SHEAR PERFORMANCE OF LIGHTWEIGHT CONCRETE SLAB WITH THE ADDITION OF OIL PALM SHELL AS LIGHTWEIGHT AGGREGATE

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Bachelor Engineering (HONS) in Civil Engineering

UNIVERSITI MALAYSIA PAHANG

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Thesis submitted in partial fulfillment of the requirements for the award of degree of the Bachelor of Engineering (HONS) in Civil Engineering

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DEDICATION

Special dedication to my beloved parents,

My father Wan Mat bin Wan Ibrahim and my lovely mother Zunaini binti Che Ibrahim.

For your love and unconditional support

Without whom none of my success would be possible

I appreciate that will last everlasting

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In the name of ALLAH, the most Gracious, and most Merciful

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Abstract

This thesis deals with the use of waste materials, oil palm shell (OPS) as a replacement for coarse aggregate in the concrete. The objectives of this thesis are to determine the potential of OPS as a coarse aggregate replacement in lightweight concrete and to study the structural behaviour of slab with the addition of OPS. The potential of palm oil by-product, OPS to be used as a replacement of coarse aggregates in the concrete production can be guaranteed. As the cost of raw materials in the concrete industry is getting higher therefore manipulating the waste material is the best way to lessen the cost of concrete. The utilization of OPS in the concrete also helps to solve environmental problem caused by the improper disposal of waste materials. The addition of OPS as a replacement to coarse aggregate produces lightweight concrete which is a very cost effective. The paper reports on the experimental works on the structural behaviour of concrete slab with the addition of OPS. This thesis describes the tests which are to be applied on concrete which are compression test and combined bending and shear test. Concrete specimens involved in this research are cube of size 100 mm × 100 mm × 100 mm and slab of size 350 mm × 500 mm × 100 mm.Three different concrete mix compositions were prepared which were the concrete without the addition of OPS (batch 1, B1), concrete with the addition of 50% OPS (batch 2, B2) and concrete with the addition of 100% OPS (batch 3, B3). The compressive strength of cube specimens was carried out at 7 and 28 days. The results show that the increase in percentage replacement of OPS decreased the compressive strength. Concrete slab specimens were tested at 28 days to observe the failure under the shear load. The results showed that increasing the content of OPS into the concrete slab gives no significant effect to the shear failure load improvement.

Abstrak

Tesis ini berkaitan dengan penggunaan bahan buangan, tempurung kelapa sawit (OPS) sebagai pengganti agregat kasar dalam konkrit. Objektif kajian ini ialah untuk menentukan tahap potensi OPS sebagai pengganti agregat kasar dalam konkrit ringan dan mengkaji tingkah laku struktur papak dengan tambahan OPS. Potensi hasil sampingan minyak sawit, OPS untuk digunakan sebagai pengganti agregat kasar dalam pengeluaran konkrit dapat dijamin. Disebabkan kos bahan mentah dalam industri konkrit semakin tinggi oleh itu memanipulasi bahan buangan adalah cara yang terbaik dalam mengurangkan kos konkrit. Penggunaan OPS dalam konkrit juga membantu untuk menyelesaikan masalah alam sekitar yang disebabkan oleh pembuangan sisa bahan yang tidak sepatutnya. Penambahan OPS sebagai gantian kepada agregat kasar menghasilkan konkrit ringan yang menjimatkan kos. Tesis ini menerangkan ujian yang dijalankan ke atas konkrit iaitu ujian mampatan gabungan ujian lenturan dan ricih. Spesimen konkrit yang terlibat dalam kajian ini ialah kiub bersaiz 100 mm × 100 mm × 100 mm dan papak bersaiz 350 mm × 500 mm × 100 mm. Tiga komposisi campuran konkrit yang berbeza telah disediakan iaitu konkrit tanpa penambahan OPS (kumpulan 1,B1), konkrit dengan penambahan OPS sebanyak 50% (kumpulan 2, B2) dan konkrit dengan penambahan OPS sebanyak 100% (kumpulan 3, B3). Kekuatan mampatan kiub diuji pada hari ketujuh dan hari kedua puluh lapan. Keputusan menunjukkan bahawa peningkatan dalam penggantian peratusan OPS menurunkan kekuatan mampatan. Papak konkrit pula diuji untuk melihat keretakan bawah ricih. Kajian menunjukkan peningkatan kandungan OPS di dalam papak konkrit tidak member kesan yang ketara kepada peningkatan beban kegagalan ricih.
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LIST OF SYMBOLS

