including crushed brick as aggregate exhibits low density, compressive strength, splitting tensile strength, flexural strengths and dynamic modulus of elasticity. However, these properties were enhanced by using the super plasticizer at early ages Moreover the absorption capacity was lowered due to the ability of this concrete for exhibit higher shrinkage, absorption, initial surface absorption more than the concrete that made with normal aggregate. The physical and mechanical properties of the crushed brick aggregate like bulk oven dry density, bulk saturated surface dry (S.S.D) density, absorption, loose density, compacted unit weight, and crushing value were studied. The results of these properties were (1.63, 2.036, 2.750, 25%, 735 kg/m³, 834 kg/m³, 42.2%, 44.2); respectively.

In 2002, AL-Soadi [46] examined the mechanical and physical properties of lightweight concrete when using clay- bricks as a coarse aggregate with the percentage of replacement varied between (0-100%) instead of normal aggregate to show the influence of increase or decrease the percentage of crushed bricks aggregate in the concrete. The researcher observed that, the using of crushed brick aggregate in producing concrete reduces the density more than using the normal aggregate, where the air dry density varies between (1845 - 2408) kg/m^3 at 28- day. On the other hand, the compressive strength ranged from 24.15 MPa to 52.43 MPa. Also, the researcher studied the physical and chemical properties of crushed brick aggregate like bulk density (in saturated and dry conditions), water absorption, apparent specific gravity, and sulfate content.

AL-Rubayie, 2007[47] studied the using of local aggregate. (ordinary aggregate, crushed clay bricks and porcelinite aggregate) to produce good lightweight concrete. The dry densities of crushed bricks concrete were varied between 1160 to 2110 kg/m^3 whilst the compressive strength results were ranged between 22.5 and 39.5 MPa. The results of splitting tensile strength were varied between 1.655 to 4.806 MPa. The modulus of rupture fluctuated between 3.748 to7.276 MPa. The absorption was ranged between 7.73 to 13.25 % based on cement content in the mix, superplasticizer addition, and replacing ratio of the fine aggregate.

According to the results of this study, at age 28-days, the porcelnite dry-density concrete was in range 1520 to 2018 kg/m^3, whereas the compressive strength was ranged from 9.0 to 37.0 MPa for the same concrete. The splitting tensile strength was varied between 1.375 MPa and4.299 MPa. The absorption of water was between 4.71and10.85 % based on the properties of concrete mixture.

Abdeen and Hodhod, 2010 [48] examined the production of LWC from local LWA. Vermiculite, light exfoliated clay aggregate and crushed fired bricks were used in their study. The first two types are formed locally for different applications purposes and the last type is available as by-product of bricks industry. Nine concrete mixtures were cast in the same proportions but using different aggregate types. The research proved the possibility of production structural LWC with unit weight less by about 45% than that in NWC with decreasing by about 50% in the compressive strength.

Al-Baghdadi, 2011[49] produced high-strength of LWC by use crashed bricks as a lightweight coarse aggregate, in addition to superplasticizer and mineral admixture. Seven mixtures of concrete have been made. The cement content or cement with mineral admixtures for the used mix varied between 300-600 kg/m^3. Many test cubes, cylinders and prisms were cast to determine the concrete mechanical properties. the researcher proved that high strength concrete with a density lower than 2000 kg/m3 could be produced by a waste of local bricks as coarse LWA in addition to use minerals admixtures (Hydrated Lime) and super plasticizers. According to this work, the cube compressive strength was varied between (27.2 to 49.6) MPa at 28-days and oven dry density ODD fluctuate between (1900 to 1960) kg/m^3; the splitting strength and flexural tensile strength and the modulus of elasticity results varied between (3.1 to 4.0) MPa and (4.5 to 7.1) MPa (22.8-26.0) MPa; respectively.

Al-Mamoori (2015) [6] studied experimentally and numerically the behavior of two way square simply supported slabs with using crushed bricks as a lightweight aggregate. She cast and test eighteen two-way reinforced concrete square slab models. The main variables in that study were: type of concrete, type of reinforcement with different reinforcement ratios and arrangements. From the results of study, it is concluded that the SLWC with an average cylinder compressive strength of about 37 MPa and average air dry density of 1896 kg/m^3 can be produced by using crushed clay bricks with the use of natural sand, high performance superplasticizers and micro silica fume.

2.10 Previous Studies on the Sandwich Concrete Panels

Kabir (2005)[50] studied the structural behavior of three dimensions Sandwich panels under static shear and bending loads. the experimental results are illustrated in Table (2-4)

Table (2-3): Experimental Results for Tested Slabs.

Specimen	Thickness (cm)	Cement Content(kg/m^3)	Pu (kg)	Max Deflection (mm)
Slab-1	16	300	2200	80
Slab-2	16	300	1900	40
Slab-3	16	300	1800	80

The numerical model was loaded in increments to emulate the experimental tests and to permit discovery of failure in flexural tests for vertical and horizontal bearing panels and also for direct shear. The load-displacement results of finite element analysis were similar to those of experimentally tested specimens. Maximum loads tests were equal to the experimental ultimate loads. At the load stage of 700 kg, the failure was started by tension failure in the lower concrete wythe. Then, at the level of

1200 kg load, the cracks propagate to the upper layers. The bottom steel mesh is yielded and the concrete is crushing, causes the instability of the system. The maximum load was 2200 kg. The founded conclusions were: The load-deflection behavior indicate that these panels transmit the load as partially composite panels under service loads. Additionally, in a linear elastic zone, the stresses and strength of each panel can be calculated by linear elastic structural analysis and the ACI code could be used.

Benayoune et. al. (2008) [10] investigated the flexural behavior of pre-cast concrete sandwich composite panel experimentally and theoretically. Six slabs have been tested under flexure load. The loads have been increased in steps till slab models reached failure. The tested six slabs included two slabs with dimensions (2000* 750) mm, two slabs with dimensions (1500 *1500) mm, while the other two slabs with dimensions (1000*500) mm, these dimensions were selected according to the behavior of solid panels. the two slabs (2000*750) mm with aspect ratio 2.67 represent one-way action panels, while the other two slabs (1500*1500) mm having aspect ratio 1 have been considered as two-way action slabs. The last group was the slabs with dimensions (1000*500) mm having aspect ratio 2 were represent the critical case that separate one-way action slabs and two-way action slabs. Concrete sandwich panel was consisting of two reinforced concrete wythes with 40 mm thickness, and one polystyrene layer in the middle with 40 mm thickness.

A square welded steel BRC mesh of 6 mm bar diameter with 100 * 100 mm openings was used as the longitudinal and transverse reinforcement for the two concrete wythes, while continuous truss-shaped connectors, with 250 mm spacing, were used to tie the inner and the outer concrete wythes so that the panels act as a composite structural unit, as shown Figure (2-1). The shear connectors were manufactured of steel bars with 6 mm diameter. It was bowed to zigzag- shape, the height for all bent was 90 mm. The shear connectors and wire mesh were connected to form continuous truss shape shear connector.

For all tested slabs, the first crack appears at the load about of (55 to 60 %) of the ultimate load. The finite element results were compared with the experimental tests results. The load capacity improves with increasing in the number of shear connectors, the ultimate load was :20 kN, 25.16 kN, 29.75 kN for shear connector numbers 2, 3 and 4; respectively. The results indicated that failure mode and pattern of cracks for sandwich panels are similar to the failure mode and pattern of cracks for solid panels particularly when the sandwich panel having a high degree of composite action. The finite element analysis of the sandwich panels resulted in good approximation of the experimental load -deflection relationship.

Dawood, 2011 [12] studied experimentally concrete sandwich panel units (wall and slab), the test was conducted on ten slab panels and ten walls models. The main variables of the study were: inner layer thickness, the strength of the concrete layer, and the type of lightweight aggregate utilized in the inner concrete layer. The slabs have been tested as simply support panel under two lines loads. Dimensions of slabs were (1200 mm * 400 mm) and the total thickness was variable between (40/50/60) mm depending on the inner lightweight layer thickness. The second variable was compressive strength for traditional concrete in the outer wythe, f_{cu}

was variable between (28/39.3/49.7). Three types of lightweight aggregate which used in the inner concrete layer: polystyrene, sawdust, porecilenite. The results showed that the reference slabs load capacity increased when the thickness was increased. More precisely when the thickness of the inner concrete layer for sandwich slabs was increased. The ultimate strength was decreased when the concrete strength of the outer concrete layers increases for sandwich slabs. When using sawdust as aggregate in the inner concrete layer, the strength of the sandwich slab was greater than the strength of sandwich slab with polystyrene or porcilenite which used as aggregate in the inner concrete layer. The maximum deflection and maximum slip for sandwich slabs relay on the thickness of the inner layer, the ultimate strength of the outer layers and the type of lightweight aggregate which used in the inner concrete layer.

Mohamad et al., 2016 [51] studied the structural behavior of recycled aggregate in concrete sandwich slabs tested under flexural load. Different recycle aggregate percentages were used as coarse aggregate in the concrete. The percentages of replacement were; exactly :25% / 50% / 75% and 100%. The structural performance of the sandwich slabs was studied experimentally and analyzed in the context of its ultimate strength, crack pattern, load-deflection curves and load-slip curves. The results indicated that the percentage of recycle aggregate used has a minor effect on the mechanical properties of recycle aggregate concrete but quite a major effect on the structural behavior of sandwich slabs under flexure. The first crack progresses approximately at 48 – 67 % of the failure load followed by panels failed with excessive cracks in the concrete bottom wythe. Also, it was observed that the flexural strength of the slabs with recycling aggregate concrete decreased with the percentage of recycle aggregate increase in the concrete. The percentage of reduction in the ultimate load of slab panels with recycle aggregate was about 15% for every 25% increase of recycle aggregate. All tested slab models showed large deformation prior to failure and exhibited partially composite behave.

Huanzhi et al., 2017 [32] investigated experimentally and theoretically the composite response of four precast concrete sandwich slabs with different numbers of W-shaped steel glass fiber reinforced polymer shear connectors and with various distribution shear connectors. The first slab had four W-shear connector rows in both ends a third, and four W-shear connector rows in the center of span panel. The second slab had the same amount of shear connector in the ends but in the center, it had the half amount of shear connectors as compared with the first slab. While the third slab had three W-shear connector rows in both ends and two W-shear connector rows in the middle of the span. Finally, the last slab had two W-shear connector rows in both ends a third and the same amount in the middle of the span.

This distribution was carried out to assess the effect of a number of W-shear connectors in both ends a third of span and in the middle of the span on the behavior and composite degree of the sandwich. The shear connector was manufactured of plane steel glass fiber reinforced polymer with10mm total diameter.

The experimental work results indicated that the number of W-shaped steel glass fiber reinforced polymer connectors in the slab ends has more effect rather than in the middle of span on the behavior on a sandwich slab. Increasing W-shaped shear connector would enhance the load capacity. Panels could show high composite degree when the W-shaped could transfer large amount of shear force from the upper layer to the lower concrete. The composite action of the tested panels which gained clearly different relay on the number of shear connectors in the ends a third of panel.

Joseph et al., 2017 [52] carried out a research on the behavior of precast concrete sandwich slabs subjected to four-point bending with varying the thickness of slab , mesh size, with or without either shear resistant ribs or traditional steel rebar’s (in addition to the wire mesh) in the lower concrete layer. Panel dimensions were (3000 * 1220 *100 or 150) mm (Length * Width * Thickness), Cube compressive strength of self- compacting concrete that used to cast the concrete layers was 45.9 MPa and flexural tensile was 4.3 MPa. The thickness of each layer was 25 mm. The results of the tests show that all slabs act as composite panel till failure occurred, and the behavior of sandwich panels is similar to solid reinforced concrete one way panels. Cracking behavior in terms of number of cracks and crack spacing of concrete sandwich panels is similar to that of Ferro cement cracking behavior owing to the presence of wire mesh. Presence or absence of shear-resistant ribs and/or rebars in the bottom layers has a significant influence on the flexural behavior of the panels.

The use of conventional rebar’s in a bottom layer besides the wire mesh increases the ultimate strength of the slabs. The truss shaped shear connectors, which made of wires used in the experimental study, are stabile to achieve composite action of the slabs.

2.11 Summary

From the previous researches, it is clear that studies on sandwich slabs are still limited. Most of concrete wythes in the sandwich panels were made of conventional concrete. So these sandwich panels are strong but they have lower strength over weight ratio. Therefore, further investigation on using both lightweight concrete in the wythes and polystyrene core layer was required. Investigate the best position and the angle of bent of shear connecter was very needed when using different types of lightweight coarse aggregate.

Chapter Three

Material Properties and Experimental Work

Material Properties and Experimental Work

3.1 Introduction

The main purpose of the experimental study is to investigate the the performance that could be achieved by using different lightweight coarse aggregate in the concrete sandwich panels subjected to a flexural load, and also to study the effect of shear connector distribution.

The main objective of this chapter is to present the properties of materials (cement, fine aggregate, normal weight and lightweight coarse aggregate, and steel reinforcements). This chapter contains a series of standard tests according to the Iraqi standards (IQS) and American standards for materials testing (ASTM).

Also, this chapter contains the description of mix-procedures that used to produce lightweight aggregate concrete LWC and normal weight concrete NWC mixes. Then, the slump test for LWC and NWC mixes during its fresh condition are explained. Also, the trial mixes, the best mixture design, slab specimens' preparation, casting and curing are described. At age of 28 days, in the hardened state, several testing procedures for some mechanical properties of concrete are presented according to the specifications which are related to density, compressive strength, and splitting tensile strength.

Also, details of the specimen panels, reinforcement steel, and layout of shear connectors are clarified. Finally, test specimens, the instrumentation, and testing setup are illustrated. All of these tests are carried out in the Structure Laboratory of the Engineering college of Karbala University. The tests of materials are conducted in materials Laboratory of the Engineering College at Babylon University.

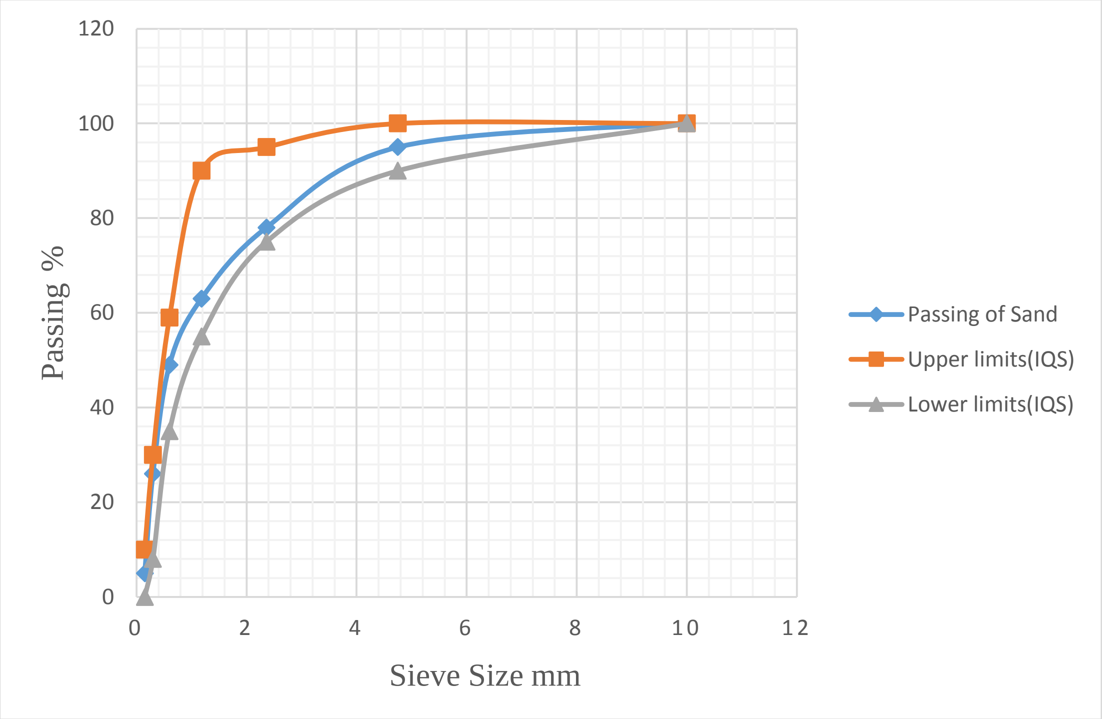
3.2 Material Properties

3.2.1 Cement

Portland cement resistant to sulfate (Type V- commercial name Aljisir) manufactured by Kerbala Cement Factory according to ASTM C150 [53], was used in this study. It was stored in air-tight plastic containers to avoid exposure to humidity The chemical and physical properties of cement are listed in the Tables (A-1) and(A-2); respectively, in **Appendix-A**. The results indicate that the used cement conforms to the Iraqi Specification No. 5/1984 [54].

3.2.2 Fine Aggregate (Sand)

In this work, natural sand brought from Al-Akhaider region was used. The results of testing show that the grading, clay content, and sulfate content are agreed to the required limits of the Iraqi Specification No.45/1984[55]. The sieve analysis of natural fine aggregate is illustrated in Figure (3-1). Table (3-1) presents the physical and chemical properties of the used fine aggregate.



Figure(3 - 1): Grading of Fine Aggregate

Table (3-1): Physical and Chemical Properties of Fine Aggregate

No.	Physical Properties	Test Results	Limits of Iraqi Specification No.45/1984
1	Specific Gravity	2.61	-
2	Sulfate Content SO_3 %	0.422 %	≤ 0.5%
3	Absorption %	0.88 %	-
4	Clay Content %	0.82 %	≤ 1.0
5	Fineness Modulus	2.73	-
6	Dry-Loose Density Kg/m	1574	-
7	Material finer than 75 µm (Sieve No. 200) (%weight)	4.0%	≤ 5.0%

3.2.3 Coarse Aggregate (Gravel)

Three types of coarse aggregate were used in this work.

3.2.3.1 Normal Weight Coarse Aggregate

Crushed gravel brought from Al-Akhaidher region was used. First of all, the coarse aggregate was washed, and then stored in a saturated surface dry condition. Maximum size was 10 mm. The grading of the coarse aggregate is shown in Figure (3-2). The results indicate that the coarse aggregate grading is within the requirements of Iraqi Specification No. 45/1984 [55]. The specific gravity, sulfate content, clay content and absorption of these coarse aggregate are illustrated in Tables (3-2).

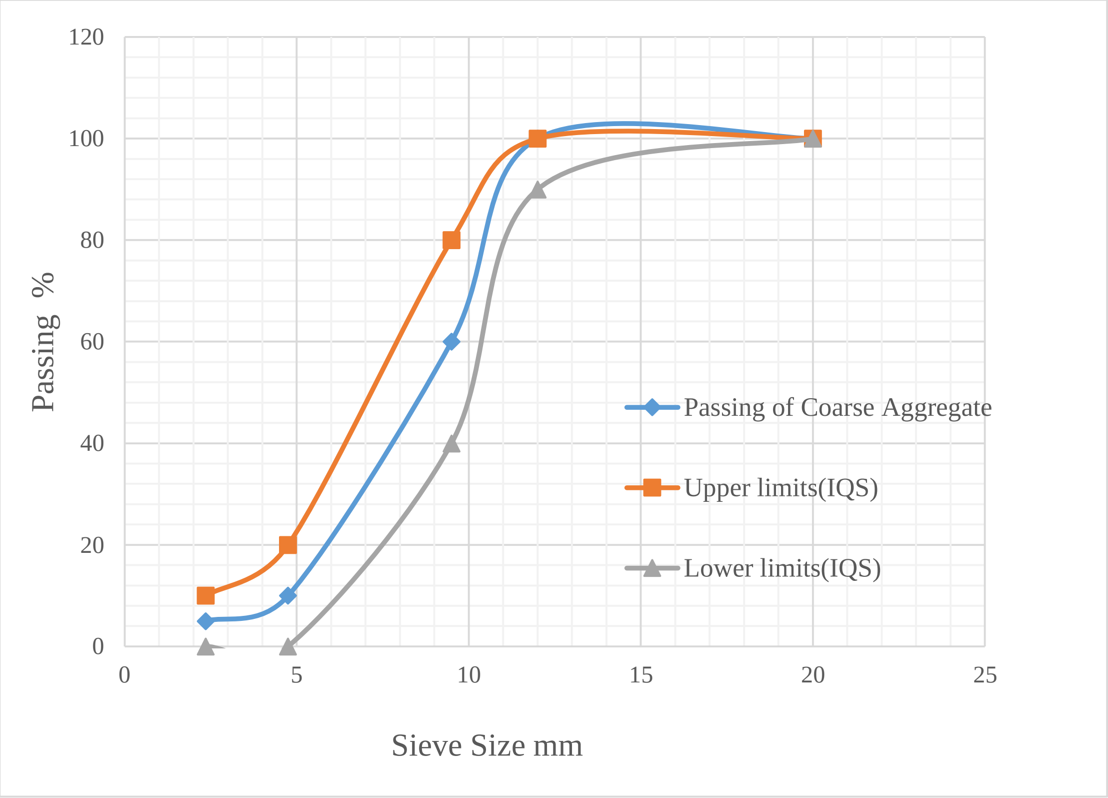


Figure (3-2): Grading of Normal Coarse Aggregate

Table (3-2): Physical and Chemical Properties of Coarse Aggregate

No.	Properties	Test Results	Limits of Iraqi Specification No.45/1984
1	Specific Gravity	2.65	-
2	Sulfate Content SO_3	0.055%	$\leq$ 0.1%
3	Absorption	0.52%	-
4	Clay	0.17%	$\leq$ 0.2%

3.2.3.2 Lightweight Coarse Aggregate (Attapulgite)

The coarse aggregate used for lightweight concrete (LWC) is the crushed lightweight aggregate obtained from crushing Attapulgite rocks brought from the raw materials that collected from Tar Al-Najaf region. Attapulgite is a fibrous silicate which has rather large a surface area and acidic characteristics that make the clay more useful as an adsorbent and catalyst. Attapulgite introduced by Carrol 1970 as: $Si_8Mg_5O_{20}$ $(OH)_2$ $.(OH_2)_4.4H_2O$ [56].

Firstly, the Attapulgite rocks were crashed into smaller sizes by hammer, as shown in Plate (3-1), then the Attapulgite was screen out by sieve series according to ASTM C330-05 specifications [22]. The discrete size fraction for each batch was recombined in suitable proportions to produce the preferred grade. The prepared raw material was located in three loose layers spread on a strand and placed in a furnace each layer was approximately 110–130 mm, and then was fired by gas as shown in Plate (3-2).

Plate (3-1): Crushing Process of Attapulgite

The production methods of Attapulgite depend on expansion and agglomeration. The increasing rate of the temperature was 5˚C/min, and when the furnace temperature reached the required degree (1100ºC), the sample was kept for half hour soaking time to guarantee execution all the required transformation in this temperature [42] .

Plate (3-2): Furnace of Burning Attapulgite

The total burning time was four hours. After that, the cooling period of the specimen was extended to the next day by open the oven door to permit heat exchange with the ambient temperature. Finally, to ensure grading exchange the Attapulgite were rescreened by sieve series according to ASTM C330-05 specifications [22].as shown in Plate (3-3).

Plate (3-3): Graded Attapulgite

This coarse aggregate has the maximum size of 10 mm and its grade conforms to ASTM C330-05 specifications [22]. Fig (3-3) shows the Attapulgite grading sample used in the concrete mix.