$f_{cu,ave}$	Average Compressive Strength
f_{cu}	Compressive Strength
δ	Deflection

LIST OF ABBREVIATIONS

BS	-	British Standard
CAR	-	Coarse Aggregate Replacement
CSA	-	Crushed Stone Aggregate
LWA	-	Lightweight Aggregate
LWC	-	Lightweight Concrete
OPC	-	Ordinary Portland cement
OPS	-	Oil Palm Shell
OPSC	-	Oil Palm Shell Concrete

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Concrete is the most important material in civil engineering industry. It is a composite material made up from cement that acts as binders and other cementitious material, coarse aggregate such as the granite stone, fine aggregate such as natural sand and water. In addition, there are several other materials, called additives that may be added to obtain special properties of concrete. These includes accelerators, retarders, air entraining agents, water-reducing agents and superplasticizer admixtures, among others. They are needed in the right proportion depending on the strength requirement of concrete. Most application of concrete can be seen as a building material. All important building elements such as foundation, column, wall, slab and roof are made from concrete. Other concrete applications can be seen as a road, pavement, runaways, bridges and dams.

For a sustainable development of structural engineering, many research efforts have been made to find alternative basic materials which are used in construction from past many years. A properly processed of waste materials such as oil palm shell, coconut shell, rubber tyre and fly ash will produce materials that meet the design specifications (Mannan and Ganapathy,2003). In this research, oil palm shell (OPS) as a coarse aggregate replacement is the one that is being referred to. However, concrete made up from oil palm shell is different from the conventional concrete in terms of the constituents' materials. OPS replace coarse aggregate in this type of concrete.

Malaysia is one of the largest palm oil producers and exporter in the world. It accounts for over half of the world's total palm oil output and is set to grow further with the global increase in vegetable oil demand (Mannan and Basri, 1998).

However, excessive waste products are generated and left to rot in large amounts and sometimes disposed through incineration which can cause pollution to the environment. The use of waste materials in concrete industry saves natural resources and dumping spaces, and helps to maintain a clean environment.

1.2 PROBLEM STATEMENT

The continuous usage of raw materials in the production of concrete may cause a depletion of natural resources someday. Following a normal growth in population, the amount and type of waste materials have increased accordingly. Many of the non-decaying waste materials will remain in the universe for years. These wastes may cause a waste disposal crisis and therefore contribute to the environmental problems. The wastes if left untreated can cause land, water and air pollution.

There was reported that an approximately 3 million tons of waste product derived throughout the electricity generated process in Malaysia (Lau, 2004). The mass production of waste material will harm our environment if no proper treatment taken to reduce it. Due to the increasing cost of materials cause by the continuous depletion of natural resources, construction material that depends on natural resources does not have consistent price in market.

Many research efforts have been made to exploit these wastes into a potential alternative construction material. In this current research, manipulating OPS as a coarse aggregate replacement in concrete is the best step in a way to lessen the negative effect to the environment. The utilization of OPS aggregates in concrete gain the economical achievement especially in reducing the market price of construction materials. OPS develops into a lightweight concrete which is a very cost effective construction materials as it can occupy about 40% of total volume concrete saving the conventional stone aggregates. Hence, this study is purposely carried out to find solution to reduce the cost of concrete production.

1.3 RESEARCH OBJECTIVES

The objectives of this research are to:

i. To determine the potential of oil palm shell as a coarse aggregate replacement in lightweight concrete aggregate.
ii. To study the structural behaviour of concrete slab with the addition of oil palm shell.

1.4 SCOPES OF RESEARCH

The research scopes includes:

i. Concrete grade C30 is used in this whole research for cubes and slabs.
ii. The type of lightweight aggregate used in this research is oil palm shell.
iii. The size of specimens used in this research are:
    a) Cube - 100 mm × 100 mm × 100 mm
    b) Slab – 350 mm × 500 mm × 100 mm
iv. Tests will be carried out to determine the performance of OPS concrete which are:
    a) Compressive Strength Test – Cube specimens
    b) Combined Bending and Shear Test – Slab Specimens
v. The coarse aggregate replacements used in this research are 50% and 100%.