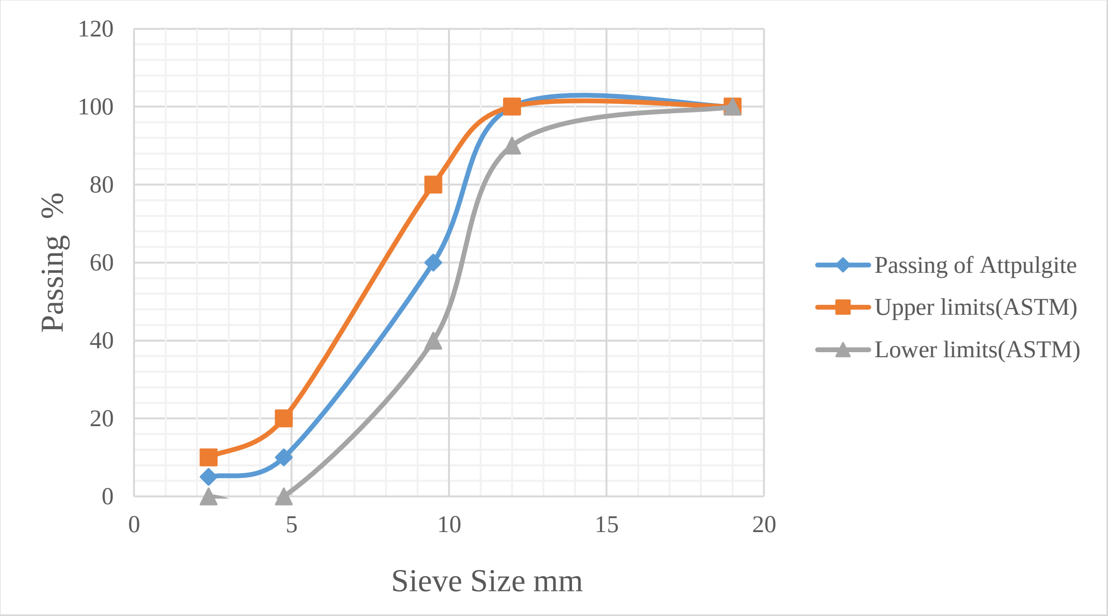


Figure (3-3): Adopted Grading of Coarse Lightweight Aggregate

3.2.3.3 Lightweight Coarse Aggregate (Clay Bricks)

The crushed bricks, which acquired from local bricks available in the market, were used as coarse lightweight aggregate to produce structural light-weight concrete SLWC. First of all, the bricks were crashed into smaller sizes by hammer, then the crushed bricks were screen out by sieve analysis according to ASTM C330-05[22] specifications as shown in Table (3-3). The series of the sieves was made up from 19,12.5, 9.5, 4.75 and 2.36 mm, as illustrated in Plate (3-4).

Table (3-3): Adopted Grading of CNWA

No.	Sieve Size(mm)	Passing %	% Passing ASTM 330-05
1	19	100	100
2	12	100	90-100
3	9.5	60	40-80
4	4.74	10	0-20
5	2.36	5	0-10

Plate (3-4): Graded Bricks

3.2.4 Water

In present work, Ordinary clean tap water was used for washing and for casting and curing all the specimens.

3.2.5 Steel Wythe Reinforcement

Each concrete wythe of sandwich slabs was reinforced with one layer of deformed steel reinforcement, consisting of 6 mm diameter bars with a spacing of 150 mm c/c obtained from BRC Turkish production, placed centrally through the thickness of outer concrete layers. The steel reinforcement was tested according to ASTM A496-05 [57]. The yield stress and the ultimate strength are shown in Table (3-4). The tensile tests were performed using the testing machine available at the Mechanical Laboratory of the Engineering Department at Karbala University is seen in Plate (3-5).

Table (3-4): Properties of Steel Reinforcement Bar

Nominal diameter (mm)	**Actual diameter (mm)**	**Elongation %**		**Yield Stress fy MPa**		**Ultimate Strength fu MPa**	
		result	limit	result	limit	Result	limit
6	5.84	6.8	6-7	584	520	836	690

Plate (3-5): Photograph of Ø6 mm Tensile Steel Testing Machine.

3.2.6 Shear Connector Steel Bars

In all panels, deformed steel bars with (4mm) diameter was used as a shear connector (Turkish made). The tensile test was carried out using the testing machine available in the Material Laboratory of the Material Engineering Department at Babylon-University as shown in Plate (3-6). The yield and the ultimate stresses are shown in Table (3-5).

Table (3-5): Properties of Steel Shear connector Bars.

Nominal diameter (mm)	**Actual diameter (mm)**	**Elongation %**		**Yield Stress fy MPa**		**Ultimate Strength fu MPa**	
		result	limit	result	limit	Result	limit
4	3.92	6.07	6-7	647	520	716	690

Plate (3-6): Photograph of 4Ø mm Tensile Steel Testing Machine.

3.2.7 Super-plasticizer (SP)

Hyperplast PC 200 High Performance Super-Plasticizer Concrete Admixture (Formerly known as Flocrete PC200) was used as a reducer to the water of the concrete mix, as shown in Plate (3-7). Table (3-6) shows the main properties of Flocrete PC200 from manufacturer data sheet [58], see **Appendix-A.**

Plate (3-7): Flocrete PC 200

3.2.7.1 Recommended dosage:

The guidance dosage of Hyperplast PC200 is 0.50 - 2.50 liter/100 kg of cementitious materials in the mix, including ground-granulated blast-furnace slag, pulverized fuel ash or micro silica. Representative trials should be conducted to determine the optimum dosage of Hyperplast PC200 to meet the performance requirements by using the materials and conditions in actual use [58].

Table (3-6): Technical Properties @25 ˚C [58]:

Main Action	**Concrete Superplasticizer**
Color	Light yellow liquid
Density	1.03 - 1.07
form	Liquid
Freezing point:	≈ -3°C
Specific gravity	1.05 ± 0.02
odor	Slight/Faint
Toxicity	Non-Toxic under relevant health and safety codes.

3.3 Concrete Mixes

3.3.1 Lightweight Concrete Mix Design

The definition of lightweight Concrete (LWC) is usually related to its density. The codes define structural lightweight aggregate concrete as a concrete SLWC with a hardened density lower than 2000 kg/m^3 and with a compressive strength higher than of 17 MPa at 28 days, while the normal weight concrete (NWC) owns density ranging between 2200 to 2600 kg/m^3. The target LWC compressive strength is more than 27 MPa at 28 days and, the target air dry density was less than 2000 kg/m^3. Concrete mixtures contain crushed bricks or Attapulgite as a coarse lightweight aggregate that was used in the production of LWC, natural sand, and superplasticizer (PC-200) that were used to produce LWC.

Many trail mixes have been carried out according to ACI committee 211.2-98 (Reapproved 2004)[59], to satisfying the desired density and compressive strength for concrete. Mix proportion (by weight), slump, hardened density, and compressive strength of the trail mixes are illustrated in table (3-7) and (3-8).

Table (3-7): Trail Mixes Proportion of Structural Lightweight Attapulgite Aggregate Concrete.

Property	No of mix					
	1	2	3	4	5	6 selected
Cement kg/m^3	450	365	450	365	365	365
Sand kg/m^3	650	478	504	769	478	769
LWA3kg/m^3	600	450	378	408	408	408
SP% Wt of cement	_	_	1	_	0.5 %	0.5 %
Water kg/m^3	180	146	157.5	164.25	146	146
W/C ratio	0.4	0.4	0.35	0.45	0.4	0.4
Proportion C:S:G	1:1.4:1.3	1:1.3:1.2	1:1.12:0.84	1:2.1:1.2	1:1.3:1.2	1:2.1:1.2
Slump cm	1	2.6	flow	4	15	5
density kg/m^3	1930	1694	2045	1845	1775	1850
fć 28 days MPa	18.5	20	24	23	24.2	25.5

Table (3-8): Trail Mixes Proportion of Structural Lightweight Crushed Bricks Aggregate Concrete that contain clay brick

Property	**No of mix**	
	1	**2 selected**
Cement kg/m^3	365	365
Sand kg/m^3	500	769
LWA3kg/m^3	450	408
SP% Wt of cement	-	0.5
Water kg/m^3	182.5	146
W/C ratio	0.5	0.4
Proportion C:S:G	1:1.3:1.2	1:2.1:1.2
Slump cm	3.5	8
density kg/m^3	1750	1871
fć 28 days MPa	25	33

3.3.2 Mix Design of Normal Concrete (NC)

The normal concrete is cast using the same mix proportion of structure Lightweight Aggregate Concrete (SLWC) that designed before. Table (3-9) shows the mix proportions of NC, inaddition to slump, density, compressive strength values.

Table (3-9): Mix Proportion of Normal Concrete.

Property	**value**
Cement kg/m^3	365
Sand kg/m^3	769
LWA3kg/m^3	408
SP% Wt of cement	0.5
Water kg/m^3	146
W/C ratio	0.4
Proportion C:S:G	1:2.1:1.2
Slump cm	9
density kg/m^3	2150
fć 28 days MPa	39.4

3.4 Mixing Method

The mixing was done in a laboratory drum mixer having a capacity of 0.1m^3. Firstly, each type of aggregate was weighted and submerged in water for 24 hours. Then the surface of the aggregate is dried and backed into the plastic vessel, also the other constituents (sand and cement) were weighted and backed into plastic vessel before the mixing process; it was essential to keep the mixer clean, wet, and free of water. Both normal weight concrete and lightweight concrete were mixed in same.

Plate (3-8): Drum-Laboratory Mixer

3.4.1 Mixing Procedures of Lightweight Aggregate Concrete of Lightweight Aggregate Concrete

The mixing procedure of lightweight concrete was implemented according to **Chandra and Berntsoon, 2002 [5]**. This procedure was separated into two steps: step one, the mixing of mortar (admixture, sand, cement, and about two -thirds of water) for three min. step two, the coarse LWA was added to the mixer with the remaining water and super plasticizer for and mixed four minutes then two minutes break, then mixed by two minutes.

3.4.2 Mixing Procedures of Normal Weight Aggregate Concrete

NWC was mixed according to ASTM C 192/C 192/M-05 [60]. Saturated surface dry coarse aggregate and fine aggregate were added in the mixer. After a few minutes, 50% of water was added to the mixer. Then, the mixer was operated for few seconds, after that cement and remaining water was added to the mixture. After a few flipping, the superplasticizer was appended. Then concrete was mixed for three minutes. Followed by three minutes break, then mixed for two minutes.

3.5 Specimens Description

3.5.1 The Molds Preparation

All the sandwich slab models were cast in plywood molds to give a slab model with net dimensions (1100*400*90) mm. The molds aspects were made of 15 mm a plate thickness as illustrated in Plate (3-9).

Plate (3-9): The Molds of Sandwich concrete slab.

3.5.2 Specimens Design

Concrete Sandwich Slab (CSS) consists of 30 mm thickness reinforced concrete layers and in the middle of them there is polystyrene layer with 30 mm thickness. Each concrete layer was reinforced by steel wire mesh with (150mm*150mm) spacing c/c and the diameter of steel wire was 6mm. The cover for the reinforcement was 12 mm. The two concrete layers were connected by the steel truss cage connectors with 150 mm spacing. The diameter of shear connectors deformed steel bar was 4 mm, these steel bars were bent to form continuous w-shaped (zigzag shape), where the angle for each bent was 45° or 27° as shown in (Plate 3-10). The height for each bent was 60 mm. The bent steel bars were tied to the two meshes to create continuous steel truss shear connector.

Plate (3-10): Bent Shear Connector Bars in 45˚ and 27˚.

3.5.3 Casting Procedure

The internal sides of cubes and cylinders and the fabricated molds of slabs were completely cleaned and oiled to prevent adhesion with concrete later. Then, the bottom layer reinforcement and shear connectors trusses are placed in the suitable position for slab molds.

Afterward, the concrete was mixed using a drum mixer, the concrete mixture was carefully poured in the slab molds [60] with first layer of concrete, then the polystyrene layer placed in a the right position. After that, the upper wire mish was tied to the shear connectors during (5-7) minutes the second layer of concrete was cast. NWC and LWAC mixes for all slabs, cube molds, cylinder molds were compacted by a vibrating table. After the casting, the upper surface of concrete was smoothly finished by using hand trowel, after 24 hours, the slab specimens were separated from their molds, and then completely immersed in water for 28 days to prevent evaporation of water.

3.5.4 Supporting and Loading System

Loading system is consisted of three major pieces (steel I-beam sections that strengthened by welding bars with (25) mm diameter on each side of it, and two steel bars 25 mm are used to apply two line loads, and plate loading). Mean supporting system consists of two parts two steel I-beam sections and two steel plate with 10 mm thickness are welded to steel bars with 25 mm; one of the bars is fixed to I- sections and the other is unrestricted as shown in Plate (3-11) & Plate (3-12)

Plate (3-11): Supporting System

Plate (3-12): Loading System

3.6 Specimen Identification and Shear Connectors Details

Twelve slab samples were used in this work; these samples were divided into three groups. The first group consisted of two specimens of normal coarse aggregate concrete. The second group consisted of five specimens of lightweight Attapulgite aggregate concrete. The third group consisted of five specimens of lightweight crushed bricks aggregate concrete. Slab specimens can be classified according to the type of coarse aggregate used or the type and form of shear connectors.

The sample are described as following:

The first concrete slab specimen (RN) reference solid conventional slab with normal weight concrete was considered as a control slab for comparison.

The second concrete slab specimen (SN-C45) is a sandwich slab with normal weight concrete in the wythes and continuous steel truss shear connectors included angle for each bent was 45°.

The third concrete slab specimen (SA-45) is a sandwich slab with lightweight concrete in the wythes (use Attapulgite as coarse aggregate) and continuous steel truss shear connectors, included angle for each bent was 45°.

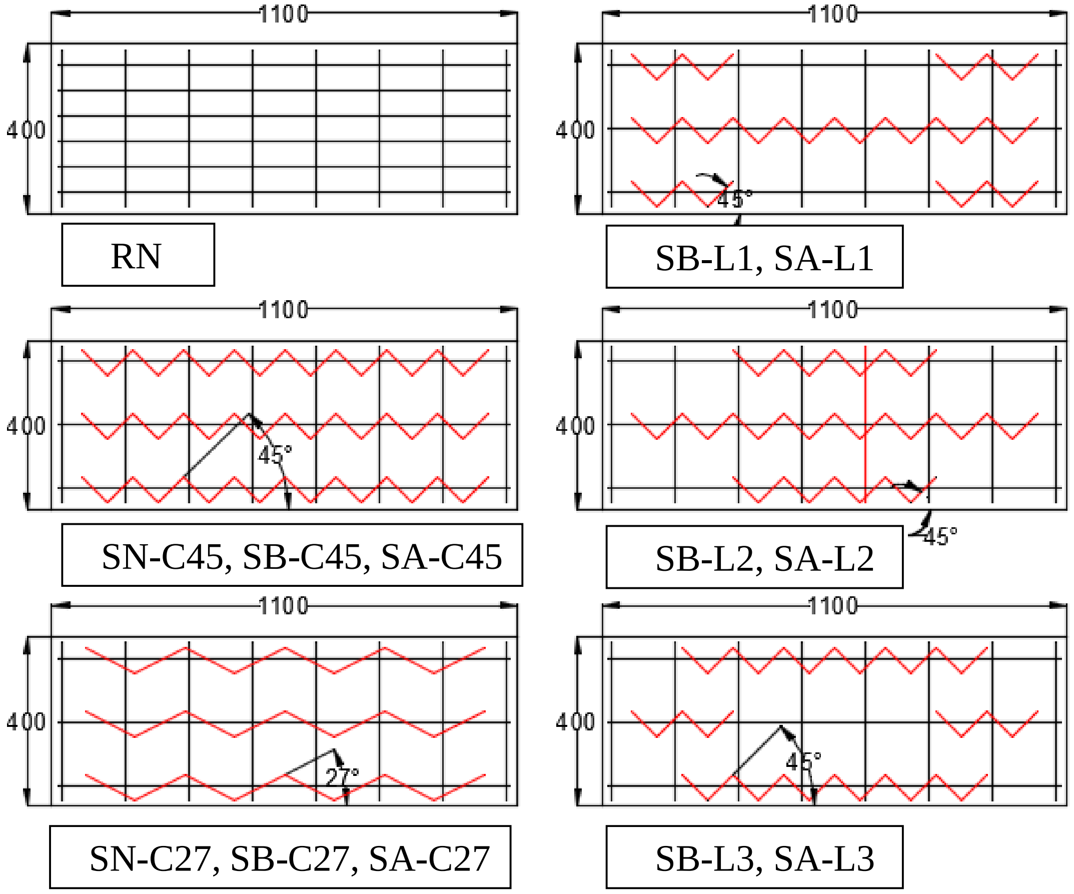
The fourth concrete slab specimen (SB-45) is a sandwich slab with lightweight concrete in the wythes (use clay bricks as coarse aggregate) and continuous steel truss shear connectors, included angle for each bent was 45°.

The fifth concrete slab specimen (SA-C27) is a sandwich slab with lightweight concrete in the wythes (use Attapulgite as coarse aggregate) and continuous steel truss shear connectors, included angle for each bent was 27°.

The sixth concrete slab specimen (SB-C27) is sandwich slab with lightweight concrete in the wythes (use clay bricks as coarse aggregate) and continuous steel truss shear connectors, included angle for each bent was 27°.

The seventh (SA-L1), eighth (SA-L2) and ninth (SA-L3) concrete slab specimens are sandwich slabs with lightweight concrete in the wythes (use Attapulgite as coarse aggregate) and discrete steel truss shear connectors, included angle for each bent was 45°. The discrete steel truss shear connectors area was 2/3 of continuous truss shear connectors area.

The tenth(SB-L1), the eleventh(SB-L2) and the twelfth (SB-L3) are sandwich slabs with same distribution shear connector of (SA-L1), (SA-L2) and (SA-L3); respectively using clay bricks, instead of Attapulgite, as coarse aggregate in concrete wythes. Figure (3-4) shows clearly shear connector layout schemes for all tested slabs



RN

SB-L1, SA-L1

SN-C45, SB-C45, SA-C45

SB-L2, SA-L2

SN-C27, SB-C27, SA-C27

SB-L3, SA-L3

Figure (3-4): Specimen shapes and Shear connector Schemes

3.7 Tests of Fresh Concrete

The test below was done to determine the fresh properties of SLWAC and NWC. All the following tests were carried out in the Structural Laboratory in the Civil Engineering Department, University of Kerbala:

3.7.1 Slump Test

The slump test procedure of normal concrete and lightweight concrete was carried out in accordance with (ASTM C143-05a)[61]. The slump test consists of a truncated cone with 100 mm diameter at the top, 200 mm diameter at the bottom and height is 300 mm and a tamping rod. The cone is completely filled with concrete mix, and then gradually pulled. This test is shown in Plate (3-13)

Plate (3-13): Slump Flow for Fresh Concrete.

3.8 Mechanical Properties of Hardened Concrete

Several tests on hardened concrete were carried out to confirm the design strength of concrete and the class of concrete. These tests are compressive strength (cubes and cylinders), splitting tensile strength, density, absorption, and voids tests.

3.8.1 Hardened Density Test

This test is essential to recognize whether the concrete is lightweight or normal weight according to ASTM C567-05a[62]. A total number of nine cylinders (200×100) mm specimens were tested, Three cylinders for each type of concrete.

3.8.2 Compressive Strength (Cylinder) Test

Compressive strength was performed and tested according to (ASTM C39-86)[63]. Nine cylinder specimens, (150×300) mm, were tested at (28) age as shown in Plate (3-14).

Plate (3-14): Compressive Strength-Cylinder

3.8.3 Compressive Strength Test (cube)

Compressive strength was done and tested according to (BS 1881: Part 116-1989)[64]. A total number of nine cubes of 100 mm was casting to test the compressive strength of concrete. The applied load was at right angle to the direction of casting.

3.8.4 Splitting Tensile Strength Test

Based on the procedure defined in (ASTM C496-04)[65], The splitting tensile strength was concluded. A total number of 24 cylinders with (100×200) mm were tested at age (28) days. Two plywood strips of 4.0 mm thick and 100 mm wide and 200 mm length are put between the cylinder and both the upper and the lower bearing blocks of the machine as presented in Plate (3-15) below.

Plate (3-15): Splitting Tensile Strength.

3.9 The Test Setup and Equipment's

All slab specimens were tested in a universal testing machine with a capacity of (1000 kN) available at the Structural Laboratory of Civil

Engineering Department at Karbala University, under monotonic loads up to ultimate load as shown in Plate (3-16).

Plate (3-16): Universal Testing Machine Used to Test Slabs.

3.9.1 Concrete Surface Strains

At both side of concrete layers, the strain was computed by Vernier caliper with 0.02 mm shown in Plate (3-17). At different loading stages, four couples of demec-discs were used to observe the horizontal distance at four levels of slab thickness in the center line of the span. The Arrangement of these demec-discs were shown in Figure (3-4)

Plate (3-17): Vernier Caliper Used to Monitor Surface Strain

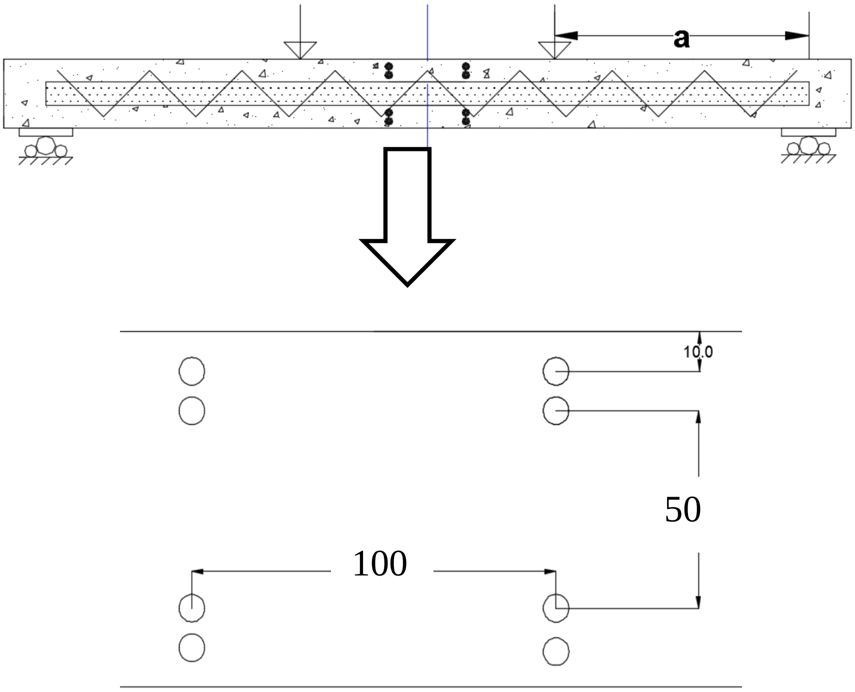


Figure (3-5): Arrangement of Demec Discs

(All Dimensions in mm)

3.9.2 Deflections and End slip of the Slab

The deflections were measured by LVDT with 100-mm range. One LVDT was used at the center of the slabs.

At one end of all specimens in the center of wythe, end slip was measured at the top and bottom layer by using LVDT with 10-mm range.

LVDT is a common type of electromechanical transducer that can convert the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal.

All LVDT were fixed in such a manner that it contacted the surface of specimens, and connected to the computer to record the readings by using LabVIEW application. Plate (3-18) shows the position of the LVDT.

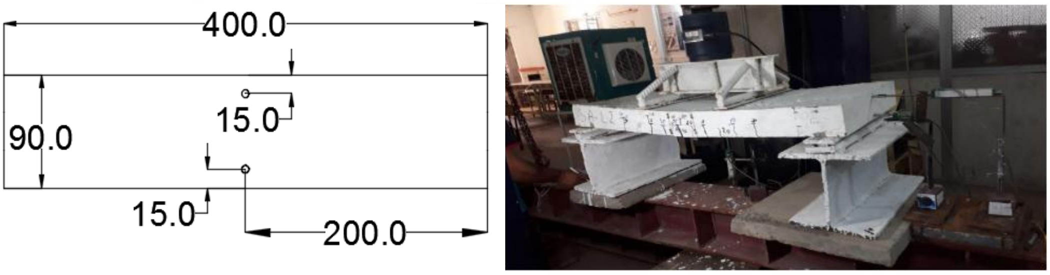


Plate (3-18):Position of LVDT at the Side of Slab

(All Dimensions in mm)

3.10 Testing Procedure

The specimens were tested as a simply supported span, the effective span was (990 mm). Two line loads were applied at L/3 from supports. The test started with the applying 5 kN load to check LVDT, then unloading to zero. At zero loading, the preliminary reading of LVDT and mechanical stains are founded. The load was applied in steps. At each load increment, observations of crack progressed on the concrete wythes which were drawn by marker pen. Also, at each test, the first cracking load was obtained and the mechanical measurement of the strains reading was listed. The process of recording measured the strain and traced the crack taking approximately three to five minutes. When this process is finished, loading was returned to the next load step. This procedure is repeated until the recorded ultimate load. The failure of the slabs was announced when noticed large deflection in addition to large flexure with no further increase in the loading readings was recorded as shown in Plate (3-19).

Plate (3-19): Typical Slabs After Testing

Chapter Four

Experimental Results and Discussion

Experimental Results and Discussion

4.1 General

This chapter presents the results of the experimental work, which were described in the previous chapter.