1.5 RESEARCH SIGNIFICANCE

The main purpose of this research is to minimize the cost production of concrete using the waste material that can be found in our country. Besides that, using the waste materials from mills will reduce the by-product that thrown away by industries thus lowering the pollutions cause options. The use of OPS in construction will lower the percentage use of coarse aggregate thus the cost production will be lower since the price of OPS is cheaper. Moreover, the alternative taken from the waste materials disposal into a more environmental friendly concrete is another additional significance of this research.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter describes the nature of oil palm shell (OPS) used in the concrete production as a replacement of conventional coarse aggregate. The OPS has becoming one of the most popular alternatives to replace coarse aggregate in concrete due to its low cost and high availability in Malaysia. Material recovery from the conversion of waste materials from the agricultural and industrial based into useful construction materials has gain benefits in reducing cost of construction materials and preserving the natural resources (Mannan and Ganapathy, 2003). That is why research efforts on the effective utilisation of various types of solid wastes had gained greater attention in the past several decades.

In this chapter, the review on properties of OPS lightweight concrete is discussed. The addition of OPS to the concrete produces lightweight concrete with properties differs from the normal concrete. In addition, comparison has been made between the physical and mechanical properties of OPS aggregates and granite stone. Previous research by Shafigh (2011) showed that it was possible to develop high strength lightweight concrete using OPS aggregates to get the strength between 43-48 MPa.

2.2 LIGHTWEIGHT AGGREGATE IN CONCRETE

The production of lightweight concrete can either by the utilization of lightweight aggregates, the incorporation of voids by aeration and the addition of little or no fine aggregate at all. In this study, the lightweight concrete with the insertion of lightweight aggregate is one that is being referred to. The real definition for lightweight aggregate is an aggregate that weighs less than the usual rock aggregate. A reduction in density is mostly achieved by partial or full replacement of the normal weight aggregate (NWA).

Zulkarnain and Ramli (2008) in their study defined the lightweight aggregate concrete as a concrete having an air-dry density below 1850 kg/m^3 whereas for normal concrete the density was reported about 2300 kg/m^3. British Standard BS EN 13055-1:2002: Lightweight aggregate for concrete, mortar and grout defined lightweight aggregate as any aggregate with a particle density of less than 2000 kg/m^3 or a dry loose bulk density of less than 800 kg/m^3.

There are varieties of lightweight aggregates that can be used to manufacture lightweight concrete. Some of them are originated from natural materials like volcanic pumice, the thermal treatment of natural raw materials like clay, slate or shale and the manufacturing of industrial by-products such as fly-ash. In this study, lightweight aggregate from the industrial by-products is one that is being referred to.

Lightweight aggregate possessed several characteristics that made it different from conventional aggregate. Clarke (1993) reported that most lightweight aggregates were manufactured and therefore careful production control, uniform and consistent is significant for mixing, placing and compaction. It was also reported that the higher porosity of the aggregate can lead to a lower thermal conductivity, density and strength of lightweight concrete made with it. Shirley (1975) in her study said that the less porous lightweight aggregate can produce concrete which is strong enough to resist stresses applied to it.

The lightweight aggregate concrete can be divided into two types in accordance to its application (Samidi,1997).One is partially compacted lightweight aggregate concrete and another one is the structural lightweight aggregate concrete. The partially compacted lightweight concrete is mainly used for precast concrete blocks and cast in-situ roofs and walls. Meanwhile, structural lightweight aggregate concrete can be used with steel reinforcement as to have a good bond between the steel and the concrete.

One of the most highlighted benefits using lightweight aggregate is the reduction in dead loads of concrete which consequently make it economical in terms of savings in foundations and reinforcement. The advantage of weight saving is most obvious for structures with a high dead to live load ratio for example long-span bridges. Next, the exploitation of lightweight aggregates that originated from waste materials or industrial by products such as palm kernel shell and saw dust is in line with the government policy to develop more sustainable construction. The utilisation of waste materials also saves the space for dumping unutilised waste products to the rivers and lakes by the nearby factories and thus avoids the pollution of land, water and air. In addition, the use of lightweight aggregate can improve the thermal properties and fire resistance of concrete. Such application of lightweight aggregate concrete can be seen in the housing construction.

2.3 OIL PALM SHELL OVERVIEW

Oil palm shell, an agricultural solid end products of oil palm manufacturing processes, is actually the hard endocarp that surrounds the palm kernel shell as shown in Figure 2.1. In Malaysia, oil palm fruits can be classified as *dura,tenera* and *pisifera*. There are some characteristics between these three species that make them differ from each other. *dura* is a homozygous dominant with thick shells while *pisifera* is a homozygous recessive without shells. A ring of fibres called “mesocarp” surrounds the kernel. *dura* is cross-pollinated with *pisifera* to produce heterozygous *tenera* with an intermediate shell thickness surrounded by a ring of fibres in the mesocarp. The illustration of the OPS species is shown in Figure 2.2.

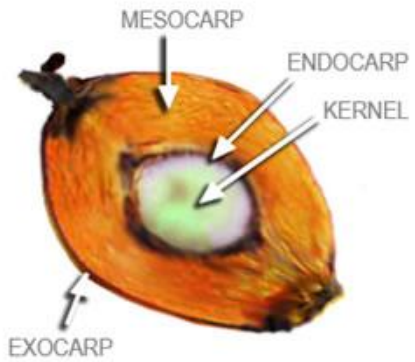

Figure 2.1: Cross-section of OPS

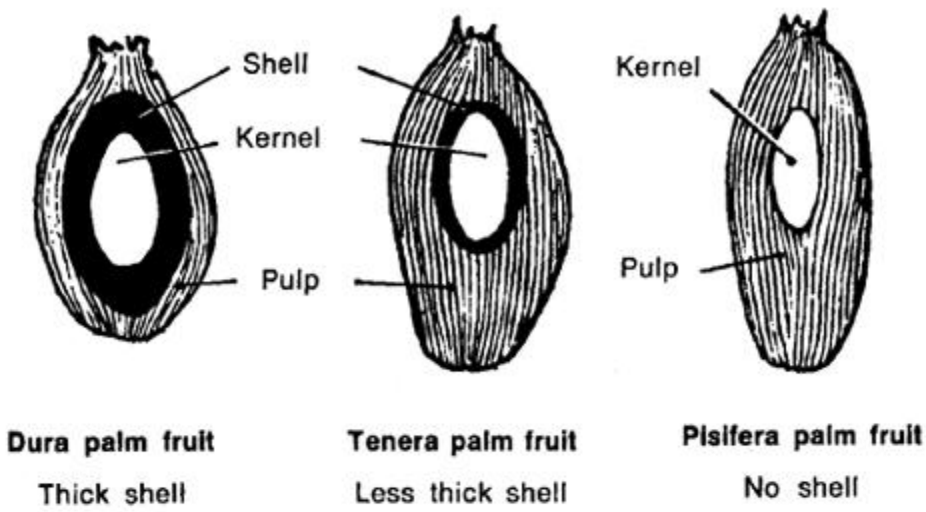

Figure 2.2: Ilustration of *dura, tenera* and *pisifera* OPS species

2.3.1 Oil Palm Shell Lightweight Concrete

Malaysia is one of the developing countries that has enormous agricultural and industrial wastes. As one of the largest oil palm producer in the world, Malaysia has total planted area coverage of 3.8 million hectares and produces over 4 million tonnes of oil palm shell (OPS) annually (Teo et al., 2006).

There are many factors leading to the increased waste production in the recent years such as the exponential growth rate of population, development of industry and technology and the growth of social civilisation. Some strategies have been undertaken in order to lessen the solid waste problems. One of them is the manipulation of properly processed materials as raw materials in the construction industry.

According to Desai (2006), a real definition of lightweight concrete is one that includes an expanding agent which increases the volume of the mixture while reducing the dead weight. It is lighter than the conventional concrete with a dry density of 300 kg/m^3 up to 1840 kg/m^3. Lightweight concrete can either be lightweight aggregate concrete or foamed concrete. A variety of lightweight aggregates can be used to produce lightweight concrete aggregate.

The inclusion of OPS as an aggregate in the concrete produces lightweight concrete because OPS is lighter than conventional coarse aggregate. Teo et al. (2006) in his research said that lightweight concrete OPS is able to produce concrete with strength of 25 MPa and above. Conventional concrete using conventional coarse aggregate has a low strength-weight ratio when compared to steel. It causes an economic disadvantage when it is used in designing structural members for tall buildings, long span bridges and floating structures. Utilisation of waste materials in producing lightweight concrete helps in providing a significant saving in the overall cost of construction and reducing solid waste that caused environmental problems.