The objective of this study is to investigate the flexural behavior of lightweight one - way sandwich slabs subjected to two lines load. To understand the structural behavior of these slabs, a set of systematic parametric investigations of the sandwich panels were carried out. At the initial stage of behavior, the focus was given to the optimum arrangements and angle of the bent of the shear connectors as part of the sandwich panel. The parameters considered in these investigations were: the position, and orientation of the shear connectors as well as the type of lightweight aggregate.

Firstly, the experimental results of hardened properties of Normal-Weight Concrete NWC and Light-Weight Aggregate Concrete LWAC of control slabs are explained and discussed as a reference.

Secondly, this chapter explains the experimental results of twelve slab specimens. Ten of them were lightweight coarse aggregate concrete slabs. The remaining two were normal coarse aggregate concrete slabs.

For these tested slabs, the cracking behavior, including first cracking load and cracks pattern, are investigated. The load versus mid span deflection at the center are studied. In addition, load versus horizontal slip at the end of the panel is examined. Furthermore, for different loading stages, concrete strain distribution along the thickness of wythes at center face of slab specimen is also presented.

4.2 General Behavior of Sandwich Slabs

All sandwich slab models consist of cork layer surrounded by two layers of reinforced concrete. Total section has a steel reinforcement ratio (0.00235) which is used for the tested specimens with a clear cover of 12 mm, the desired minimum required reinforcement ratios is (0.0018) by ACI building Code **ACI-318 [66]** to avoid the shrinkage and temperature effect. All details reviewed in chapter three were according to ACI building Code requirements, and steel reinforcement and concrete strength were selected to satisfy this demand. The slabs were designed to fail in flexure by applying two-line load. The general behavior of the tested slabs can be summarized as below.

For the all sandwich slabs, first cracks were capillary and observed at the early stage of loadings, then the applied loads were increased until the number of cracks is increased. Also, the first crack width is increased. As the loads were increased further, crack progressive to the top wythe. Several flexure crack initiate in the tension face at load intervals, increasing gradually in number and becomes wider. For the solid slab, the deformation was initially seen at the elastic range (linear) at the early stage of loadings. Then the applied load was increased until the first crack occurred when the maximum moments had reached at the slab center of region.

As the loads are increased, the degradation of stiffness happened and failure was finally occurred. Table (4-1) shows the general properties and details of sandwich slabs.

Table (4-1) General Properties for Sandwich Slabs

Properties		**Value**
Slab dimensions (Length, width* thickness)		1100 mm*40 mm * 90 mm
Core thickness		30 mm
Wythes thickness		30 mm
Diameter of reinforcement(Ø)		6 mm
Type of loading		Two line load
Type of supporting		Simply supporting
Degree of bent of shear connector	9 slabs	Shear connectors bent at 45
	2 slabs	Shear connectors bent at 27
Layout and distribution of shear connector	5 slabs	Continuous truss shear connectors
	6 slabs	Discrete truss shear connectors
Type of coarse aggregate	2 slabs	Normal coarse aggregate
	5 slabs	Lightweight coarse aggregate (Attapulgite)
	5 slabs	Lightweight coarse aggregate (crushed bricks)

4.3 Hardened Properties of Concrete

The mechanical hardened properties for control cubes and cylinders for both lightweight concrete types and normal concrete are tested at age of 28 days and their results are presented in Table (4-2).

Table (4-2): Mechanical Properties of Concrete Cubes and Cylinders

Slab Model Symbol	**Air Dry Density Kg/m^3**	**Compressive Strength MPa**			**Tensile Strength MPa f_{ct}**
		f'_c	**f_{cu}**	**f_{cu}/ f'_c**	
SN	2305	32	39	1.218	3.35
SA	1940	21	25.5	1.214	2.75
SB	1954	25.2	30	1.190	2.83

4.3.1 Hardened-Density of lightweight concrete

Table (4-2) shows the hardened density for lightweight and normal weight concrete. The results indicate that hardened density for lightweight aggregate concrete when using crushed bricks are below 1945 kg/m^3, while it is below 1940 kg/m^3 for Attapulgite as coarse lightweight aggregate. This conforms to the requirements of several codes for structural lightweight coarse aggregate concrete that state the maximum density does not exceed 2000 kg/m^3. The hardened dry density is important because it represents the permanent load of the structure element self-weight. Also, the weights of all types of reinforcement should be taken into account. The dry density of slab specimens is determined by weighing the slab model at age 28 days using mechanical weighing balance. Then find total hardened density as shown below.

"total density of slab (kg/m^3) = total weight(kg) / volume of slab (m^3)"

Table (4-3): Hardened-Density of Slab Models

Slab Model Symbol	Weight of Reinforcement Kg	Total Weight of Slab kg	Difference in Total Weight Compare with RN (%)	Hardened Density of Reinforced Slab kg/m^3
RN	2.737	94.5	0.00	2386
SN-C45	3.209	65.0	- 31.22	1641
SA-C45	3.209	55.7	- 41.06	1407
SB-C45	3.209	57.4	- 39.26	1449
SA-C27	3.082	54.5	- 42.33	1376
SB-C27	3.082	56.5	- 40.21	1426
SA-L1	3.051	54.3	- 42.53	1371
SA-L2	3.051	54.8	- 42.01	1384
SA-L3	3.051	54.1	- 42.75	1366
SB-L1	3.051	56.4	- 40.32	1424
SB-L2	3.051	56.3	- 40.42	1422
SB-L3	3.051	55.8	- 40.95	1409

From Table (4-3), the hardened design density of NWC sandwich slab is lower than solid slab model by about 31.22%. While the hardened design density of LWCA sandwich slabs is lower than NWC sandwich slab by about 14.26%, 11.70%, used Attapulgite / crushed bricks as a coarse aggregate.

On the other hand, in comparison with SA-C45 and SB-C45, using two-thirds of steel area of the shear connectors reduces the average values of hardened design density by about 2.33%, 1.98%, when using Attapulgite and crushed bricks as a coarse aggregate; respectively.

Also, the hardened oven dry density for LWAC which produced from Attapulgite and crushed bricks as a CLWA is about 1850 kg/m^3, 1871 kg/m^3; respectively, which is calculated from the experimental test as general value for all sandwich slabs.

4.3.2 Cylinders and Cubes Compressive Strength

One of the important things is to investigate the behavior of LWAC and NWC that used in the slab models having the same mix proportion is 1:2.1:1.2.

The average value of cylinders' compressive strength f_c` for LWAC were (21 MPa) and (25.2 MPa); respectively, when using Attapulgite and crushed bricks as coarse aggregate. whereas the average compressive strengths of cubes f_{cu} were (25.5 MPa) and (30 MPa); respectively, when using Attapulgite and crushed bricks as coarse LWA, while, for normal weight concrete, the average value of cylinders and cubes compressive strength were 32 MPa and 39 MPa; respectively as presented in Table (4-2)

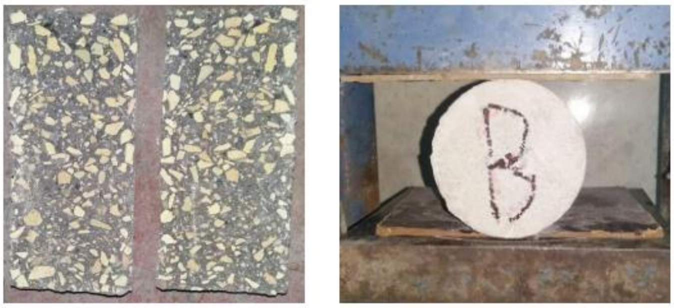
As general, it was observed that the lightweight concrete with crushed bricks has a cylinder compressive strength less than 21.25% in comparison with normal weight concrete for the same mix proportion. on the other hand, when using Attapulgite as CLWA, the cylinder compressive strength reduced by about 38.24%. Plate (4.1) shows the cylinder compressive strength test for each type of CLWA concrete.

Plate(4-1): Compressive Strength Test of Cylinders

4.3.3 Splitting Tensile Strength

The splitting tensile strength f_{sp} results for lightweight concrete and normal concrete are illustrated in Table (4-2). The average values of splitting tensile strength for LWAC were 2.75 MPa and 2.83 MPa when using Attapulgite and crushed bricks as coarse LWA; respectively, whereas the average tensile strength was about 3.35 MPa as an average value for NWC.

At the same mix proportion, it was obtained that when crushed-bricks used as coarse aggregate, the LWAC will have a splitting tensile strength less than 15.52% as compared with normal concrete. While using Attapulgite as CLWA reduced the splitting tensile strength by about 17.91%, this difference in the value of splitting strength is mostly assigned to an important role of the water which absorbed and stored inside the crushed-bricks or Attapulgite. Plate (4-2) shows the tensile strength test and failure modes of cylinders.



Plate(4-2): Split tensile test and failure modes of cylinders

4.4 Experimental Results of Slab Models

Case study No.1: Checking the qualifications of replacement traditional solid slab by concrete sandwich slab. For this purpose, **group 1: RN & SN-C45** slabs are used.

Case study No.2: Investigating the efficiency of using a different type of lightweight coarse aggregate concrete as a structural member, five sandwich slab specimens were tested which contain Attapulgite as a lightweight coarse aggregate, another five sandwich slabs contain clay bricks as a lightweight coarse aggregate, where the other contain a normal coarse aggregate. For comparison, **group 2: SN-C45 & SB-C45 & SA-C45** slabs are used.

Case study No.3: focusing on the optimum layout and the position of the shear connectors. A (2/3) of steel reinforcement shear connector area was used in different arrangement and positions. Two groups are used for this purpose **group 3:(SB-L1 & SB-L2 & SB-L3)** slabs and **group 4:(SA-L1 & SA-L2 & SA-L3)** slabs.

Case study No.4: Investigating the effect of orientation (angle of bent) of shear connectors. **group 5: SA-C45 & SA-C27** slabs and **group 6: SB-C45 &SB-C27** slabs are used.

Case study No.5: For same shear connectors steel area and two types of shear connectors used (continuous cage, discrete W-shaped), different in angle of bent (45, 27) were also studied. For comparison, **group 7: (SA-C27 & SA-L1 & SA-L2 & SA-L3)** slabs and **group 8: (SB-C27 &SB-L1& SB-L2 & SB-L3**) slabs are used.

4.4.1 Load-Deflection Curves

All deflection readings were recorded till the ultimate load is occurred, one LVDT was located vertically at the center of the slabs in the vertical direction. All the slabs were measured by this procedure of measuring deflection. The recorded ultimate load and the deflection are shown in Table (4-4).

For general reinforced concrete elements with a specified reinforcement ratio, the load-deflection relationship of the section can be founded. From the load-deflection relationship, the ductility index, ($\mu\Delta$), can be found. it is based on deflection computed at mid-span of the slab. The deflection ductility index ($\mu\Delta$) is the ratio of deflection at the ultimate stage of the slab to the deflection at the yielding point of steel.

Generally, a high ductility index indicates that structural members tested are capable of undergoing large deformations prior to failure.

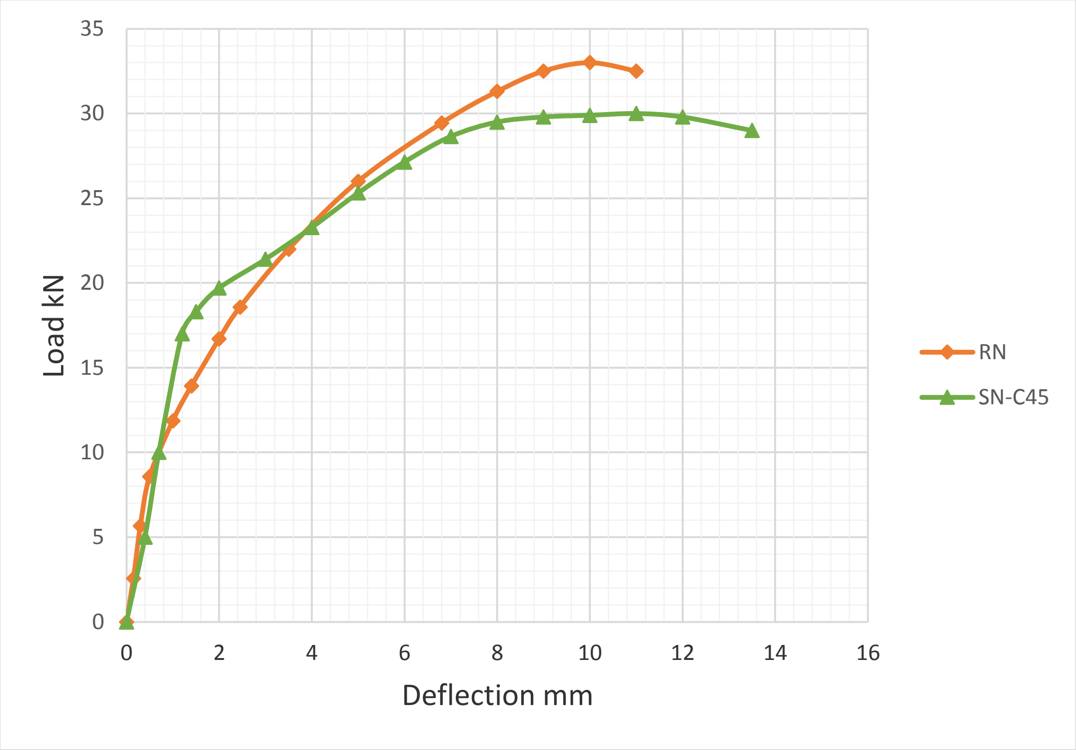
Case study No 1: Benefits of sandwich slabs.

Table (4-4) shows the ultimate Load and maximum deflection value for RN & SN-C45 Slabs.

Table (4-4): Ultimate Load and Max Deflection of RN&SN-C45 Slabs

Specimen Symbol	***Ultimate Load kN Pu***	**Difference in Ultimate-load as compare with reference %**	***Max Deflection mm***	**Difference in deflection as compare with reference %**
RN	**33.00**	_	**11**	_
SN - C45	**30.00**	**-9.09**	**13.50**	**22.72**

The main benefits of using sandwich principle were reducing the total weight by about **31.21%** and the deflection increment by about **22.72%** as compared with a solid slab. Also, the toughness will increase by **25.11%**, while the strength will reduce about **9.09%.** This reduction accompanied by an increase in the ductility index (μΔ) by **2.27%**. Figure (4-1) shows load-deflection curve for solid slab model and sandwich slab with normal concrete.



Figure(4-1): Load-Deflection profile of RN & SN-C45

Case Study No.2: Best type of coarse aggregate.

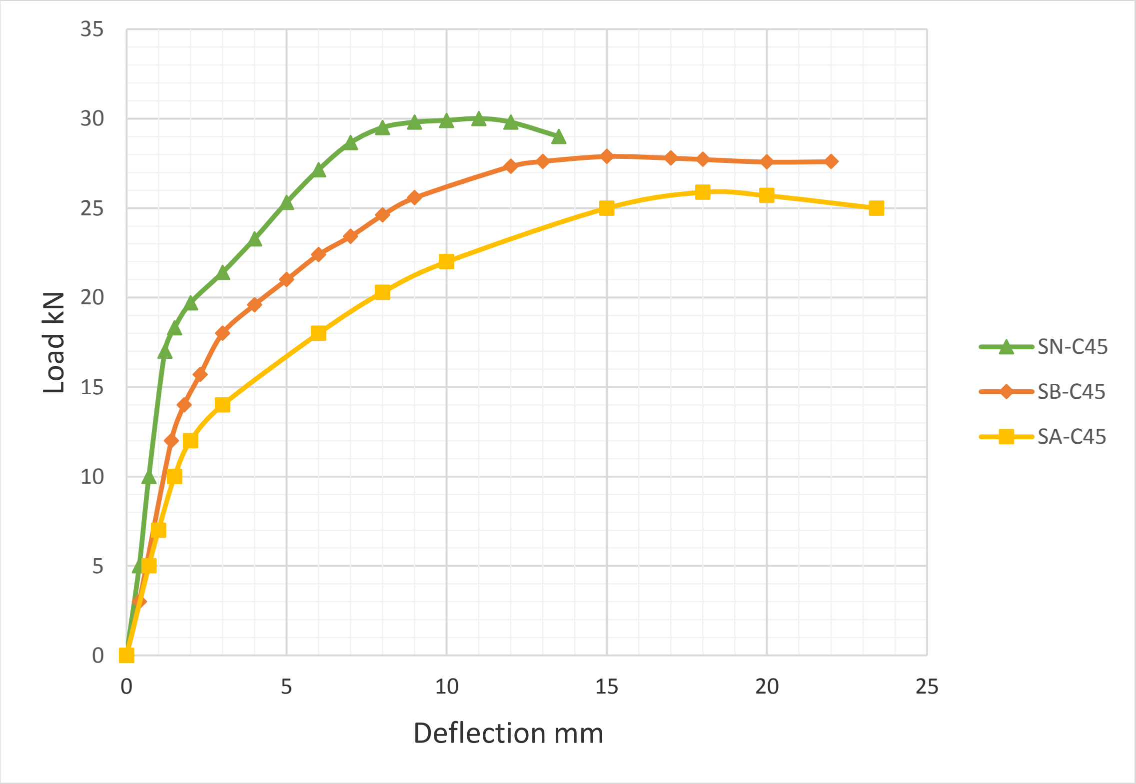
Table (4-5) shows the ultimate Load and maximum deflection value for SN-C45, SB-C45 &SA-C45 Slabs.

Table (4-5): Ultimate Load and Max Deflection of SN-C45& SB-C45 &SA-C45 Slabs

Specimen Symbol	***Ultimate Load kN Pu***	**Difference in Ultimate-load as compared with reference slab %**	***Max Deflection Mm***	**Difference in deflection as compared with reference slab %**
SN – C45	**30.00**	_	**13.50**	_
SB – C45	**27.84**	**-7.2**	**22.00**	**62.96**
SA – C45	**25.89**	**-13.7**	**23.42**	**73.48**

The use of clay bricks as a lightweight coarse aggregate will reduce the total weight by about **11.70%**. and enhancement the deflection, ductility index (μΔ), toughness will be **62.96%, 39.64%, 54.04%**: respectively. While the ultimate load will have reduced by about **7.2 %** as compared with sandwich normal weight aggregate.

In case of using Attapulgite instead of normal aggregate, the increment in the max deflection value, ductility index (μΔ), toughness was **73.48%, 38.75%, 43.82%**: respectively. Another benefit gained was decreasing the total weight by **14.31 %**. While, the ultimate load will only reduced by about **13.7 %**. Figure (4-2) shows the load-deflection curve for SN-C45, SB-C45 & SA-C45.



Figure(4- 2): Load-Deflection Profile of SN-C45 & SB-C45 & SA-C45 Slabs

Case Study No 3: Effect of layout of shear connectors

Table (4-6) shows the ultimate Load and maximum deflection values for SB-L1, SB-L2 &SB-L3 slabs and their counterparts of Attapulgite slabs.

Table (4-6): Ultimate Load and Max Deflection of the Sandwich Slabs with Discrete W-shape shear connectors

Specimen Symbol	*Ultimate Load kN Pu*	Difference in Ultimate-load as compared with reference slab %	*Max Deflection mm*	Difference in deflection as compared with reference slab %
SB - L1	**21.65**	**-**	**15.42**	**-**
SB - L2	**17.60**	**-18.71**	**18.00**	**16.73**
SB – L3	**19.89**	**-8.13**	**16.23**	**5.25**
SA - L1	**20.50**	**-**	**16.00**	**-**
SA– L2	**16.00**	**-21.95**	**19.60**	**22.5**
SA – L3	**18.91**	**-7.76**	**16.53**	**3.31**

SB-L1 slab exhibits increasing in the ultimate load by about **(23.01%** and **8.85%)** as compared with **SB-L2 & SB-L3** slabs in **group 3**, this increment accompanies by enhancing in their toughness by about (**24.52%** and **27.02%**): respectively. While maximum deflection value will have reduced by about (**14.33%** and **4.99%**): respectively, as well as ductility index is decreased by about (**14.44%** and **5.12%**): respectively.

SB-L3 slab shows more load capacity by about **13.01%** when comparing with **SB-L2** slab. On the other hand, max deflection value, toughness, ductility index will decrease by about (**8.28%, 1.97%** and **9.83%**): respectively. Figure (4-3) illustrates load deflection curves for **SB-L1**, **SB-L2** & **SB-L3** slabs.

For **SB-L1, SB-L2, SB-L3** slabs, the reduction in the total weight was **1.70%,1.92%, 2.79%** when compared with **SB-C45** slab**,** while the decreeing in the weight of steel reinforcement was **4.92 %**, this reduction is important in economic benefits.

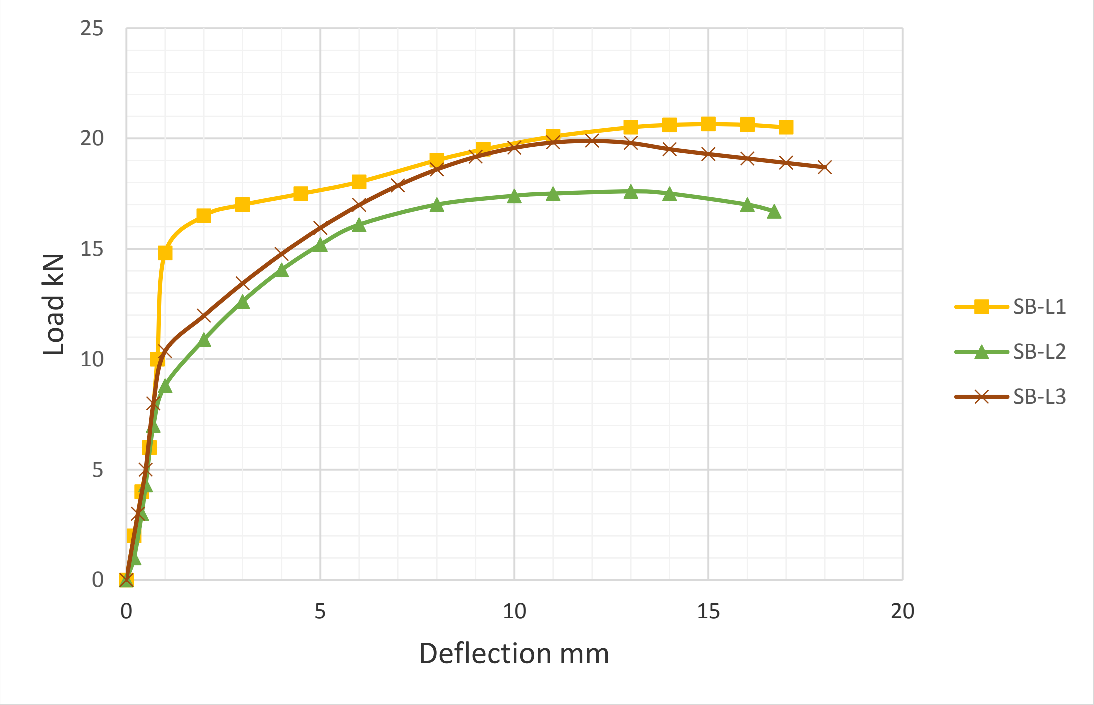


Figure (4-3): Load-Deflection Curve for SB-L1,SB-L2 & SB-L3 Slabs.

The results indicate that behavior of slabs which contain Attapulgite, to some extent, similar to the behavior of those containing crushed bricks. Therefore, **SA-L1** slab shows increment in the ultimate load by **28.13%, 8.41%** as compared with **SA-L2, SA-L3** slabs: respectively. Also, the ductility index will increase by about (**8.57%, 20.69%**). On the other hand, toughness will increase by (**4.11%**) when compared with **SA-L2** slab, while it decreases by (**1.94%**) as compared with **SA-L3** slab**.** Figure (4-4) illustrates load deflection curve for SA-L1, SA-L2 & SA-L3 slabs.