Previous research by Shafigh (2008) was to develop high strength lightweight concretes using OPS as lightweight aggregate and to determine the influence of curing conditions on the compressive strength of high strength OPS concrete. Experimental research was done with eight different OPS concrete mixtures. All concrete specimens were cured under five different types of curing conditions. The result showed that 28-day compressive strength of OPS concretes vary around 43-48 MPa. It showed that these concretes are high strength. Hence, it can be concluded that the production of high strength lightweight concrete using OPS is possible.

2.3.2 Properties of Oil Palm Shell

Mannan and Ganapathy (2003) had done some research investigations to determine the physical and mechanical properties of OPS aggregates. The properties of OPS aggregates were compared with the crushed granite as in Table 2.1.

Table 2.1: Comparison of OPS and granite properties

Physical and mechanical properties	**Granite**	**OPS**
Maximum size (mm)	12.5	12.5
Specific gravity (saturated surface dry)	2.61	1.17
Water absorption for 24 h (%)	0.76	23.3
Aggregate abrasion value, Los Angeles (%)	24.0	4.80
Bulk density (compacted) kg/m^3	1470	590
Fineness modulus (F.M)	6.33	6.24
Flakiness index (%)	24.94	65.2
Elongation index (%)	33.38	12.4
Aggregate impact value (%)	17.29	7.86

Source: Mannan and Ganapathy (2003)

Fresh concrete is said to be workable when it is easily placed and fully compacted without having any segregation or bleeding. In their previous research, Mannan and Ganapathy (2003), had prepared several mix proportions of normal concrete and OPS concrete to study their engineering behaviors. When comparing the results of workability, the fresh OPS concrete had shown marginally better workability than that of normal concrete. Other than slump and compaction factor for the same water to cement ratio, the smooth surfaces of OPS may have led to a better workability of fresh concrete. The workability of fresh concrete depends mainly on the materials, mix proportion and environmental condition. In general, most aggregates occupy about 70% of the total volume of concrete.

Mannan and Ganapathy (2003) did an experimental research to compare the compressive strength behaviour of normal concrete and OPS concrete. From the research, the developed compressive strength for 28 days samples of OPS concrete were lower than that of normal concrete. The development of compressive strength in OPS concrete was about 49-55% lower than that of normal concrete.

In general, the strength of concrete decreased when its density decrease. It is well aware that OPS concrete was lighter than normal concrete. Besides, the strength, stiffness, thickness and density of OPS aggregate are also lower than that of crushed stone aggregate which are the governing factors for the compressive strength in concrete.

2.4 CURING OF CONCRETE

Curing is one of the important parts in concrete production and it can be best described as a process in which a concrete is kept moist and warm enough to ensure the hydration of cement take place. Curing gives a strong influence on the properties of hardened concrete because a proper curing will increase durability, strength, abrasion resistance, volume stability and resistance to freezing. Curing is also a key player in mitigating cracks, which can severely affect durability.

Shafigh et al. (2014) in his research investigated the effect of the curing environment on the 28-day compressive strength of OPS concrete with crushed OPS aggregate. The concrete specimens were cured under five curing regimes which are fully immersion in water until the age of testing, air curing and curing in water for 6, 4 and 2 days respectively. The experimental results reported that concrete specimens under fully curing had the highest 28-day average compressive strength followed by 6, 4 and 2 days of curing and air curing respectively. The results concluded that poor curing would marginally decrease the compressive strength of concrete. Table 2.2 lists the advantages and disadvantages of different curing types whereas Figure 2.3 to Figure 2.7 show the various methods of curing.

Table 2.2: Advantages and disadvantages of different curing types

Curing type	Advantages	Disadvantages
Membrane curing	• It reduces evaporation. • It protects concrete surface from weathering.	• It reduces strength of concrete. • It offers high cost.
Ponding method	• It helps in cement hydration process. • It is advantageous for horizontal surface.	• It requires plenty amount of water. • It cannot be used in vertical surface.
Steam curing	• It takes less time for concrete to cure compared to others. • Steam curing is better in cold weather.	• It requires high cost as curing is done in temperature above 22 ºC. • Steam curing method cannot be applied in large surface.
Sprinkling water	• Concrete never dries as water is applied frequently.	• It is costly because it requires a huge amount of water.
Wet covering	• Add moisture to the concrete during early hardening. • Absorption of the heat of hydration.	• Requires plenty amount of water. • Concrete surface is not allowed to dry even for a short period of time during curing period.