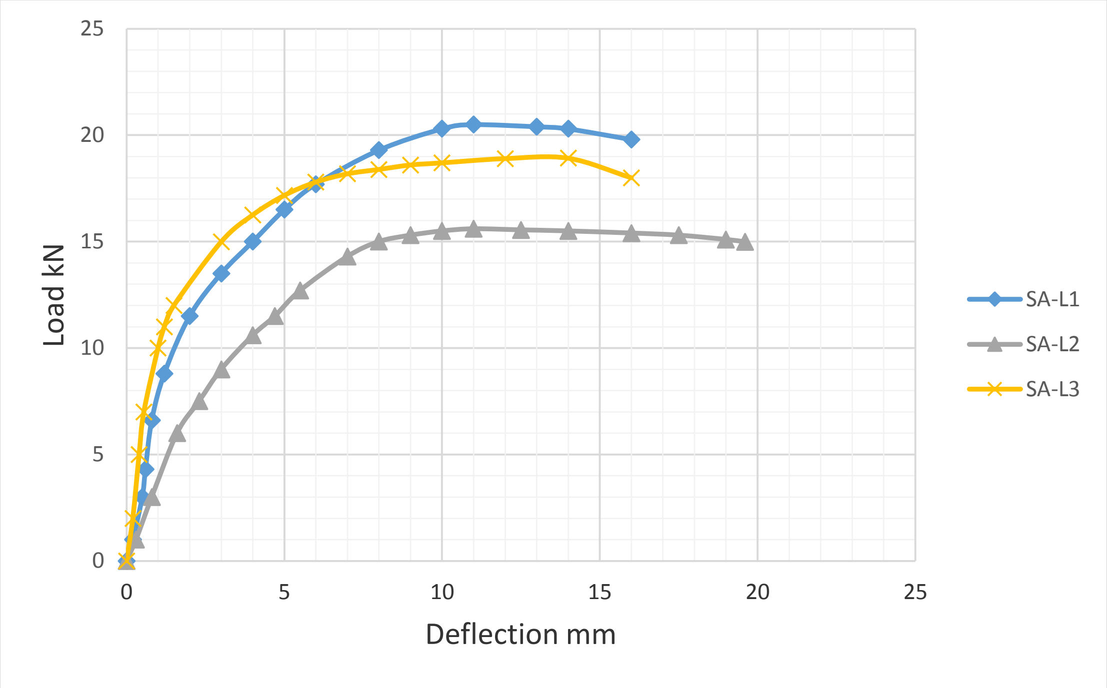


Figure (4-4): Load Deflection Curve for SA-L1,SA-L2 & SA-L3 Slabs.

Case Study No4: Effect of the bent angle of continuous truss shear connectors.

Table (4-7) shows the ultimate Load and maximum deflection value for SB-C45, SB-C27 &SA-C45, SA-C27 slabs.

Table (4-7): The Ultimate Load and Maximum Deflection Value for SB-C45, SB-C27 &SA-C45, SA-C27 Slabs.

Specimen Symbol	***Ultimate Load kN Pu***	**Difference in Ultimate-load as compare with reference %**	***Max Deflection mm***	**Difference in deflection as compare with reference %**
SB – C45	**27.84**	_	**22.00**	_
SB-C27	**23.63**	**-15.12**	**16.51**	**-24.95**
SA - C45	**25.89**	_	**23.42**	_
SA-C27	**21.42**	**-17.26**	**18.30**	**-21.86**

The using continuous truss shear connectors bent in 45° instead of 27° will increase the ultimate load, max deflection value by about **17.82%, 33.25%**: respectively. Also, ductility index (μΔ), toughness will have increased by **14.17%, 66.23%**. While total weight will have increased by about **1.60%.** Figure (4-5) shows the load-deflection curve for SB-C45& SB-C27.

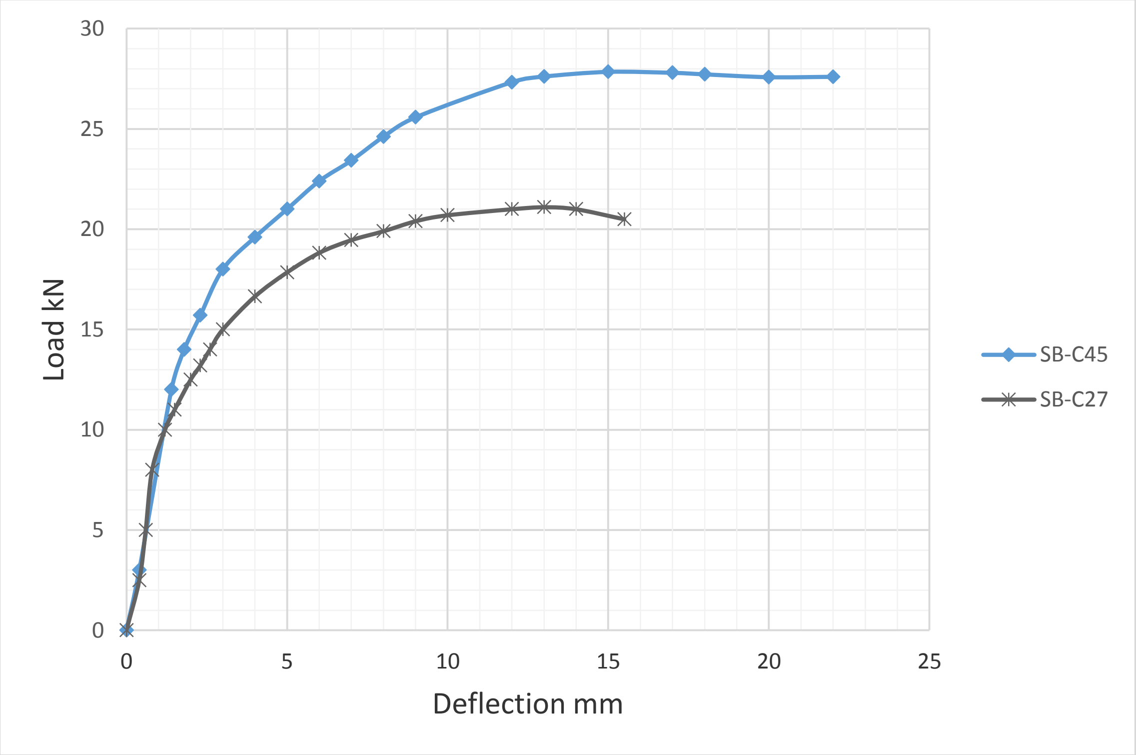


Figure (4-5): Load-Deflection Profile of SB-C45 & SB-C27 Slabs

In case of using Attapulgite in **group 5**. **SA-C45** slab exhibits increment in each of the ultimate load, max deflection value, ductility index (μΔ), toughness by about (**20.86%, 27.97%, 14.36%,46%**): respectively, when comparing with **SA-C27**. This enhancement was accompanying with an addition in total weight by **2.2%**. Figure (4-6) shows the load-deflection curve for SA-C45, SA-C27.

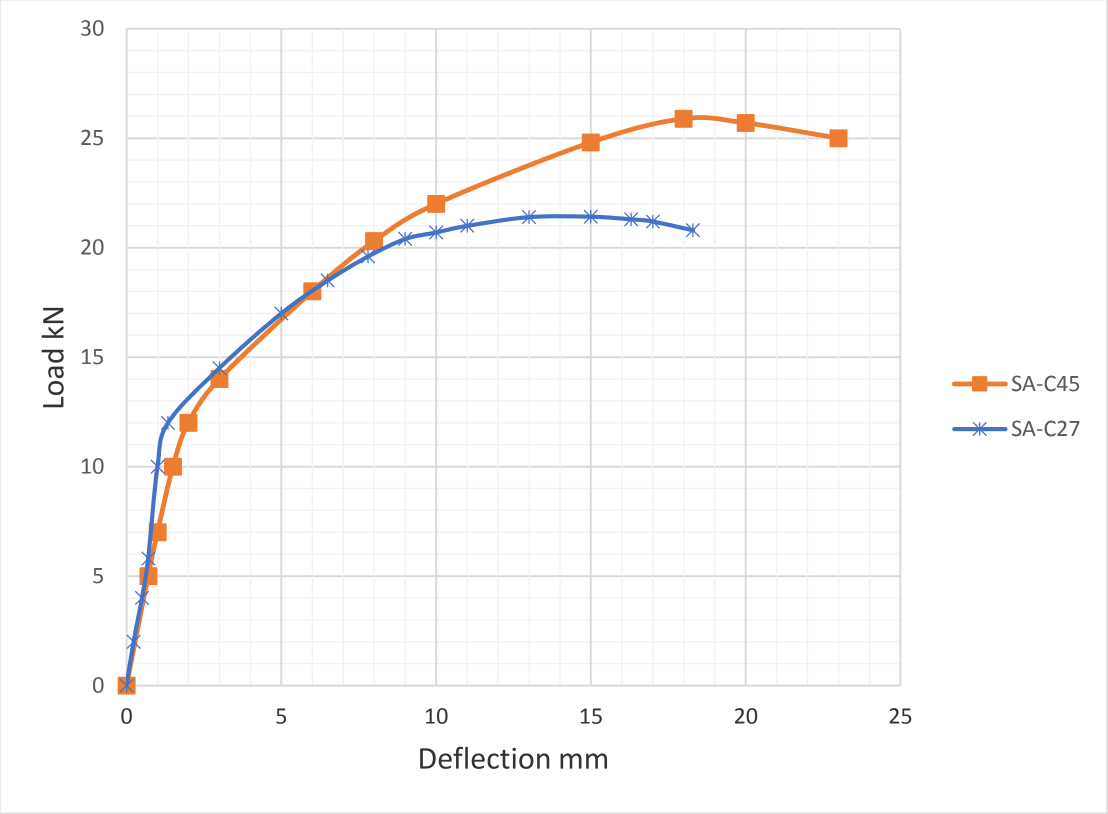


Figure (4-6): Load-Deflection Curve for SA-C45, SA-C27 Slabs

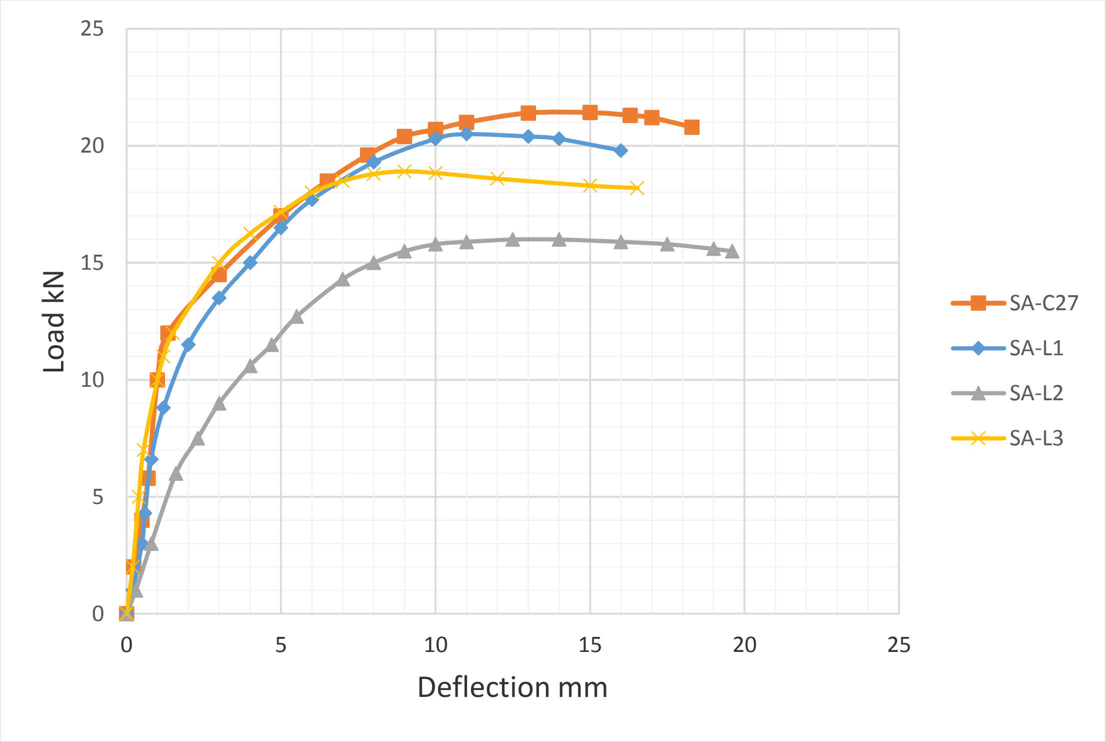
Case Study No5: Effect of the shape of the shear connectors.

Table (4-8) shows the ultimate Load and maximum deflection value for SB-C27, SB-L1, SB-L2, SB-L3 slabs and their counterparts of Attapulgite.

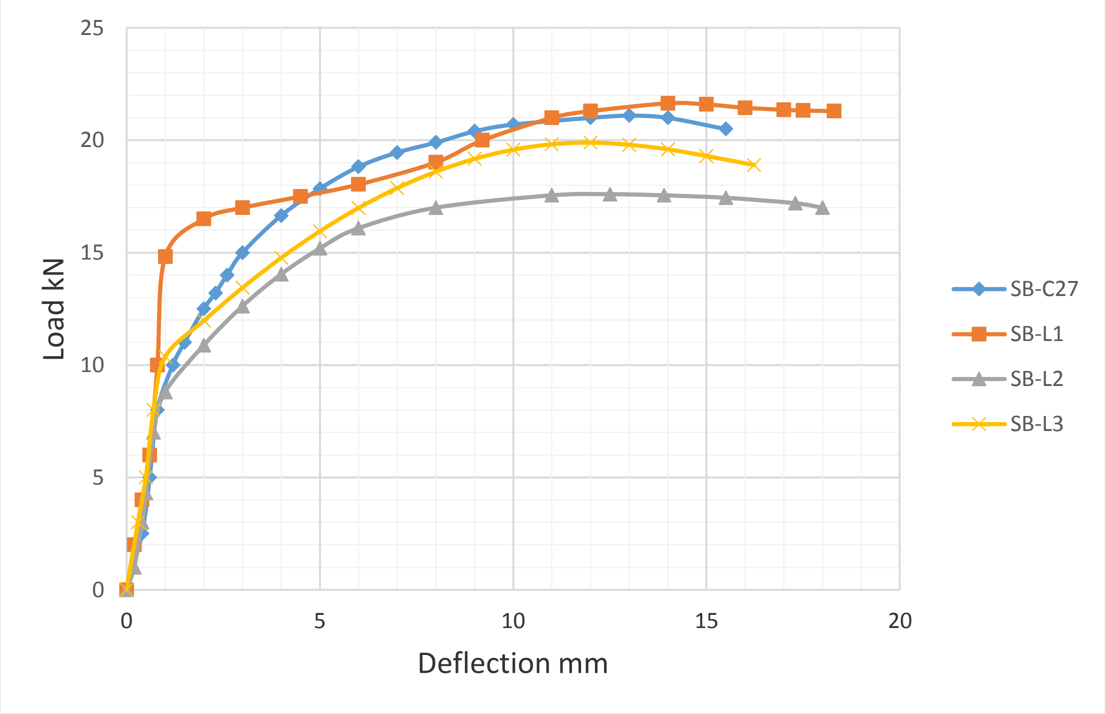
Table (4-8): The ultimate Load and maximum deflection value for SB-C27, SB-L1, SB-L2, SB-L3 slabs and their counterparts of Attapulgite.

Specimen Symbol	*Ultimate Load kN Pu*	Difference in Ultimate-load as compare with reference %	*Max Deflection mm*	Difference in deflection as compare with reference %
SB-C27	23.63	_	16.51	_
SB - L1	21.65	-8.38	15.42	-6.60
SB – L2	17.60	-25.52	18.00	9.02
SB – L3	19.89	-15.83	16.23	-1.69
SA-C27	21.42	-	18.30	-
SA - L1	20.50	-4.29	16.00	-12.57
SA – L2	16.00	-25.30	19.60	7.10
SA – L3	18.91	-11.72	16.53	-9.67

From Table (4-8), it’s clear that the continuous truss shear connector in **SB-C27** and **SA-C27** slabs enhanced in ultimate load capacity by about **9.14%, 4.49%** when compared with **SB-L1** and **SA-L1** slabs: respectively. Also, in case of using Attapulgite **SA-C27** slab shows increasing in the ductility index and toughness by about (**2.63%, 11.43%, 23.86%**): respectively for ductility and by about (**22.95%, 28.00%, 20.57%**) for toughness as compared with **SA-L1, SA- L2, SA-L3** slabs. This behavior unlike to the case of using crushed bricks, where **SB-C27** slab exhibits increasing in the toughness when it compared with **SB-L2, SB-L3** by about (**13.45%, 15.74%**) but it shows decreasing by about (**8.88%**) when compared with **SB-L1** slabs. On the other hand, **SB-C27** slab shows decreasing in the ductility index by (**10.65%, 23.55%, 15.21%**) as compared with **SB-L1, SB-L2, SB-L3** slabs: respectively, as shown in Figure (4-7) & Figure (4-8).



Figure(4-7): Load-Deflection Profile for SA-C27 ,SA-L1 ,SA-L2& SA-L3 Slabs



Figure(4-8): Load-Deflection Profile for SB-C27,SB-L1,SB-L2& SB-L3 Slabs

Figure (4-9) & Figure (4-10) show toughness and ductiliy index for all slabs.

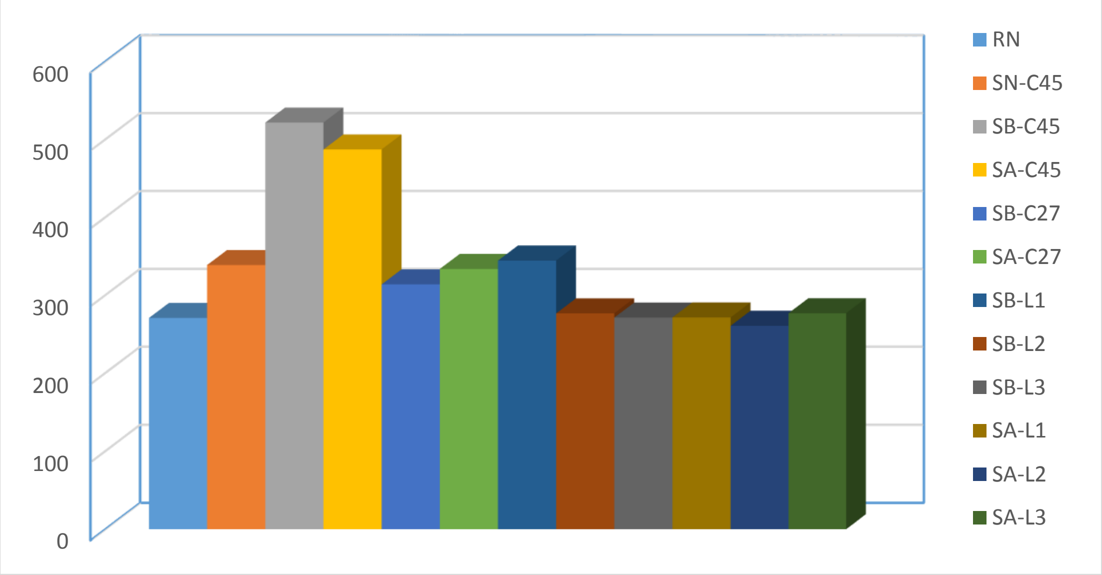


Figure (4-9): Area Under Load Deflection Curve (Toughness)for All Slab Models.

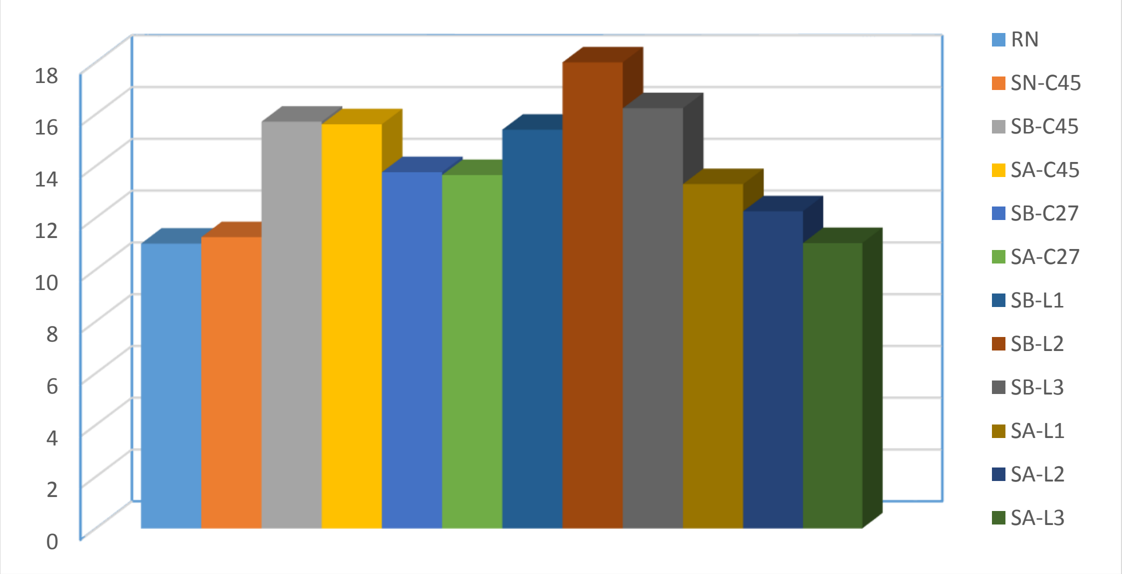


Figure (4 -10): Ductility Index for All Type of Slab Models

4.4.2 Cracking Behavior

Cracks formation were monitored during the test to evaluated the behavior of the sandwich slab specimens with multiple variables and to make a comparison between the slabs in cracking behavior. The first cracking loads, cracking patterns and maximum crack width in bottom layer at the failure of all slabs will be shown in the next subsections.

4.4.2.1 First Cracking Loads

For all slabs, the first cracking loads ($\mathbf{P_{cr}}$) which were gotten from the experimental tests are presented in Table (4-9). In general, the noticeable first crack load of all slabs varied with the range (17.04% to 43.10%) according to the average of the experimental ultimate loads. Tables (4-9) shows the first cracks load and the ratio of first crack load to the ultimate load.

Table (4-9): First Cracks Load and Ultimate Load of All Slabs

Specimen Symbol	*Load kN*		$\frac{P_{cr}}{P_u}$ %
	Pcr	*Pu*	
RN	11.86	33	35.94
SN - C45	10	30	33.33
SA - C45	8	25.89	30.90
SA - C27	5.6	19.86	28.19
SA - L1	6.6	20.5	32.19
SA - L2	4	16	25
SA - L3	4.5	18.91	23.79
SB – C45	12	27.84	43.10
SB – C27	8.3	21.20	39.15
SB – L1	6	20.65	29.05
SB – L2	3	17.60	17.04
SB – L3	6.6	19.89	33.18

4.4.2.2 Cracking Pattern and Crack Width

At early loading stages, the deformation was linear elastic. After that the loads were increased till the first crack appeared at the tension face of lower wythe of the slab.

With load increasing, many flexural cracks began to appear first at the maximum moment region and under the applied load at the lower tension face throughout the slab. With gradual increases load, the crack numbers increased and cracks became wider and progressed upwards throughout the other layers, and also noticed through two sides of the slab specimens. As the applied loads are increases, a reduction in stiffness occurred and one mode of failure progressed that can be classified as a flexural failure by steel yielding of tension. After that, the concrete in compression face is crushed.

The solid slab model undergoes the same stages of behavior, but it has higher stiffness, the load has been increased gradually until the sudden failure by crushing of concrete is occurred. The number of cracks was reasonable and the crack width was larger as compared to sandwich models.

All sandwich slab models showed similar behavior, the failure was gradual and they fail due to steel yielding. **SN-C45** slab has less number of cracks as compared with **SA-C45** slab and **SB-C45** slab. **SA-C45** slab has the more number of cracks and small crack width as compared to other two sandwich slab as shown in Plate (4-3).