Source: Carns (2010)

Figure 2.3: The curing of concrete by membrane curing method

Figure 2.4: The curing of concrete by ponding method

Figure 2.5: The steam curing method applied the heat to the concrete

Figure 2.6: Sprinkling water method of curing

Figure 2.7: Wet covering is overlapped onto the concrete surface for curing

2.5 SLAB

A concrete slab serves as a foundation of a house or building in construction. It is flat, uniform, being placed at ground level and is not segmented. Concrete slab has becoming the most common material for a foundation for a building rather than the other types of slab foundations such as brick, stone and concrete block. Concrete slab is important because it is a part of the home that bears the loading placed onto it. It also protects other housing materials from elements that may compromise their function such as moisture and insects. Besides, it lays out the dimensions of a home.

Among the concrete slabs, various available types have been applied and used in building construction. The most popular types are:

i. Raft slab.
ii. Waffle slab.
iii. Suspended slab

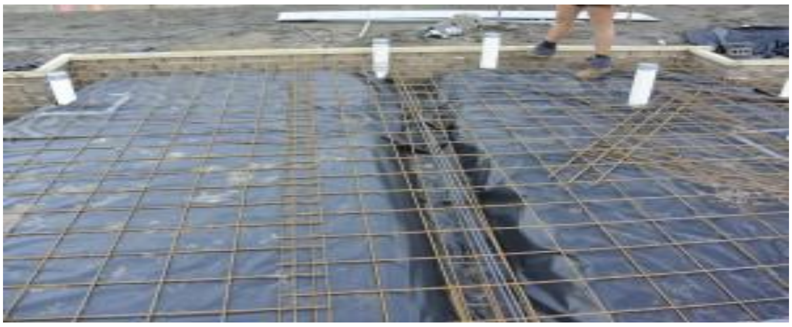

Figure 2.8: Raft Slab

Figure 2.9: Waffle Slab

Figure 2.10: Suspended Slab

2.6 PREVIOUS WORK ON OIL PALM SHELL AGGREGATE

A previous research was done by Al Qadi (2008) to study the impact and crack resistance of high strength OPS lightweight concrete slabs reinforced with geo-grid. Impact testing was done on the test specimen to study the initiation of first crack load and the ultimate crack load. The observed raw data recorded from the drop-weight impact test rig for the specimens with and without geo-grid reinforcement were studied. From the observation, the number of blows had no significant difference the specimens with the lowest OPS amount required the number of blows to initiate the first crack as compared to the specimens that has a higher OPS amount. The same situation was applicable for the number of blows required to cause the ultimate failure. By comparing the specimens with and without geo-grid reinforcement, the slab with the addition of geo-grid showed an increase in the number of blows required to initiate the first crack and ultimate failure.

Che Muda et al. (2012) did a research on the flexural strength and deflection behaviour of concrete slab casted with OPS as aggregates and reinforced with geo-grid. From the findings of his research, flexural strength of slab samples expressed in modulus of rupture shows the effect of OPS content and amount of geo-grids towards flexural strength. When OPS content was increased, flexural strength of concrete slab reduced, while it increased when amount of geo-grid is increased. Mannan et al. (2005) reported that the pre-treatment of OPS as a coarse aggregate in lightweight concrete must be conducted to improve the quality of the OPS. Several types of pre-treatment had been made on OPS. According to him, OPS is likely to decay under vigorous environment therefore the preservative treatment is the best way to obtain the good quality of OPS aggregate.

2.7 SUMMARY

The use of waste materials such as OPS as a coarse aggregate replacement gives benefits not only to the construction industry alone, but to the nature itself. The manipulation of OPS waste materials into a reusable item in construction helps to solve the depletion of natural resources that is used as construction materials. The utilization of OPS aggregates also helps in reducing the cost of concrete construction as the price of OPS concrete is definitely lower than conventional concrete. The natural environment is preserved because the abundant amount of waste materials can now being used in proper way and eventually saves the storage space on land.

The development of OPS concrete into a lightweight concrete is made possible based on the previous research because it had shown that the bulk density of OPS concrete is much lower than normal one. This section also reviews several curing methods which influence the properties of hardened concrete. Each types of curing have their own advantages and disadvantages. Proper curing must be applied to the concrete because the previous research had shown that poor curing would definitely affect the compression strength of concrete.