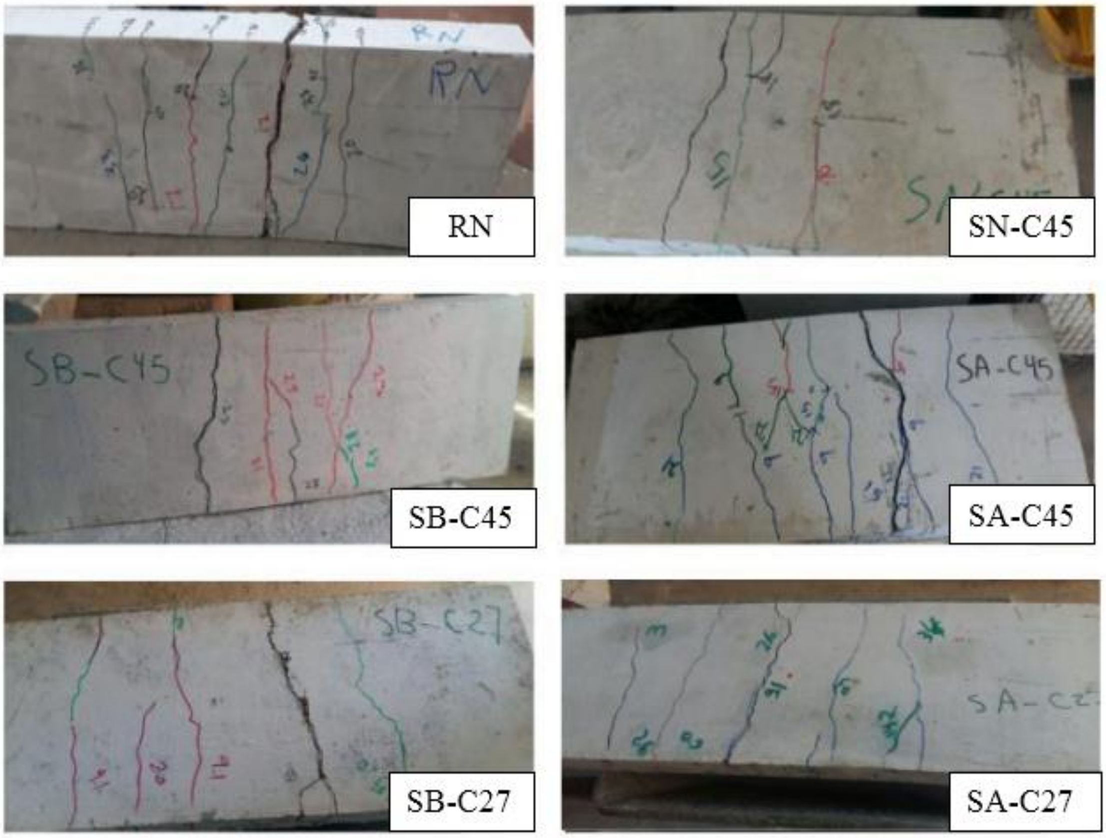


Plate (4-3): Cracks Patterns for Solid Slab and Sandwich Slab with Continuous Shear Connectors at Lower Face of Bottom Layer

In general, the use of (2/3) area of shear connector reinforcement increased the cracks number and reduces the crack width. While reducing the angle of bent to 27˚, cracks number reduce and the crack width increase in comparison with the sandwich slabs with 45˚ shear connectors bent angle. As shown in Plate (4-4).

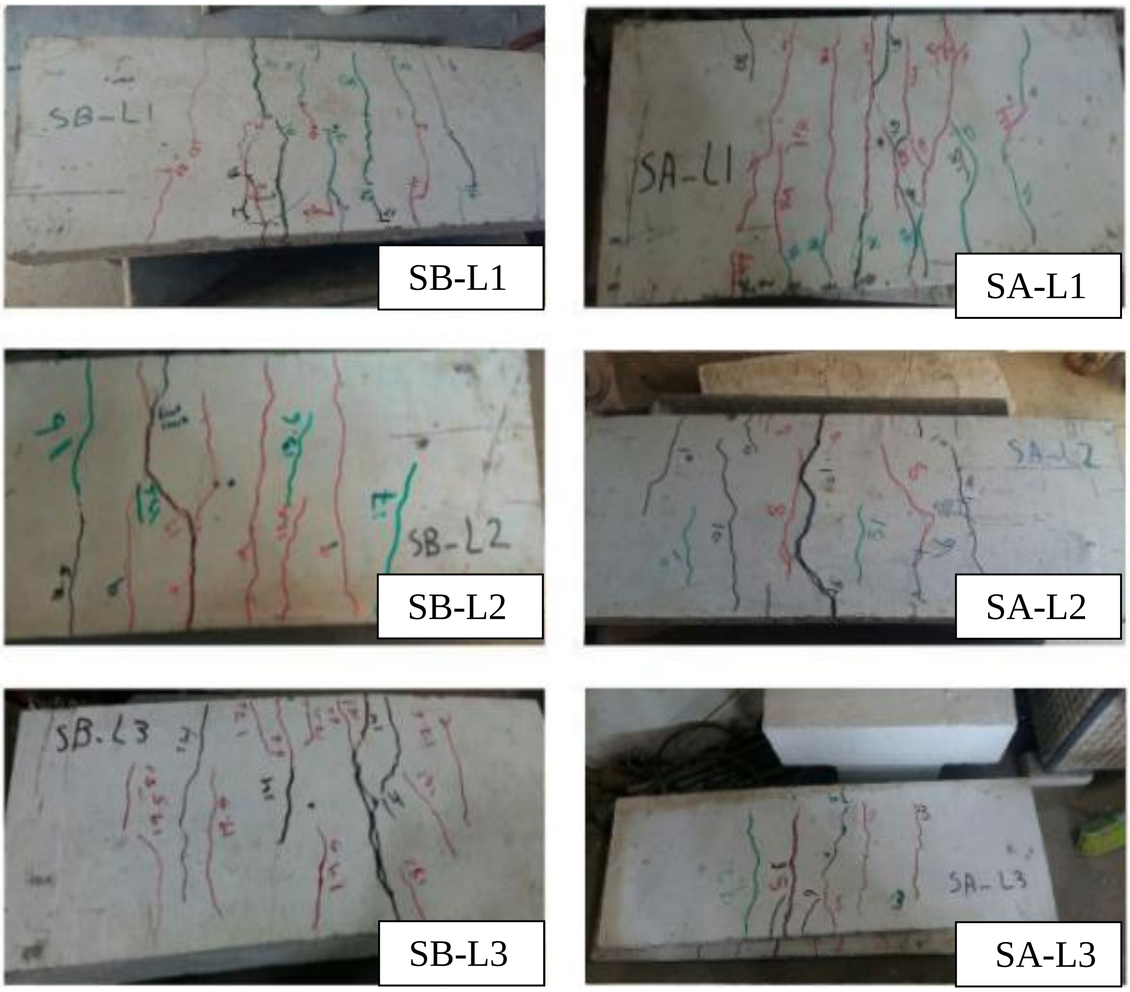


Plate (4-4): Cracks Patterns for Sandwich Slab with Discrete Shear Connectors at Lower Face of Bottom Layer

4.4.3 Concrete Surface Strain

The strains of concrete were measured by using the Vernier caliper as it was explained in chapter three, the strain was measured in concrete at two layers. The results of strain for all slabs represented in Figures (4-11) to (4-22). It’s clear that all sandwich slabs have high degree of composite action in the low applied load stage. But when the load increase the composite degree will be decreased.

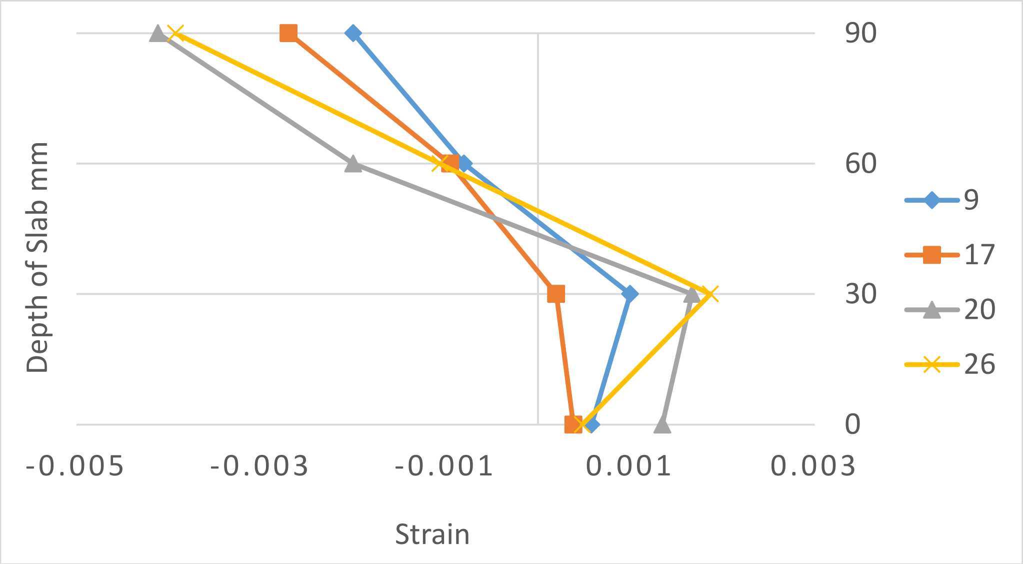


Figure (4-11): Strain disparity across the Depth of RN Slab at Various Load Stages

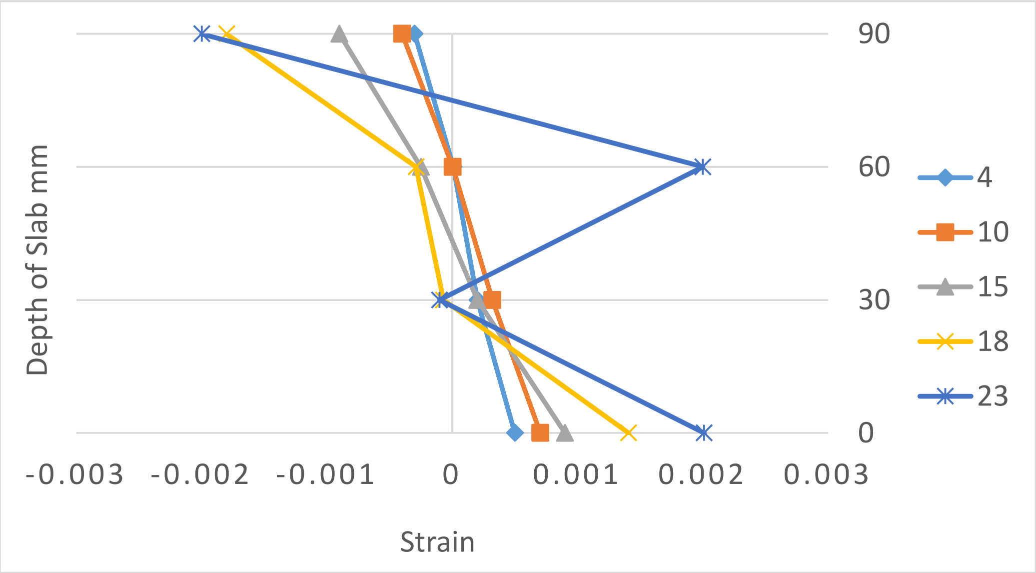


Figure (4-12): Strain disparity across the Depth of SN-C45 Slab at Various Load Stages

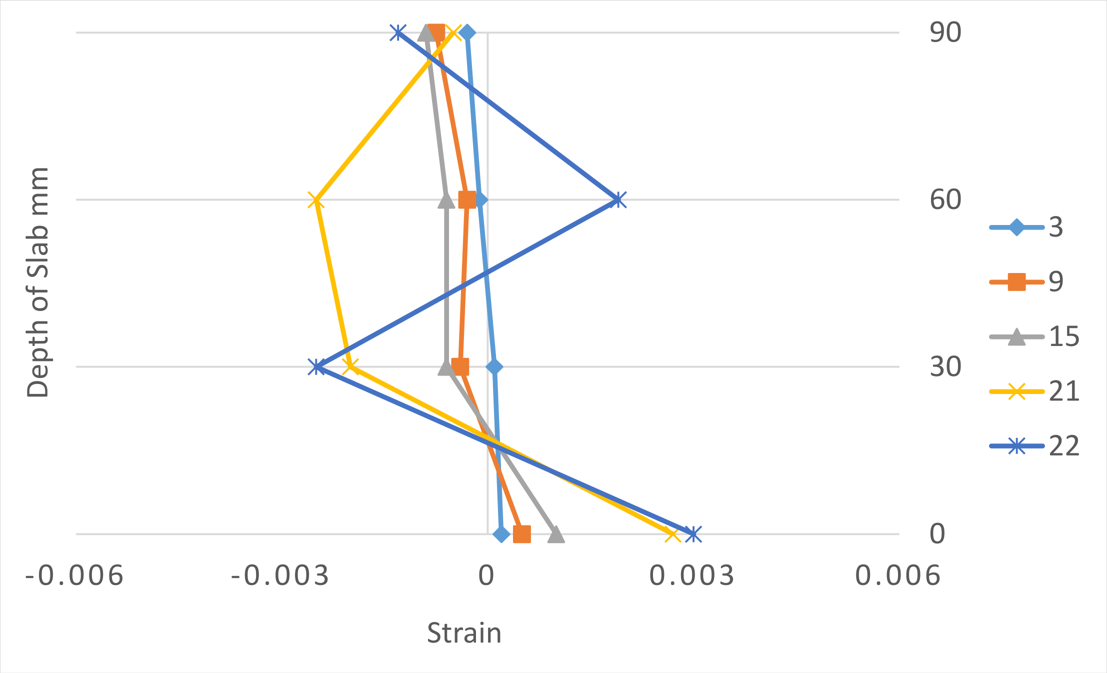


Figure (4-13): Strain disparity across the Depth of SA-C45 Slab at Various Load Stages

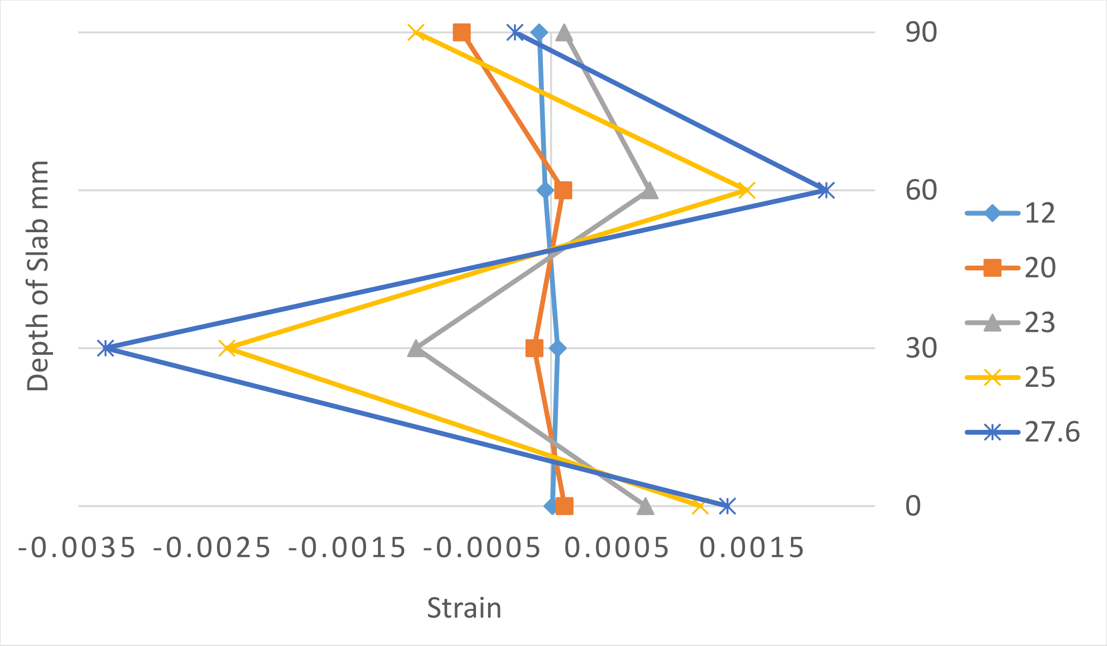


Figure (4-14): Strain disparity across the Depth of SB-C45 Slab at Various Load Stages

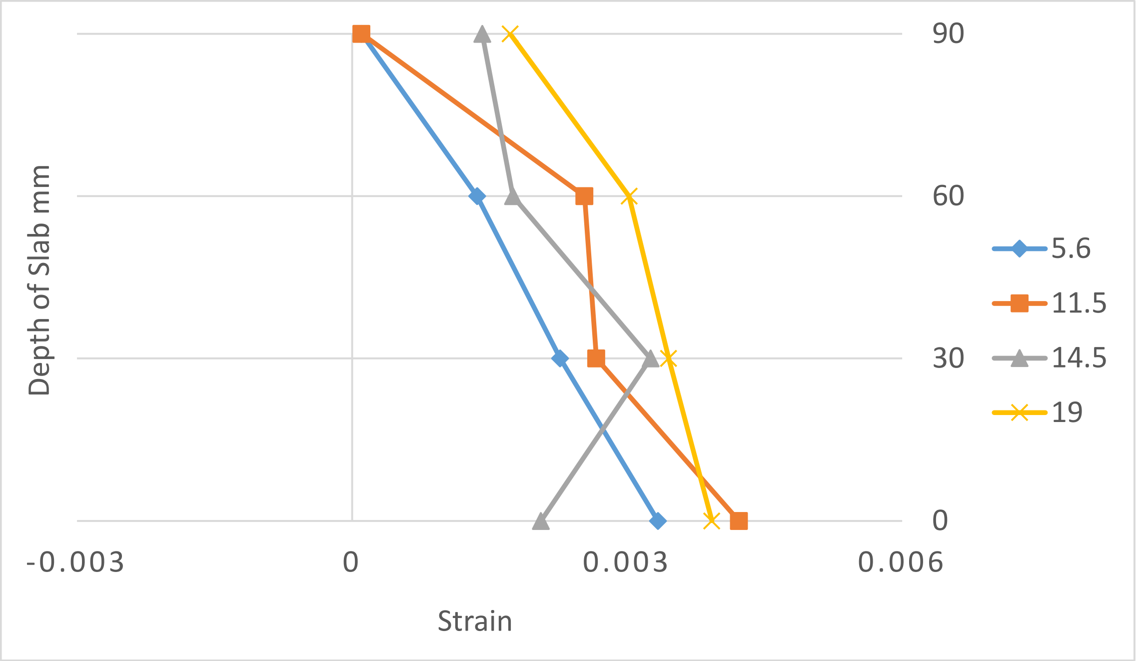


Figure (4-4): Strain disparity across the Depth of SA-C27 Slab at Various Load Stages

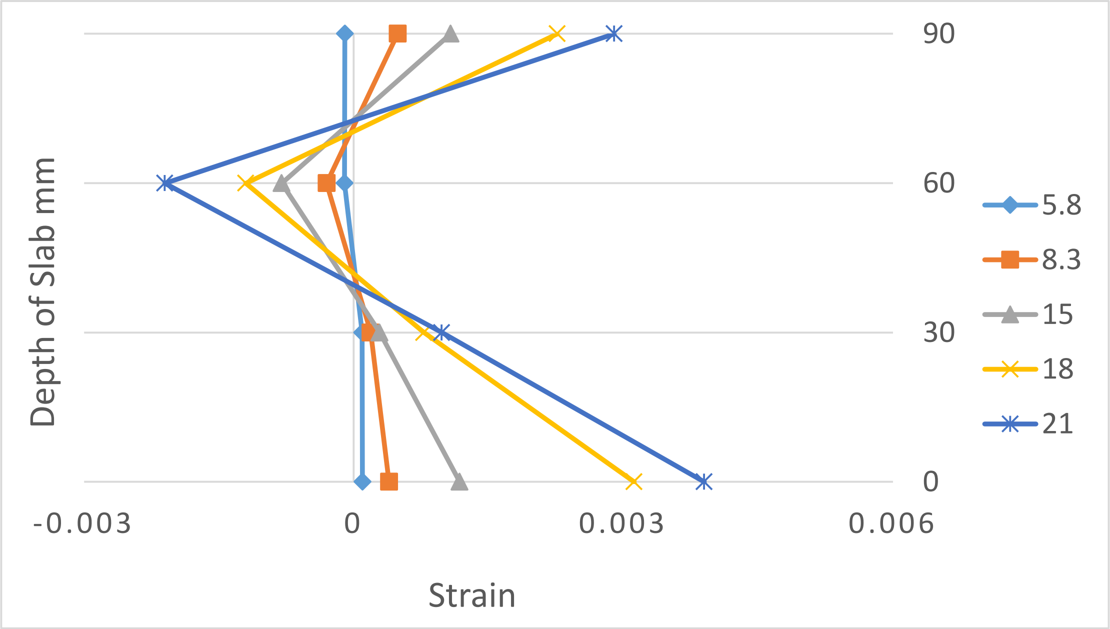


Figure (4-16): Strain disparity across the Depth of SB-C27 Slab at Various Load Stages

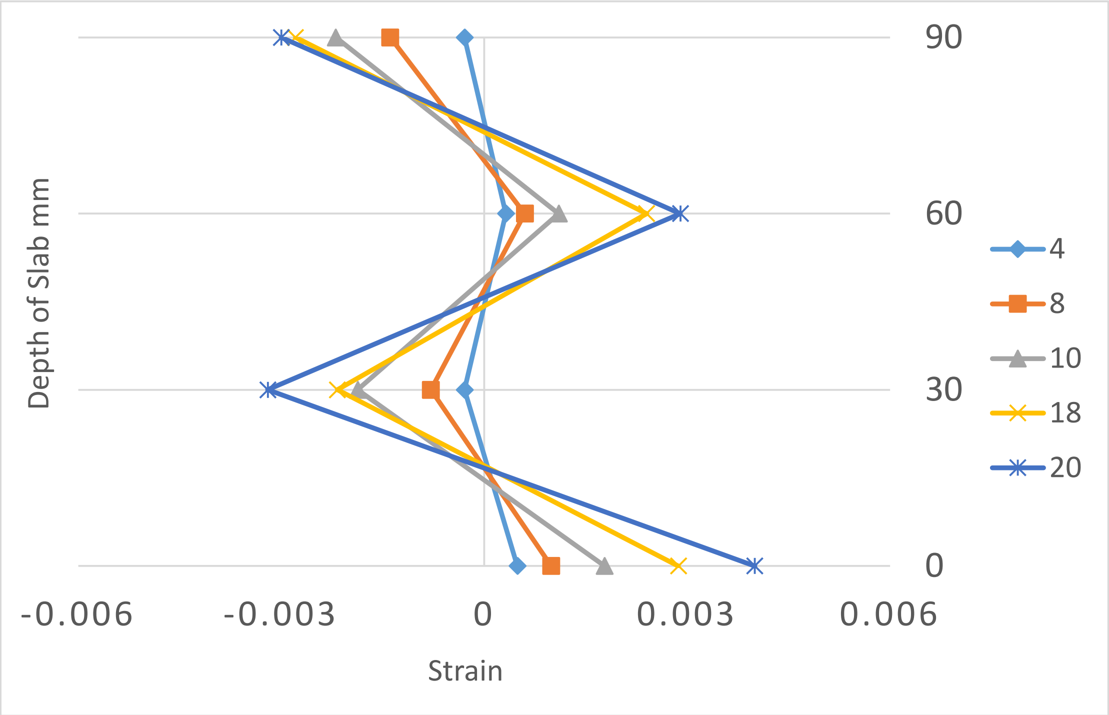


Figure (4-5): Strain disparity across the Depth of SA-L1 Slab at Various Load Stages

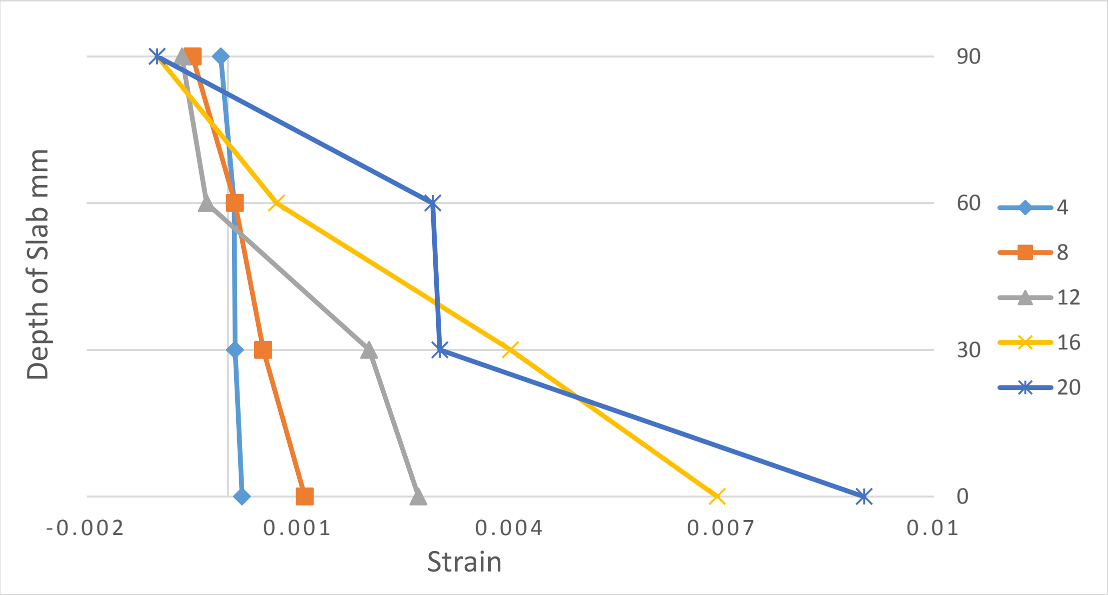


Figure (4-18): Strain disparity across the Depth of SB-L1 Slabs at Various Load Stages