This section also focused on the types of slab often constructed in our country. The concrete slab itself can be found in many types such as raft slab, waffle slab and suspended slab. The previous work investigated the high strength OPS lightweight concrete slab reinforced with geo-grid. The research showed that the variability of OPS content in the concrete modified the structural behaviour of the concrete.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the overall processes for research methodology. The materials and their quantities, the preparation of the test specimens and the test procedures are discussed.

This research was performed in a few stages in order to achieve the stated objectives. The first stage was the preparation of equipment and materials required for the experimental works. They were prepared with the right amount and quantities just before the research works were carried out to prevent the shortage later on. The next stage was the casting of concrete specimens which took place in the laboratory and then followed by the curing of specimens at 7 and 28 days. The testing of concrete specimens was performed on the date of testing after the curing process. The data were analyzed to draw up conclusions for the works. A few recommendations were made for the improvement of future works. Figure 3.1 shows the flowchart of the works to give the general overview of this research works.

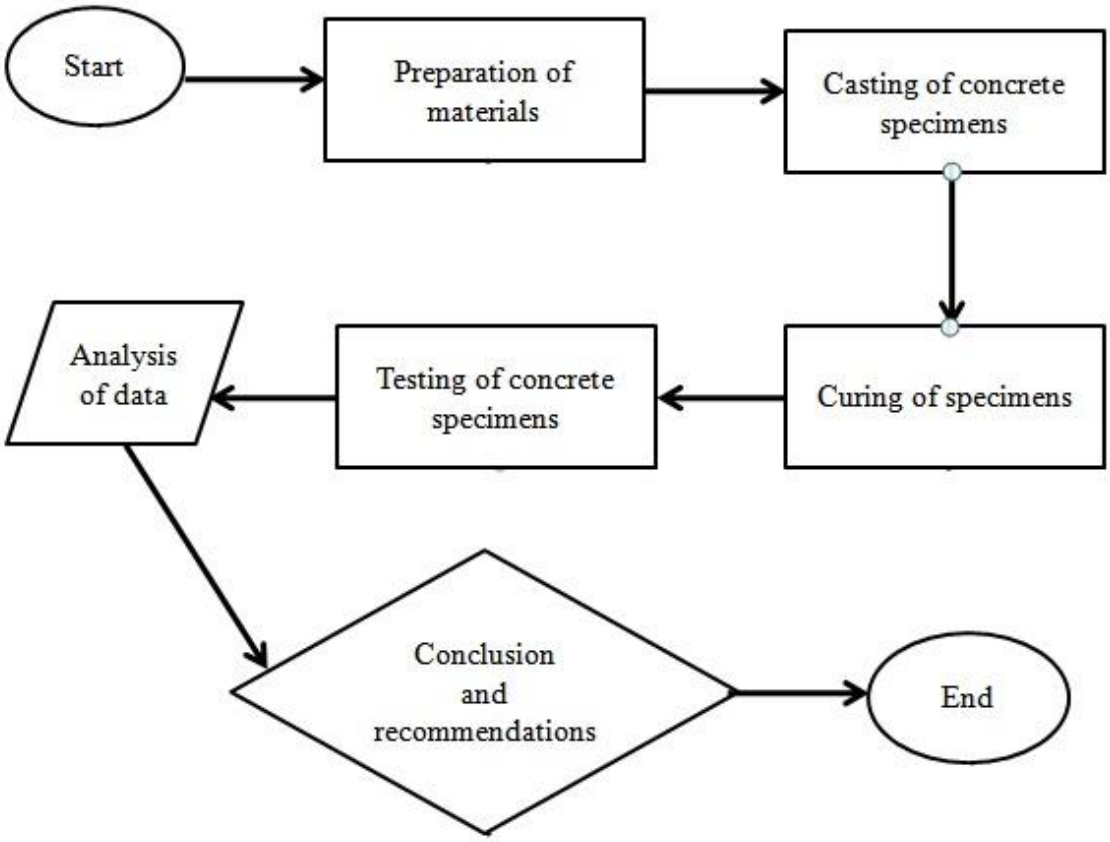

Figure 3.1: Flowchart of research work for the study

3.2 MATERIALS PREPARATION

3.2.1 Cement

Cement is one of the important materials in the concrete. It can be defined as the bonding material having cohesive and adhesive properties which makes it capable to unite the different construction materials. The cement used in this study is Ordinary Portland Cement (OPC) as shown in Figure 3.2. OPC is a type of powder material that is widely used in the building construction. The use of OPC complies with the Malaysian Standard MS 522: Part 1: 1989. It is kept in a sealed container and stored in the humidity controlled room to avoid exposure to moisture. The chemical and physical properties of this type cement were presented in Table 3.1.