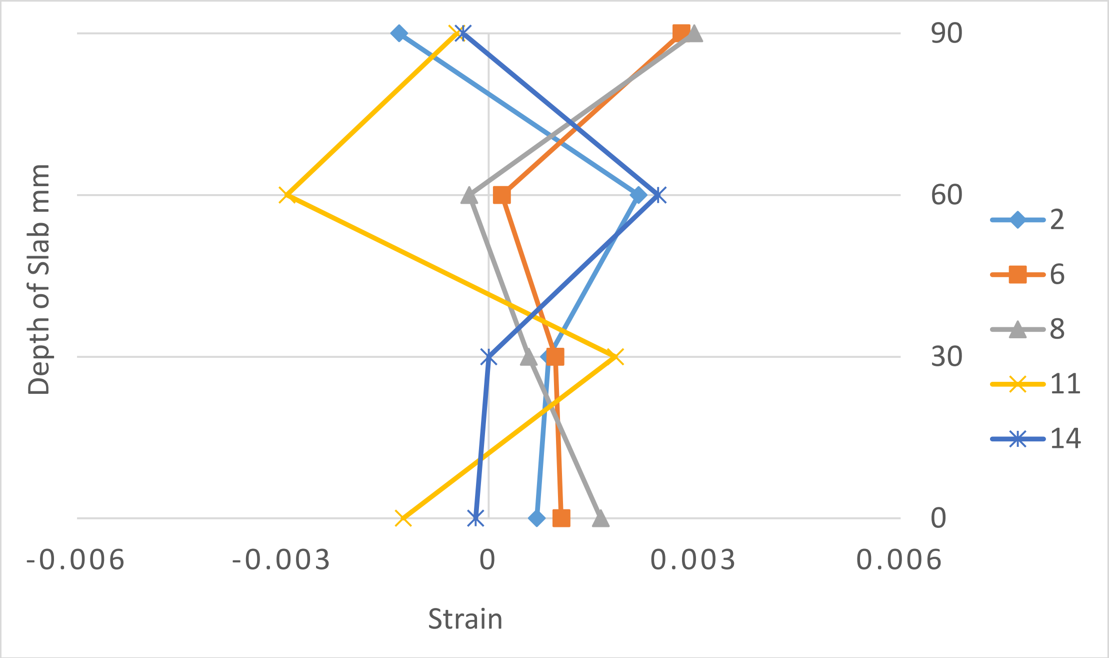


Figure (4-6): Strain disparity across the Depth of SA-L2 Slab at Various Load Stages

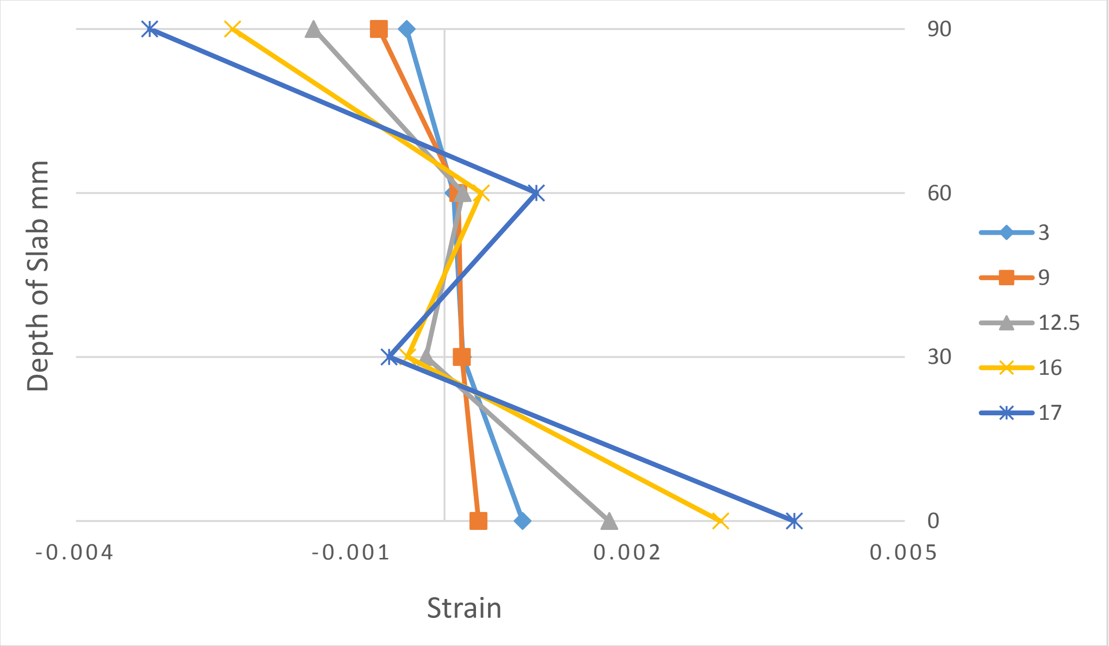


Figure (4-20): Strain disparity across the Depth of SB-L2 Slab at Various Load Stages

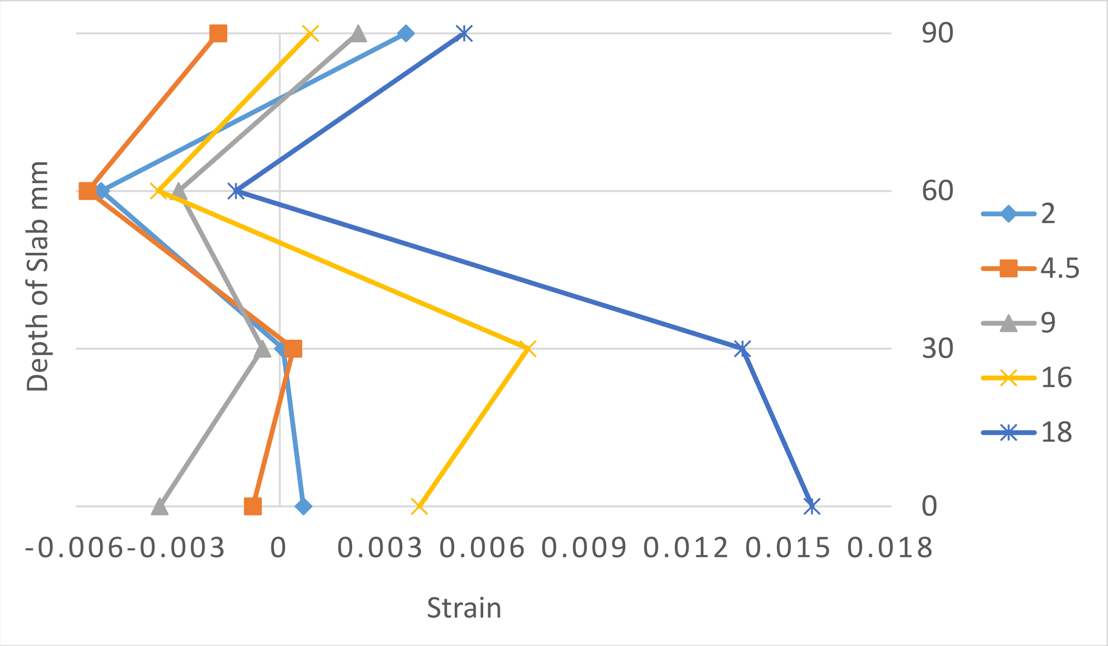


Figure (4-21): Strain disparity across the Depth of SA-L3 Slab at Various Load Stages

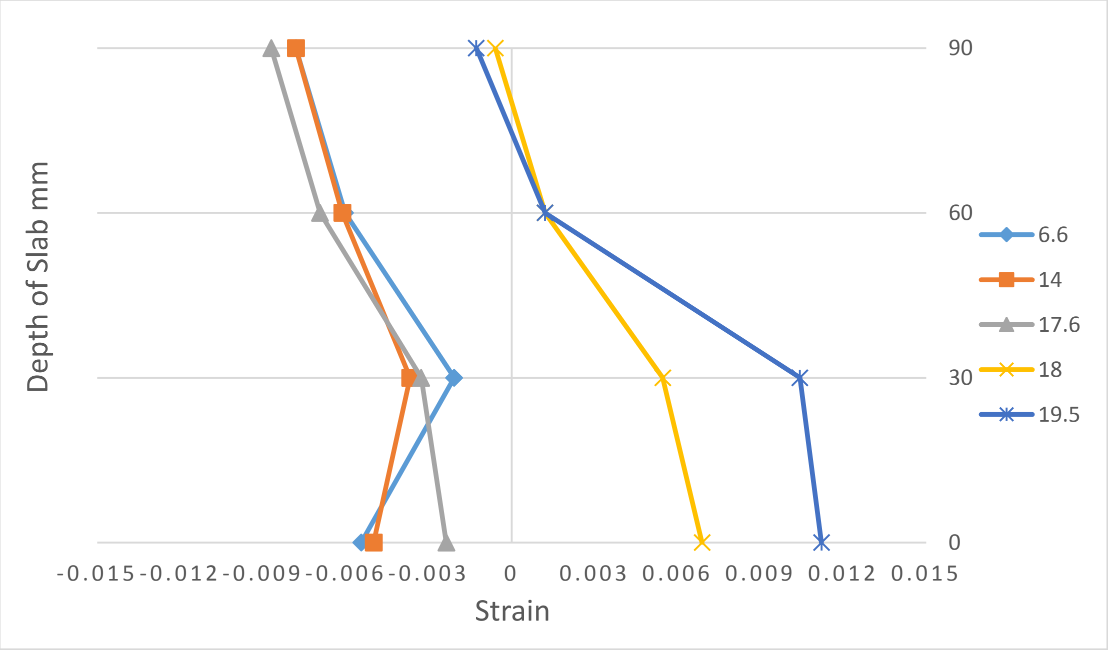


Figure (4-7): Strain disparity across the Depth of SB-L3 Slab at Various Load Stages

4.4.4 Load Slip Behavior

At the initial loading stages of behavior of tested slabs, the steel truss shear connectors will resist the applied shear forces in addition to the adhesion between the isolation layer (polystyrene) and concrete layers. When the first crack appeared the adhesion between the layers disappeared. So most of the shear forces were supported by the steel truss connectors at this stage. In the current study, all slabs show a high degree of composite action till the failure stage when the ultimate load was reached (16 kN for SA-L2) to (30 kN for SN-C45).

From Figures (4-23 to 4-25), it is clear that the slip increases when the type of aggregate in concrete layers changes. **SN-C45** slab model shows more composite action and small slip when compared with **SA-C45 & SB-C45** slabs. This is may be owing to the density of concrete which increases with the increase in the compressive strength. Also, **SB-C45** slab exhibits similar behavior when compared with **SA-C45** slab due to the LWA weakness which gave lesser resistance to slip.

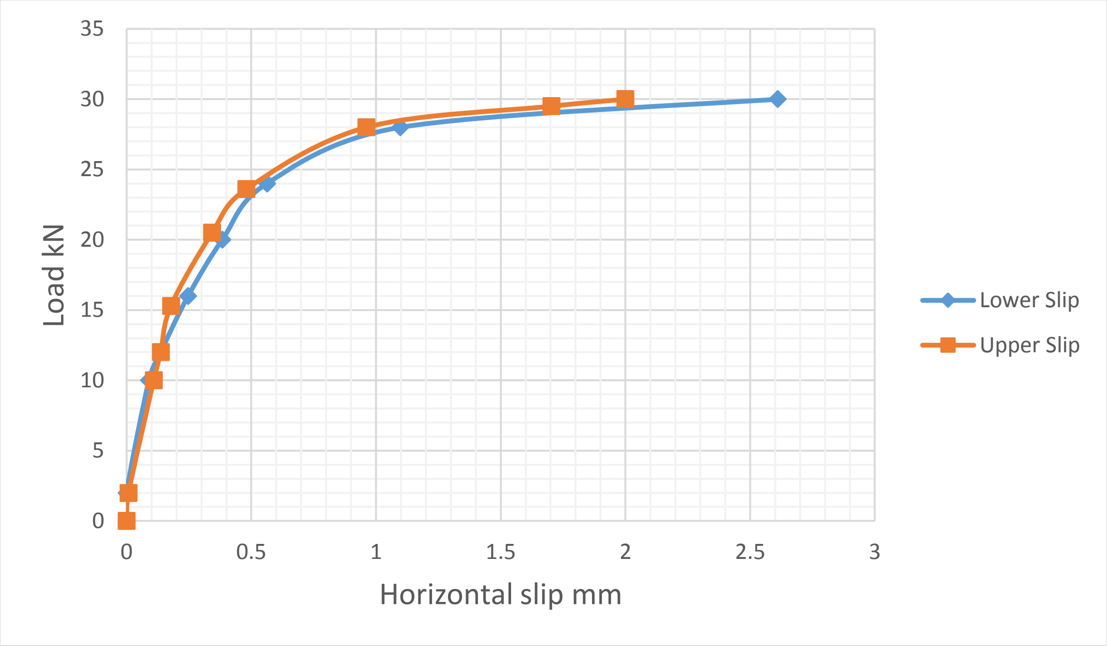


Figure (4-23): Load - Slip Relationship for **SN-C45** Slab

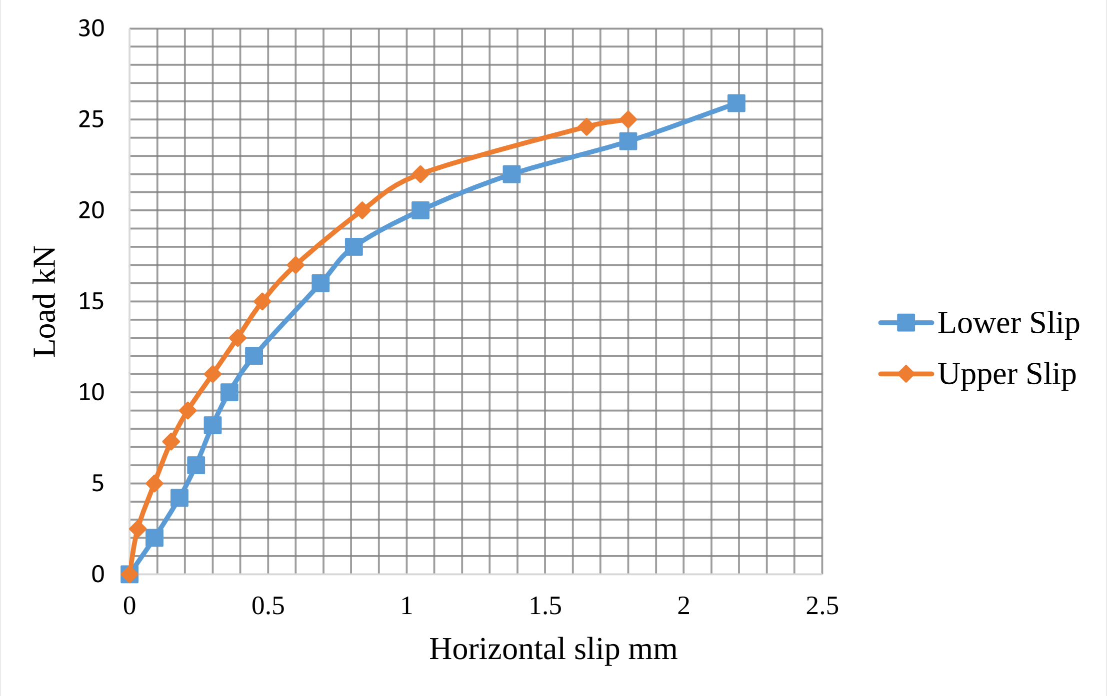


Figure (4-24): Load - Slip Relationship for **SA-C45** Slab

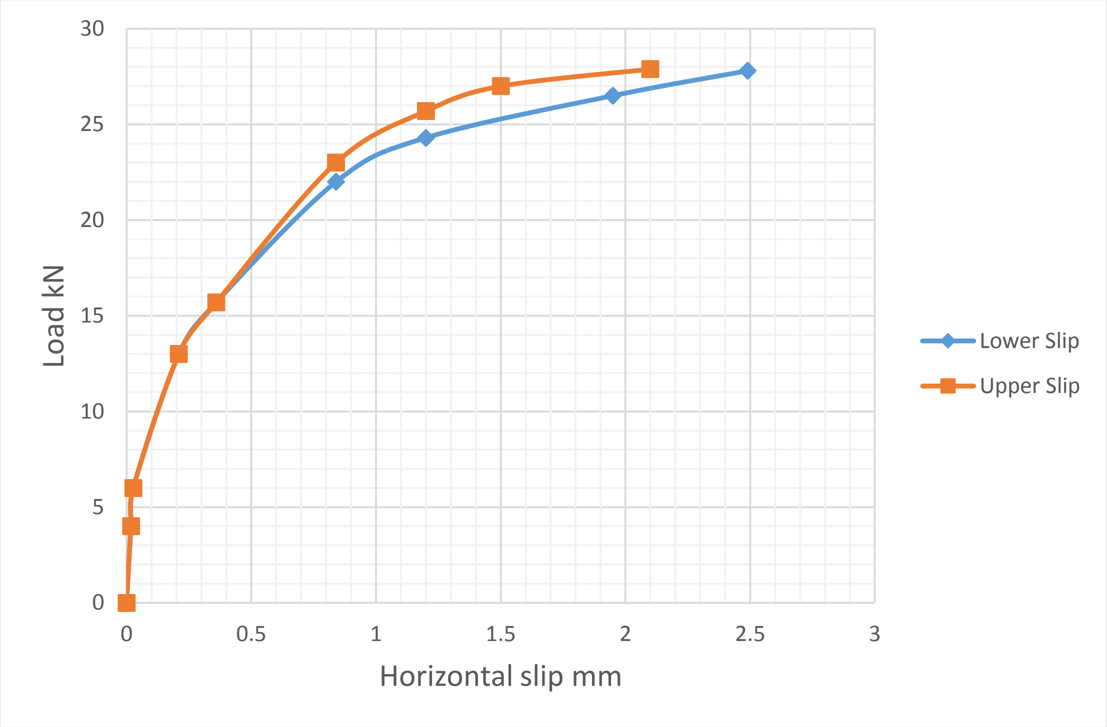


Figure (4-25): Load - Slip Relationship for **SB-C45** Slab

As illustrated in figures (4-26 to 4-28), **SA-L2** has a large slip as compared with **SA-L1**& **SA-L3,** accompany with a low degree of composite action, this may due to the significant impact of the shear connectors position.

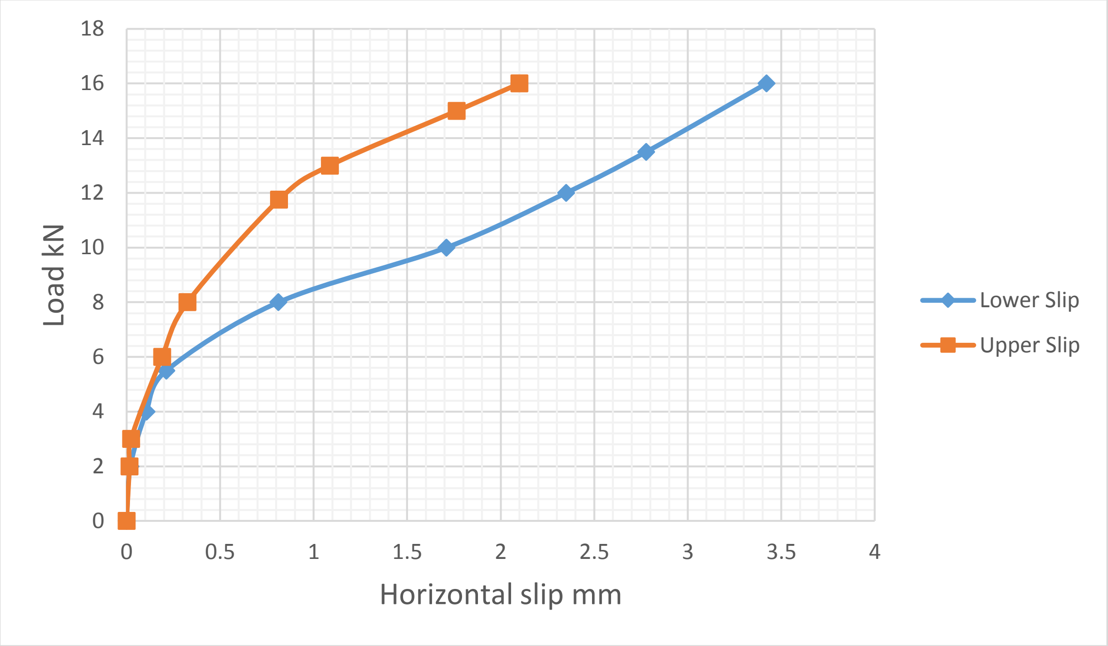


Figure (4-26): Load - Slip Relationship for SA-L2 Slab

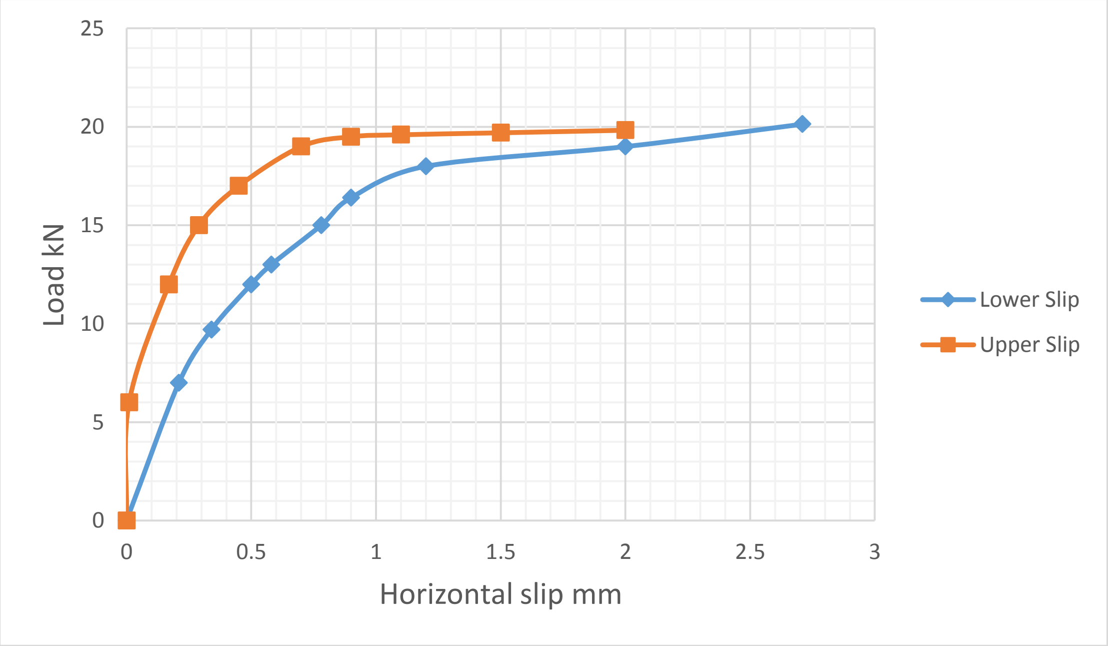


Figure (4-27): Load - Slip Relationship for SA-L1 Slab

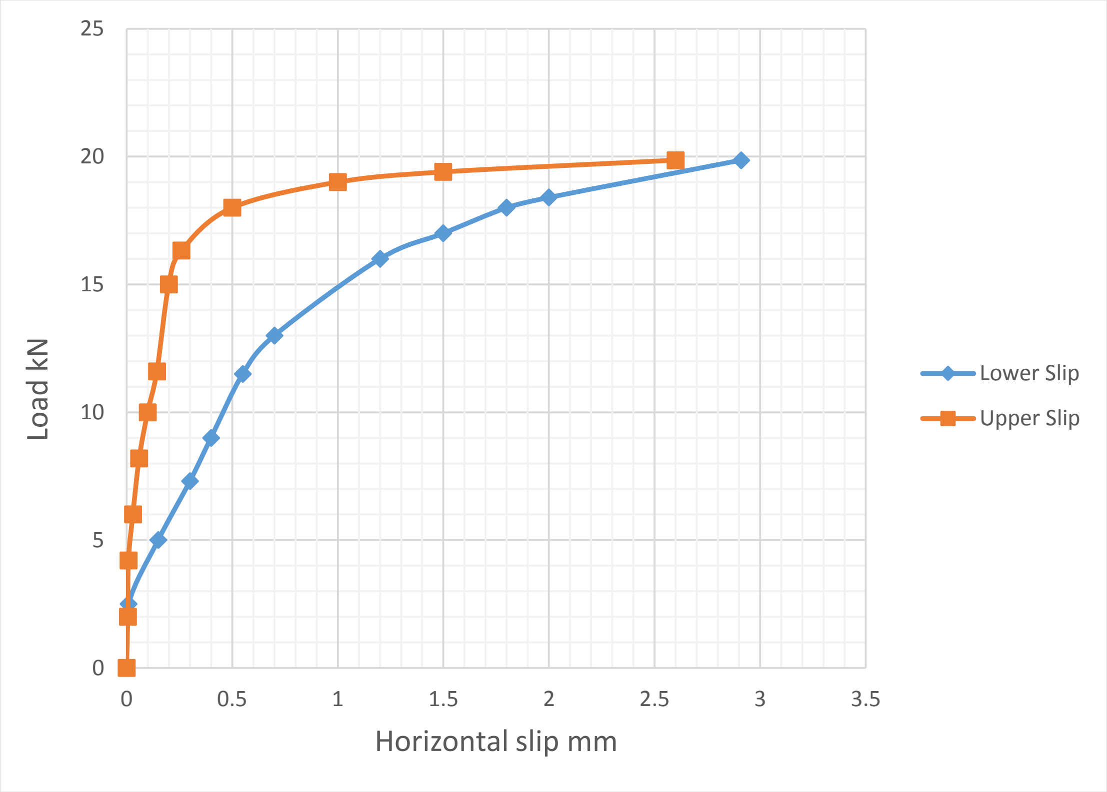


Figure (4-28): Load - Slip Relationship for SA-L3 Slab

Also, because of the presence of large steel shear connectors area in the ends of one-fourth of the span, **SB-L2** show large slip as compared with **SB-L1** & **SB-L3,** accompany with a low degree of composite action, as shown in figures (4-29 to 4-31).

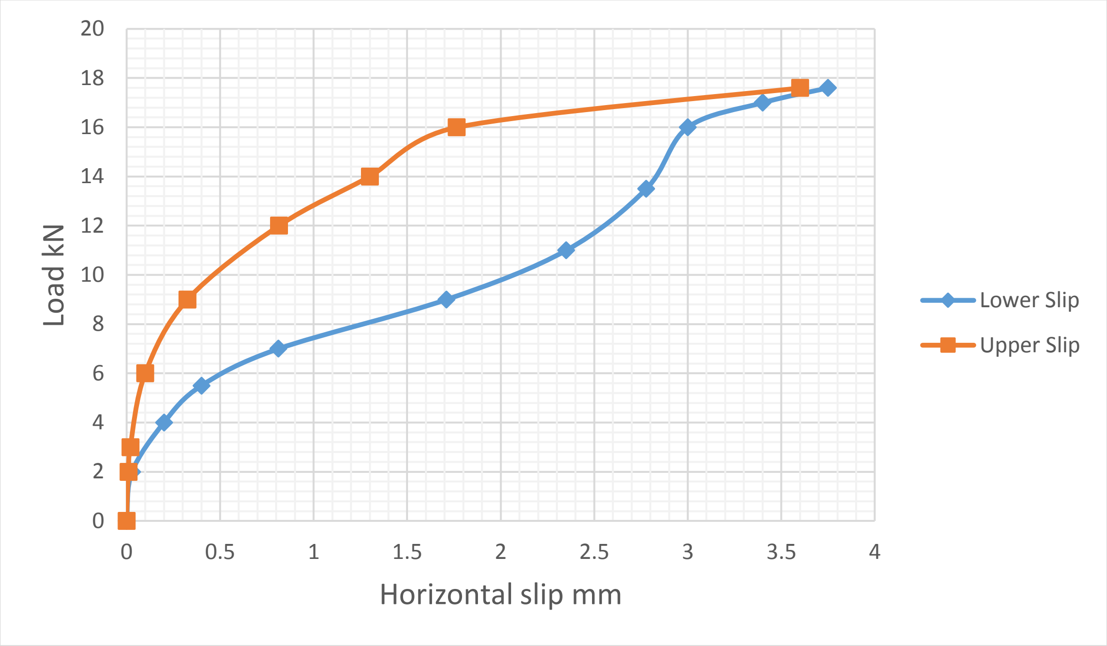


Figure (4-29): Load - Slip Relationship for SB-L2 Slab

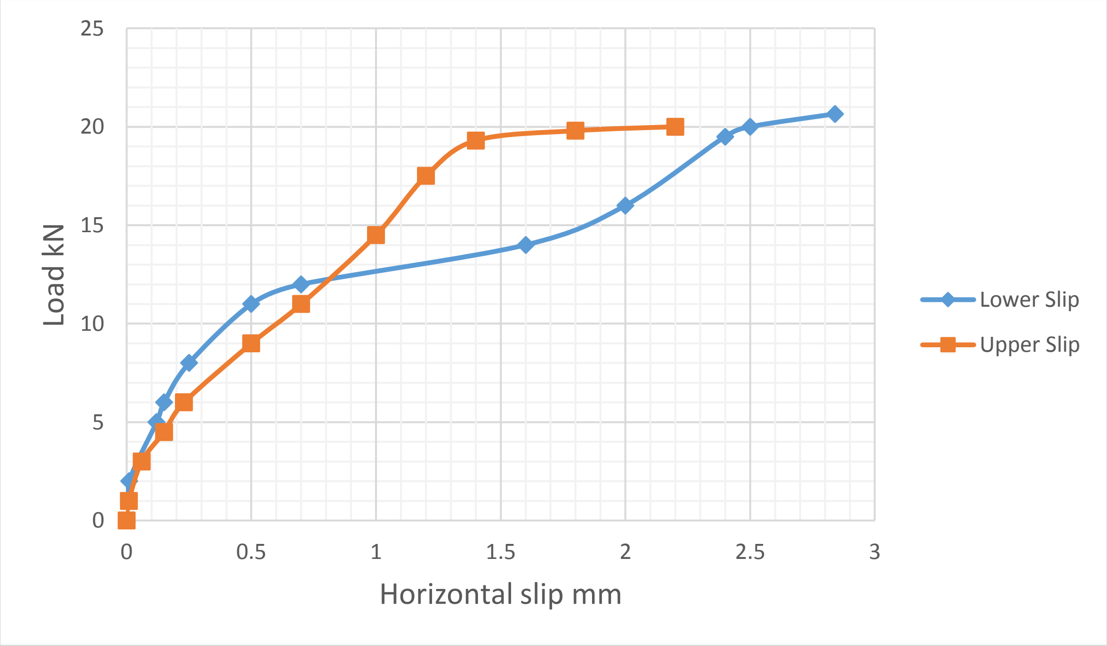


Figure (4-30): Load - Slip Relationship for SB-L1 Slab

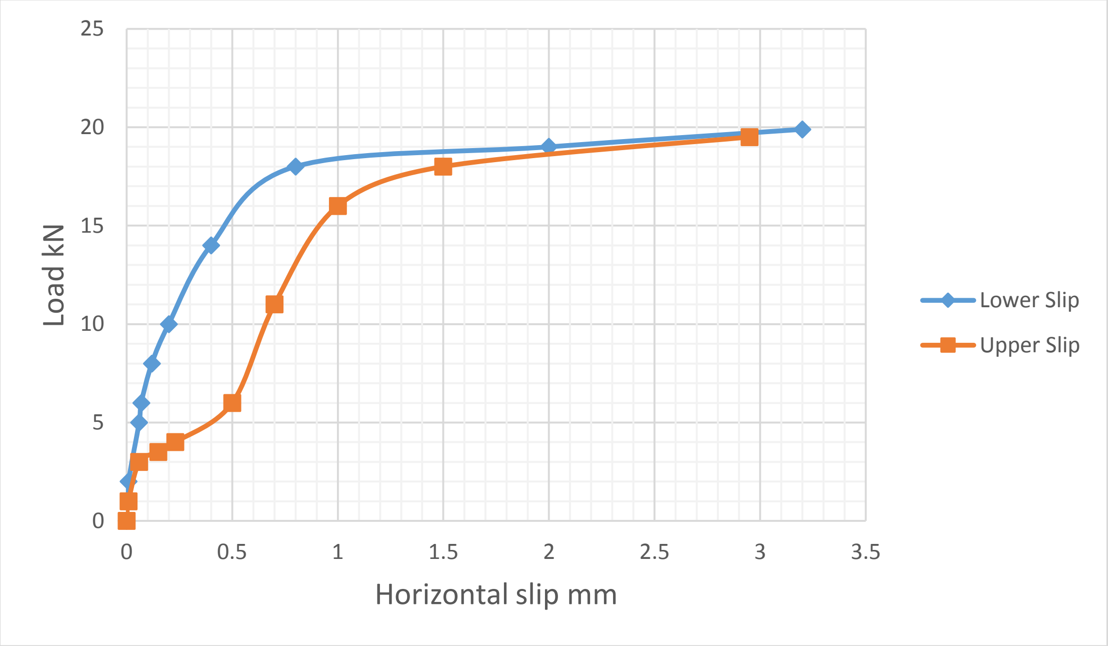


Figure (4-31): Load - Slip Relationship for SB-L3 Slab

SA-C27 & **SB-C27** slabs exhibit decreasing in composite action with an increase in the horizontal slip as compared with **SA-C45** & **SB-C45**; respectively. As presented in figures (4-32 and 4-33). On the other hand, SA-C27 has a less composite degree and a less horizontal slip when comparing it with **SB-C27**, due to the difference in density between the inner layer and outer layers.

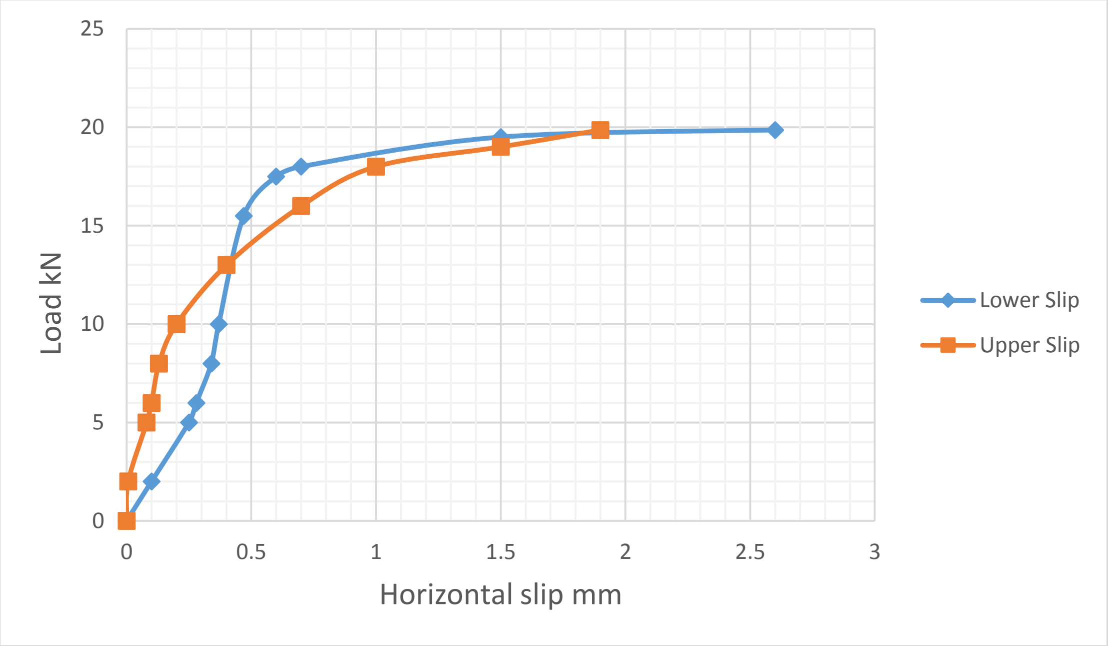


Figure (4-32): Load - Slip Relationship for SA-C27 Slab

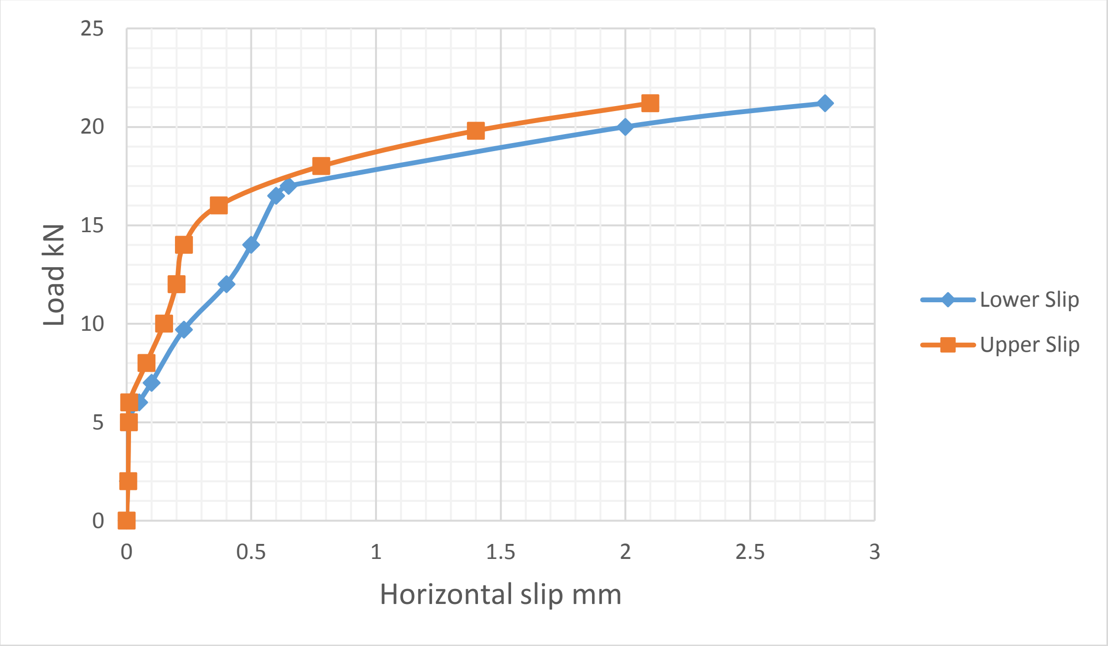


Figure (4-33): Load - Slip Relationship for SB-C27 Slab

Chapter Five

Conclusions and Recommendations

Conclusions and Recommendations

5.1 General

The main aim of this work is to investigate the structural sustainability of light weight sandwich concrete slabs. This chapter present a review of the most important conclusions obtained from experimental tests results for sandwich concrete slabs under two lines load. Also, the head points of recommendations and suggestion for future work are offered.

5.2 Conclusions

1. Structural lightweight aggregate concrete, with a cylinder compressive strength about 25.2 MPa and air dry density of 1954 kg/m could be produced from waste crushed bricks as a coarse lightweight aggregate, natural sand, and high-performance superplasticizer (PC-200). These values agree with the requirements of structural lightweight concrete according to ACI 213R-03 and ASTM 330-05 and conforming to the lower limit of compressive strength of 17.0 MPa and the air dry density range 1680–1920 kg/m^3. On the other hand, SLWAC can be produced by another type of local rocks. Lightweight concrete that contains Attapulgite as a coarse aggregate has a cylinder compressive strength about 21 MPa and air

dry density of 1940 kg/m^3.these numbers also conforms to the requirements structural lightweight concrete according to ACI 213R-03 and ASTM 330-05.

2. The major advantage of the sandwich principle reduces the total weight by about **31.21%** and enhances the deflection by about **22.72%** as compared with a solid slab. Also, the toughness and the ductility index (μΔ) increase by **25.11%**,**2.27%.** while the strength reduces by **9.09%.**
3. The use of clay bricks or Attapulgite as a lightweight coarse aggregate with continuous shear connectors bent with inclined angle 45° will reduces the total weight. moreover, it enhances the deflection, ductility index (μΔ), toughness in comparison with sandwich normal weight aggregate.

4. The presence of shear connectors in the ends one-fourth of span has significant performance more than in the center of a panel. For the same shear connector steel area. Therefore, **SB-L1** slab exhibits increasing in the ultimate load by about **(23.01%, 8.85%)** as compared with **SB-L2 & SB-L3**, this increment accompanies by enhancing in the toughness by about (**24.52%, 27.02%**). While maximum deflection value is reduced by about (**14.33%, 4.99%**), as well as ductility index decreases by about (**14.44%, 5.12%**). The results indicate that behavior of slabs which contain Attapulgite, to some extent, similar to the behavior of those containing crushed bricks.

5. The using continuous truss shear connectors bent in 45° instead of 27° increases the ultimate load, maximum deflection value, ductility index (μΔ), and toughness. While total weight are increases.

6. The results indicate that continuous truss shear connector shows **SB-C27, SA-C27** enhanced in the ultimate load capacity by about **9.14%, 4.49%** when compared with **SB-L1, SA-L1**: respectively.

7. The Number of cracks in all sandwich slabs which contain Attapulgite is more than the number of cracks in the other slabs. And the distance between cracks was converge more than cracks in the normal aggregate sandwich slab.

8. Using discrete W-shape shear connector increases the number of cracks and the distance between cracks is converged more than sandwich slabs when using continuous shear connectors.

9. The Position of the shear connector and inclined bent angle have a significant effect on slip value and composite degree.

5.3 Recommendations for Future Work

1- Using different types of concrete in the outer layers of the concrete sandwich slab such as self-compaction concrete, high strength concrete, reactive powder concrete...etc.

2- Studying the reinforced concrete sandwich slabs with different boundary conditions or different types of loading such as concentrated load, dynamic, and impact loading.

3- Investigate the behavior of two-way sandwich concrete slabs.

4- Studying the behavior of sandwich concrete slab subjected to fire.

5- A theoretical investigation can be made to determine the ultimate strength of the concrete wall panels subjected to concentric and eccentric loading.

6- Other different types of the shear connector can be used, such as circular, spirals, shear studs’ connectors, …etc.

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Appendix-A

Material Properties

A-1 Cement:

Table (A-1) Chemical Analysis of the Cement

No.	Compound composition	Chemical composition	Weight (%)	Iraqi specification No. 5/1984
1	Lime	CaO	62.23	-
2	Silica	SiO_2	19.50	-
3	Alumina	Al_2O_3	4.56	-
4	Iron oxide	Fe_2O_3	3.56	-
5	Magnesia	MgO	2.95	5% max
6	Sulfate	SO_3	2.59	2.85 max
7	Loss on ignition	L.O.I	3.25	4% max
8	Insoluble residue	I.R	1.26	1.5% max
9	Lime saturation factor	L.S.F	0.95	0.66-1.02
10	Tricalcium aluminates	C_3A	6.06	-
11	Tricalcium silicate	C_3S	57.47	-
12	Diacalcium silicate	C_2S	12.55	-
13	Tetracalcium alumina ferrite	C_4AF	10.83	-

Table (A-2) Physical Properties of the Cement

Physical properties	Test results	Iraqi specification No. 5/1984
Fineness using Blain air permeability apparatus (m^2/kg)	328	Not less than 230
Setting time using Vicat's instrument		
Initial (min.)	110	Not less than 45
Final (min.)	225	Not more than 600
Compressive strength for cement paste		
3 days age (N/mm^2)	21.5	Not less than 15
7 days age (N/mm^2)	31.2	Not less than 23

A-2 Fine Aggregate:

Table (A-3) Grading of Fine Aggregate

No.	Sieve size	Passing (%) fine aggregate	Passing (%) Iraqi specification 45/1984 for zone No.(2)
1	4.75 mm	95	90-100
2	2.36 mm	78	75-100
3	1.18 mm	63	55-90
4	600 µm	49	35-59
5	300 µm	26	8-30
6	150 µm	5	0-10

A-3 Coarse Aggregate:

A-3-1 Lightweight Coarse Aggregate(Attpulgite)

Table (A-4) Physical Properties of Attpulgite Coarse Lightweight Aggregate

Test	results		specifications	limits
	befor burning	after burning		
Loose uint weight dry (kg/m³)	**952**	**755**	**ASTM C29**	**≤880**
Rodding unit weight dry (kg/m³)	**1018**	**795**	**ASTM C29**	**------**
Loose bulk density unit weight ssd (kg/m³)	**1280.44**	**1015.475**	**ASTM C29**	**------**
Rodding bulk density unit weight ssd (kg/m³)	**1369.21**	**1069.275**	**ASTM C29**	**------**
void(loose)%		**44.7**	**ASTM C29**	**------**
void(rodding)%		**41.7**	**ASTM C29**	**------**
density (od) (kg/m³)		**1359**	**ASTM C127**	**------**

density (ssd) (kg/m^3)		**1828**	**ASTM C127**	**------**
apparent density (kg/m^3)		**2566**	**ASTM C127**	**------**
relative density (kg/m^3)		**1.36**	**ASTM C127**	**≤2.6**
relative density (kg/m^3)		**1.83**	**ASTM C127**	**------**
apparent relative density (kg/m^3)		**2.57**	**ASTM C127**	**------**
absorption %		**34.5**	**ASTM C127**	**5-30**
Sulfate Content SO_3		**0.055%**	**IQS No.45/1984**	≤ 0.1%
Clay		**0.17%**	**IQS No.45/1984**	≤ 0.2%

A-3-2 Lightweight Coarse Aggregate(crushed bicks)

Table (A-5) Physical Properties of Crushed Bricks Coarse Lightweight Aggregate

Test	results	specifications	limits
loose uint weight (bulk density unit weight) dry (kg/m^3)	**805**	**ASTM C29**	**≤880**
rodding unit weight (bulk density unit weight) dry (kg/m^3)	**887**	**ASTM C29**	**------**
loose bulk density unit weight ssd (kg/m^3)	**978.88**	**ASTM C29**	**------**
rodding bulk density unit weight ssd (kg/m^3)	**1078.592**	**ASTM C29**	**------**
void(loose)%	**50.6**	**ASTM C29**	**------**
void(rodding)%	**45.6**	**ASTM C29**	**------**
density (od) (kg/m^3)	**1632**	**ASTM C127**	**------**

density (ssd) (kg/m³)	**1985**	**ASTM C127**	**------**
apparent density (kg/m³)	**2526**	**ASTM C127**	**------**
relative density (specific gravity od)(kg/m³)	**1.635**	**ASTM C127**	**≤2.6**
relative density (specific gravity ssd)(kg/m³)	**1.98**	**ASTM C127**	**------**
apparent relative density(apparent specific gravity) (kg/m³)	**2.53**	**ASTM C127**	**------**
absorption %	**21.6**	**ASTM C127**	**5-30**

A-4 Chemical Admixture (SP-200)

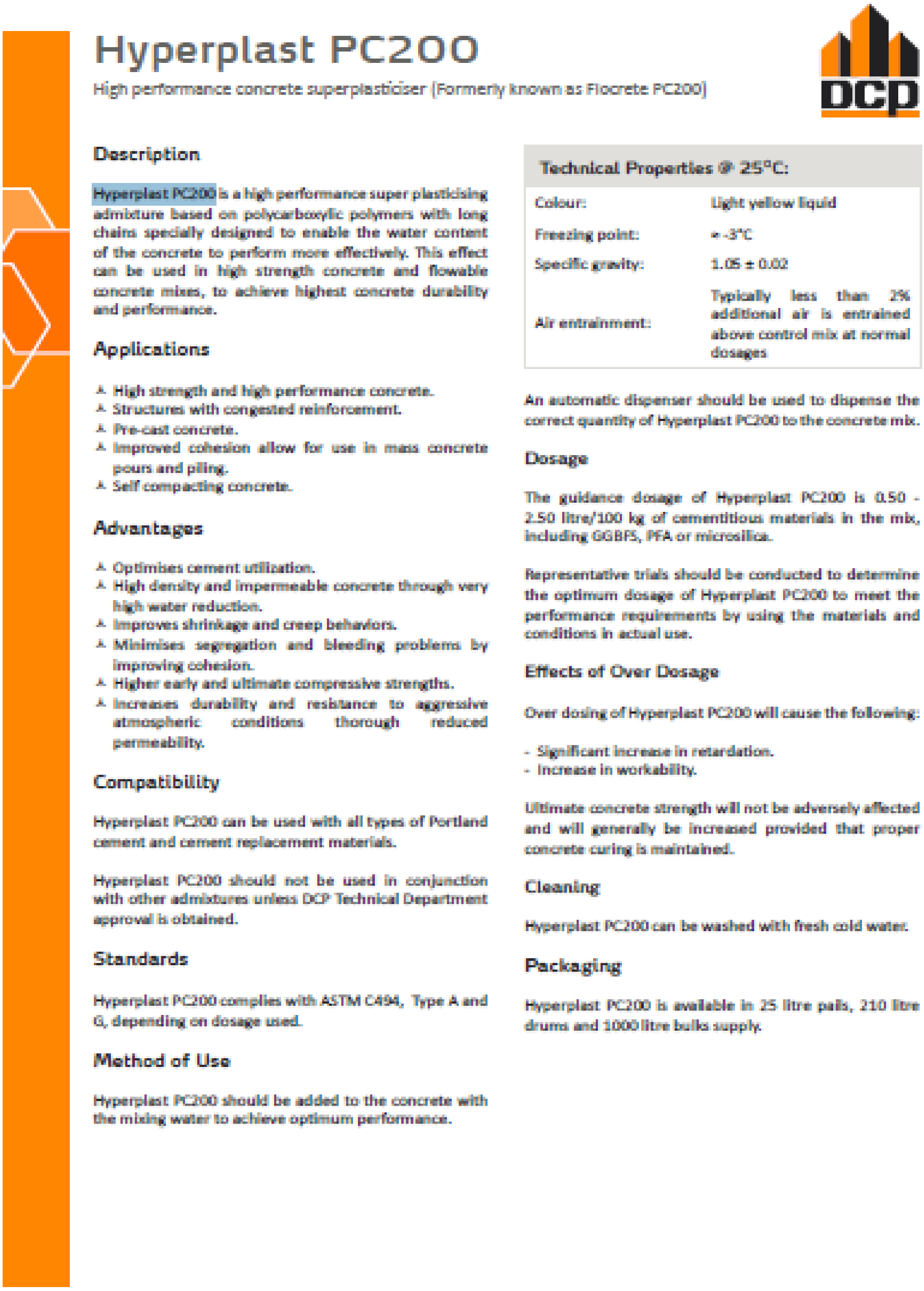
The Manufacture Company Catalogue of Hyperplast PC200

Applications

- High strength and high performance concrete.
- Structures with congested reinforcement.
- Pre-cast concrete.
- Improved cohesion allows for use in mass concrete pours and piling.
- Self-compacting concrete.

Advantages:

1. Optimizes cement utilization.
2. High density and impermeable concrete through very high water reduction.
3. Improves shrinkage and creep behaviors.
4. Minimizes segregation and bleeding problems by improving cohesion.
5. Higher early and ultimate compressive strengths.
6. Increases durability and resistance to aggressive atmospheric conditions thorough reduced permeability.



Hyperplast PC200

High performance concrete superplasticiser (Formerly known as Flocrete PC200)

DCP

Description

Hyperplast PC200 is a high performance super plasticising admixture based on polycarboxylic polymers with long chains specially designed to enable the water content of the concrete to perform more effectively. This effect can be used in high strength concrete and flowable concrete mixes, to achieve highest concrete durability and performance.

Applications

- High strength and high performance concrete.
- Structures with congested reinforcement.
- Pre-cast concrete.
- Improved cohesion allow for use in mass concrete pours and piling.
- Self compacting concrete.

Advantages

- Optimises cement utilization.
- High density and impermeable concrete through very high water reduction.
- Improves shrinkage and creep behaviors.
- Minimises segregation and bleeding problems by improving cohesion.
- Higher early and ultimate compressive strengths.
- Increases durability and resistance to aggressive atmospheric conditions thorough reduced permeability.

Compatibility

Hyperplast PC200 can be used with all types of Portland cement and cement replacement materials.

Hyperplast PC200 should not be used in conjunction with other admixtures unless DCP Technical Department approval is obtained.

Standards

Hyperplast PC200 complies with ASTM C494, Type A and G, depending on dosage used.

Method of Use

Hyperplast PC200 should be added to the concrete with the mixing water to achieve optimum performance.

Technical Properties @ 25°C:	
Colour:	Light yellow liquid
Freezing point:	≈ -3°C
Specific gravity:	1.05 ± 0.02
Air entrainment:	Typically less than 2% additional air is entrained above control mix at normal dosages

An automatic dispenser should be used to dispense the correct quantity of Hyperplast PC200 to the concrete mix.

Dosage

The guidance dosage of Hyperplast PC200 is 0.50 - 2.50 litre/100 kg of cementitious materials in the mix, including GGBFS, PFA or microsilica.

Representative trials should be conducted to determine the optimum dosage of Hyperplast PC200 to meet the performance requirements by using the materials and conditions in actual use.

Effects of Over Dosage

Over dosing of Hyperplast PC200 will cause the following:

- Significant increase in retardation.
- Increase in workability.

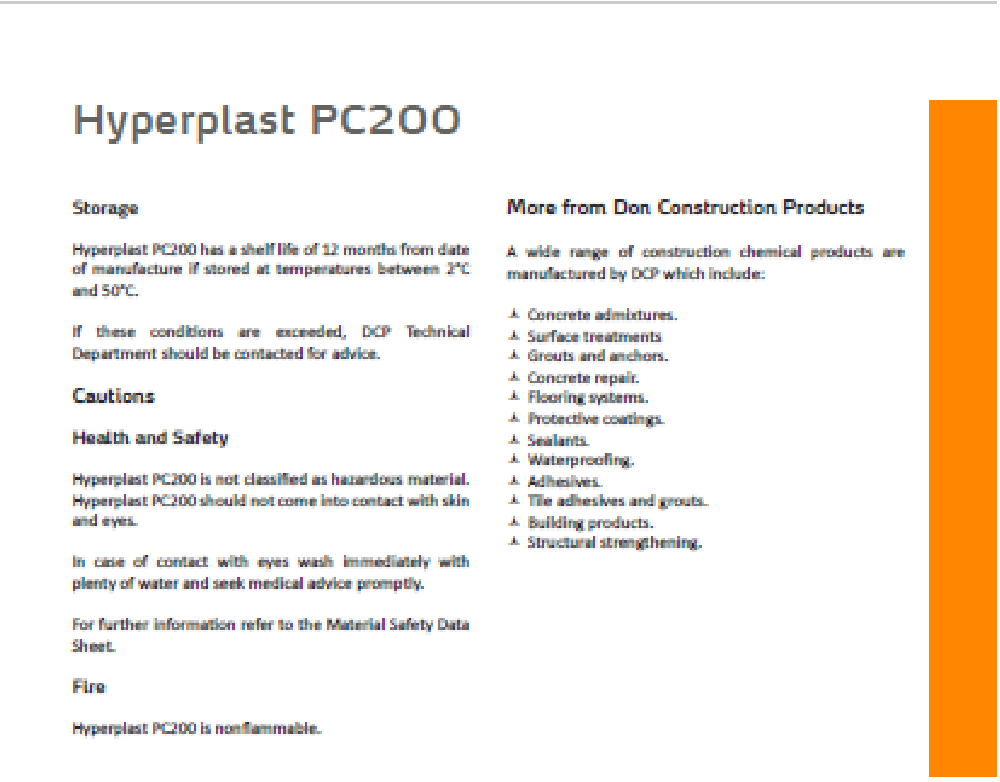
Ultimate concrete strength will not be adversely affected and will generally be increased provided that proper concrete curing is maintained.

Cleaning

Hyperplast PC200 can be washed with fresh cold water.

Packaging

Hyperplast PC200 is available in 25 litre pails, 210 litre drums and 1000 litre bulks supply.



Hyperplast PC200

Storage

Hyperplast PC200 has a shelf life of 12 months from date of manufacture if stored at temperatures between 2°C and 50°C.

If these conditions are exceeded, DCP Technical Department should be contacted for advice.

Cautions

Health and Safety

Hyperplast PC200 is not classified as hazardous material. Hyperplast PC200 should not come into contact with skin and eyes.

In case of contact with eyes wash immediately with plenty of water and seek medical advice promptly.

For further information refer to the Material Safety Data Sheet.

Fire

Hyperplast PC200 is nonflammable.

More from Don Construction Products

A wide range of construction chemical products are manufactured by DCP which include:

- Concrete admixtures.
- Surface treatments
- Grouts and anchors.
- Concrete repair.
- Flooring systems.
- Protective coatings.
- Sealants.
- Waterproofing.
- Adhesives.
- Tile adhesives and grouts.
- Building products.
- Structural strengthening.

Appendix-B

Theoretical Analysis

Flexural Calculations

h = 90 mm, cover= 15 mm, $h_{\circ}$= 30 mm

$$d = h - \frac{d_b}{2} - cover = 90 - \frac{6}{2} - 15 = 72\ mm$$

$$As\ bar = \frac{\pi d^2}{4} = 28.27\ \ mm^2$$

$$As^{+} = 3 * 28.27\ \ = 84.81\ mm^2$$

$$As_{min} = 0.0018 * bt \qquad\qquad for\ Fy > 414\ MPa$$

$$As_{min} = 0.0018 * 400 * 30 = 21.6\ \ mm^2$$

$$As > As_{min} \qquad\qquad \therefore o.k$$

2- shear calculations

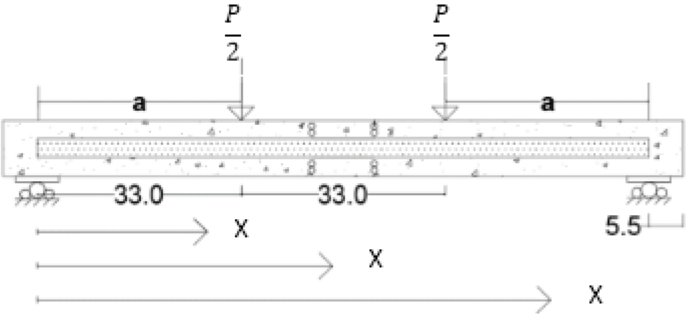
Beam shear

$$Vc = \frac{1}{6}\sqrt{21} * 1000 * 30 * 10^{-3} = 22.91\ kN$$

$$V = \frac{P}{2} \qquad \rightarrow \qquad \therefore V = \frac{27.87}{2} = 13.93\ kN$$

$$\therefore V < Vc \quad \text{O.K}$$

3- Find deflection equation by Direct Macaulay's method (General Equation Method)



EI $\bar{\bar{y}}$ = M(x)

EI $\bar{\bar{y}} = \frac{\boldsymbol{P}}{\mathbf{2}}\mathrm{x} - \frac{\boldsymbol{P}}{\mathbf{2}} < x - a > - \frac{\boldsymbol{P}}{\mathbf{2}} < x - 2a >$

EI $\bar{y} = \frac{\boldsymbol{P}}{\mathbf{2}}\,\frac{X^{2}}{2} - \frac{P}{4} < x - a >^{2} - \frac{P}{4} < x - 2a >^{2} + C_1$

EI y $= \frac{\boldsymbol{P}}{\mathbf{2}} * \frac{X^{3}}{6} - \frac{P}{12} < x - a >^{3} - \frac{P}{12} < x - 2a >^{3} + C_1 X + C_2$

@ X= 0 , y= 0 → $0 = 0 - \frac{P}{12} < 0 > - \frac{P}{12} < 0 > + C_1(0) + C_2$

$C_2 = 0$

@ X= 3a , y= 0 → $0 = \frac{P}{12}(3a)^{3} - \frac{P}{12} < 2a >^{3} - \frac{P}{12} < a >^{3} + C_1(3a) + C_2$

$\therefore C_1 = -\frac{\boldsymbol{P}}{\mathbf{2}}a^{2}$

At any X ,

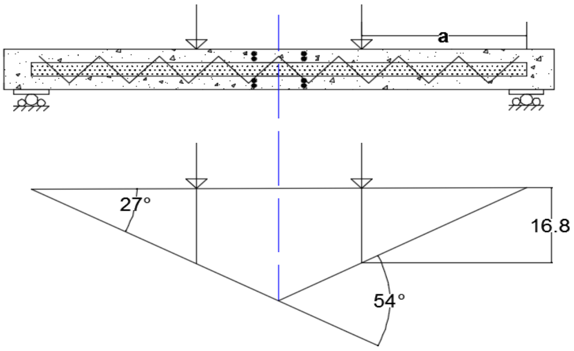
$y = \frac{1}{EI}\left[\frac{\boldsymbol{P}}{\mathbf{2}} * \frac{X^{3}}{6} - \frac{P}{12} < x - a >^{3} - \frac{P}{12} < x - 2a >^{3} - \frac{\boldsymbol{P}}{\mathbf{2}}a^{2}X\right]$

y (at x =1.5 a) = $y_{\max}$

$y_{\max} = \frac{1}{EI}\left[\frac{\boldsymbol{P}}{\mathbf{2}} * \frac{(1.5a)^{3}}{12} - \frac{P}{12} < (1.5a) - a >^{3} \cancel{-\frac{P}{12}} < (1.5a) - 2a >^{3} - \frac{\boldsymbol{P}}{\mathbf{2}}a^{2}(1.5a)\right]$

$\mathbf{y_{max}} = \boldsymbol{\omega}_{\mathbf{max}} = \frac{\mathbf{-23}}{\mathbf{48}} * \frac{\boldsymbol{Pa^{3}}}{\boldsymbol{EI}}$

4- finding the relation between P_u and Mu by using (Yield Line Theory):



Ext. work = Int. work

$$\sum \boldsymbol{P\,\delta} = \sum \boldsymbol{M\theta}$$

$$\sum \boldsymbol{P\,\delta} = \boldsymbol{\frac{P}{2} * 2 * \delta}$$

$$\sum \boldsymbol{M\theta} = \boldsymbol{2 * m * \theta}$$

$$\boldsymbol{\theta} = \boldsymbol{\frac{4\delta}{l}}$$

$$\boldsymbol{\frac{P}{2} * 2 * \delta = 2 * m * \frac{4\delta}{l}}$$

$$P = \boldsymbol{\frac{8\,M}{l}}$$

5- Degree of composite action at elastic stage

$$\sigma = \frac{\mathrm{Mc}}{\mathrm{I_e}} \ldots\ldots\ldots\ (a)$$

note that the depth of the panel, h = c

The stress of the top and bottom concrete wythe is given by Equations b and c, respectively

$$\sigma_{\mathrm{Top}} = \frac{\mathrm{M\ c_{Top}}}{\mathrm{I_e}} \ldots\ldots\ldots\ (b)$$

$$\sigma_{\mathrm{Bottom}} = \frac{\mathrm{M\ c}_{Bottom}}{\mathrm{I_e}} \ldots\ldots\ldots\ (c)$$

$$\sigma = \sigma_{\mathrm{Bottom}} - \sigma_{\mathrm{Top}}$$

Substituting equations (b) and (c) in equation (d) yields

$$= \sigma_{\mathrm{Bottom}} - \sigma_{\mathrm{Top}} = \frac{\mathrm{M\ c_{Top}}}{\mathrm{I_e}} + \frac{\mathrm{M\ c}_{Bottom}}{\mathrm{I_e}} \ldots\ldots\ldots\ (d)$$

$$= \sigma_{\mathrm{Bottom}} - \sigma_{\mathrm{Top}} = \frac{M}{I_e}\left(c_{Bottom} + c_{Top}\right)$$

Note that, the full height of the panel,

$$\mathrm{h = c} = c_{Bottom} + c_{Top}$$

$$= \sigma_{\mathrm{Bottom}} - \sigma_{\mathrm{Top}} = \frac{M\ h}{I_e}$$

$$I_e = \frac{M\ h}{\sigma_{\mathrm{Bottom}} - \sigma_{\mathrm{Top}}}$$

$$\boldsymbol{\kappa_e = \frac{P_e - P_{non}}{P_{full} - P_{non}} = \frac{I_e - I_o}{P_g - P_o} = \left(\frac{Mh}{\sigma_b - \sigma_t} - I_0\right) / \left(I_g - I_0\right)}$$

where

$\boldsymbol{\kappa_e}$ is the degree of composite action achieved of the panel at elastic stage;

$\boldsymbol{I_e}$ is the effective moment of inertia;

$\boldsymbol{I_g}$ is the moment of inertia of PCSP section, calculated assuming fully composite action for the test panels.

$\boldsymbol{I_o}$ is the moment of inertia of PCSP section, calculated assuming non composite action for the test panels

$\boldsymbol{\sigma_{Bottom}}$ is the stress at the bottom wythe of the panel;

$\boldsymbol{\sigma_{Top}}$ is the stress at the top wythe of the panel;

$\boldsymbol{M}$ is the applied bending moment;

$\boldsymbol{h}$ is the depth of the panel;

$$I_g = \frac{b\,h^3}{12} = \frac{400 * 90^3}{12} = \mathbf{243 * 10^5\ mm^4}$$

$$I_o = 2 * \frac{b\,h^3}{12} = 2 * = \frac{400 * 30^3}{12} = \mathbf{18 * 10^5\ mm^4}$$

$\mathbf{M} = \frac{P * a}{2}$ (from B.M.D) , P = Load at elastic stage

6- Degree of composite action at the ultimate stage

For all slab panels (L = 1100 mm, b = 400 mm, and h = 90 mm),

Each wythe was reinforced with 3 of 6 mm diameter bars, As = 84.81 mm^2. (as example for Attapulgite f_{cu}= 25.5)

Steel yield stress; f_y = 584 N/mm2, concrete, f_{cu}= 25.5 N/mm2

T = Fs = As × f_y = 84.81× 584 = 49529.04 N

C = Fc = 0.85 fc b a = 0.85×25.5 × 400 × a = 8670 × a

At equilibrium, T = C

a $= \frac{Fs}{Fc} = \frac{As\,f_y}{0.85\,fc\ b}$ = 5.71 mm. (Depth of the neutral axis)

d = 18 mm (distance from the compression edge to the center of steel, each wythe separately 15 cover + 6/2).

However, the total ultimate moment will be as follows:

Mu (one wythe) = Fs (d − a/2) = 0.750 kN m.

Mu = 2 × 0.725 = 1.5 kN m (for both wythes).

Hence, the ultimate load carrying capacity of the slab = $\frac{8\,M}{L}$

The total load resisted by the panel as non-composite was P = 12.12 kN.

- For the upper bound situation, the panel was assumed as fully composite at ultimate strength

capacity and the ultimate flexural capacity of the panel was computed as follows:

Where;

Fs = 49529.04 N, a = 5.71 mm, d = 90 – 18 = 72 mm.

Therefore,

Mu = Fs (d − a/2) = 3.42 kN m.

The ultimate load carrying capacity of the slab = $\frac{8\,M}{L}$

The total load resisted by the panel as fully composite was P = 27.67 kN .

$$\kappa_n = \frac{P_{Ex} - P_{Nu}}{P_{Fu} - P_{Nu}}$$

where

P_{Ex} = The experimental ultimate load ;

P_{Nu} = The theoretical calculated ultimate strength assuming non composite action;

P_{Fu} = The theoretical calculated ultimate strength assuming fully composite action.

κ_n = The percentage of composite action at ultimate strength

Now for all panels, the percentage of composite action at ultimate strength was computed

Tested Slab Samples	Experiment Ultimate-load P_{Ex} (kN)	Theoretical calculated ultimate load		Percentage of Composite Degree at the ultimate-load κ_n (%)
		Non-composite P_{Nu} (kN)	Fully-composite P_{Fu} (kN)	
SN-C45	**30**	**12.543**	**28.27**	**111**
SB-C45	**27.84**	**12.065**	**28.04**	**98.74**
SB-C27	**21.20**			**57.18**
SB-L1	**20.65**			**53.74**
SB-L2	**17.60**			**34.64**
SB-L3	**19.89**			**48.98**
SA-C45	**25.89**	**12.12**	**27.67**	**88.55**
SA-C27	**19.86**			**49.77**
SA-L1	**20.5**			**53.89**
SA-L2	**16**			**24.95**
SA-L3	**18.91**			**43.66**

الخلاصة

المنشأت السندويجية الخرسانية هي نظام بنائي مبتكر وحديث مبني على الاستعمال الأفضل للمواد . الشكل الابسط من البلاطات السندويجية يتكون من طبقتين من الخرسانة تحيط بمادة قليلة الوزن ورخيصة. الطبقتين الخرسانية تربطان بروابط القص . الوظيفة الرئيسية لهذه الروابط هي نقل قوى القص لضمان عدم انزلاق الطبقات فوق بعضها البعض عند تعرضها للاحمال ، وكذلك لغرض ربط طبقتي الخرسانة وجعلها تتصرف كوحدة واحدة.

تتضمن الدراسة الحالية تحريات عملية عن تصرف البلاطات الخرسسانية العاملة باتجاه واحد وكذلك بلاطة خرسانية صلدة. وقد درس تأثير أستعمال مبدأ الساندويج. تحتوي الطبقات الخرسانية على ركام خفيف الوزن او ركام عادي ، كانت المتغيرات الاساسية لهذة الدراسة : نوع الركام المستعمل لأنتاج الخرسانة ،الموقع المثالي لروابط القص من خلال استعمال نسب مختلفة لمساحة حديد روابط القص في الربعين الطرفيين من الفضاء بالمقارنة مع الربعين الداخليين من الفضاء .وقد درس تاثير زاوية الانحناء لروابط القص من خلال استعمال زاويتي انحناء (27° و45°) بنسب تسليح قص مختلفة .كذلك تم دراسة تاثير روابط القص المنفصلة التي تكون على شكل W بالمقارنة مع روابط القص المستمره على طول الفضاء .

في الدراسة الحالية، هناك نوعين من الركام خفيف الوزن التي استعملت لانتاج خرسانة خفيفة الوزن (مكسر الطابوق، الاتبولكايت :وهي صخور طبيعية تكسر وتحرق في درجة حرارة معينة) تم فحص العديد من الأسطوانات والمكعبات لغرض فحص خواص الخرسانة.

تشير نتائج الفحوصات العملية الى انه يمكن أنتاج خرسانة بمقاومة انضغاط للأسطوانة بمقدار 21 ميكاباسكال وبكثافة جافة مقدارها 1949 كيلوغرام لكل متر مكعب حيث تم الحصول عليها بأستعمال الاتبولكايت كركام خشن مع الرمل الاعتيادي والاسمنت و الملدنات الفائقة (PC-200) وتعتبر هذه الخرسانة خفيفة الوزن حسب معهد الخرسانة الأمريكي ACI 213R-03 .

عند أستبدال الاتبولكايت بمكسر الطابوق مع المحافظة على نفس نسب الخلط ، كانت مقاومة الانضغاط للاسطوانة 25.2 ميكاباسكال وبكثافة جافة مقدارها 1954 كيلوغرام لكل متر مكعب.

تصرفت كل البلاطات السندويجية كوحدة أنشائية واحدة . وأظهرت متانة وصلابة اكثر من البلاطات (الصلدة) بألاضافة الى نقصان الوزن الكلي بحدود (31.21%- 42.75%) من وزن البلاطة الخرسانية الصلدة.

في البلاطات الساندويجية ، أظهر استعمال مكسر الطابوق تحسن بمقدار الهطول ، المطيلية ، القساوة بحوالي 62.96%، 39.64%، 54.04% عند مقارنته مع أستعمال الركام الخشن الاعتيادي الوزن ، مع انخفاض في الوزن الكلي بحدود 11.70%. من جهة أخرى ، استعمال الاتبولكايت كركام خشن في البلاطات يحسن القيمة العظمى للهطول ، المطيلية ، القساوة سوف تصبح 73.48%، 38.75%، 43.82% ،هذا بألاضافة الى فائدة اخرى مكتسبة وهي نقصان الوزن بحدود 14.31 %.

من الواضح أن وجود الراوابط القصية في الربعيين الطرفيين من الفضاء له تأثير اكبر من وجودها في النصف الوسطي من الفضاء .كذلك اثبتت النتائج ان استعمال روابط القص المستمرة بزاوية انحناء 27° افضل من استعمال روابط القص المنفصلة التي تكون على شكل W.

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قسم الهندسة المدنية

الأستدامة الأنشائية للبلاطات الخرسانية السندويجية خفيفة الوزن

رسالة

مقدمة الى كلية الهندسة جامعة كربلاء
وهي جزء من متطلبات نيل درجة الماجستير
في علوم الهندسة المدنية / البنى التحتية

من قبل

سعاد عباس علي

(بكالوريوس هندسة مدنية 2014)

بأشراف

أ.م.د. ليث شاكر رشيد

مارس 2019 رجب 1440