Figure 3.2: Ordinary Portland Cement is grey in colour

Table 3.1: Chemical properties of OPC

Chemical Compounds	Content (%)
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6.0
MgO	0.5-4.0
Alkalis	0.3-1.2
SO_3	2.0-3.5

Source: Okpala (2007)

3.2.2 Fine Aggregates

The fine aggregates used in this research are natural sand aggregates as shown in Figure 3.3. The sand will likely affect the workability of concrete with undeniable moisture condition. Therefore, sand is left air-dried for 24 hours to get rid of the surface moisture. This procedure saturated the moisture in the sand that will minimize the sand capability to absorb water.

Figure 3.3: Natural sand

3.2.3 Coarse Aggregates

Aggregates generally occupy 60-75% of the concrete volume and they strongly influence the hardened properties of concrete. Coarse aggregate used in this research is crushed stone aggregate (CSA) as shown in Figure 3.4. The sieve analysis is carried out using sieve machine to obtain the required size of 10 mm. The careful grading of size is important to get a good quality of concrete mixture. The coarse aggregate is left air-dried for 24 hours before being used in casting process to remove the surface moisture that may affect the water absorption capability of that aggregate.

Figure 3.4: Coarse aggregate

3.2.4 Oil Palm Shell (OPS)

OPS as shown in Figure 3.5 are used as a replacement of coarse aggregate in this research. It was taken from the palm factory in Panching, Gambang. OPS were left air-dried for a week outside the laboratory to obtain approximately a saturated surface–dry condition. Shell is commonly varying in thickness because fruits of different species are processed together. Therefore it is sieved to get the required size of 10 mm.

Figure 3.5: Crushed oil palm shell

3.2.5 Water

The water used should be free from any contaminants or impurities or that may affect the setting time and strength of concrete. Potable water is used in this research for the hydration of cement paste and to provide workability during mixing and for placing. Tap water is used for the whole concrete casting process as shown in the Figure 3.6.

Figure 3.6: Tap water is used for the casting process

3.2.6 Steel Reinforcement

Steel is used as reinforcement in the concrete to produce reinforced concrete. The idea of combining concrete and steel produced a material that is stronger than either material alone because the good bond between them allows an effective of transfer of stress or load so both materials act together in resisting specimen action. In this research, steel reinforcement of size 12 mm is used as shown in the Figure 3.7.

Figure 3.7: Steel bars are used in this research to reinforce the concrete slab

3.2.7 Superplasticizer

Superplasticizers for use in concrete are one of many ingredients that are known as admixtures. Some of them are synthetic while others are derived from natural products and can be classified as Sulphonated Melamine Formaldehyde Condensate, Sulphonated Napthalene Formaldehyde Condensate and Modified Lignosulphonates. Superplasticizer is a type of high range water reducing admixture according to the ASTM-C494. It is used in this research as in Figure 3.8 to increase the workability of fresh concrete. The required amount of super plasticizer used in this research is 0.08 kg/m^3 for all the concrete mixes.

Figure 3.8: Superplasticizer is measured to a required amount in a beaker

3.3 MIX DESIGN AND CASTING PROCESS

The concrete mix is prepared for grade 30 N/mm^2.The concrete mix composition is summarized in Table 3.2. For each batches there is different percentages of coarse aggregate replacement which can be referred in Table 3.3. The crushed stone aggregate (CSA) is being replaced with the OPS based on the percentage requirement for each batch. Steel reinforcements of size 3H12 are installed in the concrete slabs just before being used for casting.

Table 3.2: Concrete mix composition

Grade,MPa	**Coarse aggregate, kg/m^3**	**Fine aggregate, kg/m^3**	**Cement, kg/m^3**	**Superplastisizer, kg/m^3**
30	Refer Table 3.3	762	400	0.8

Table 3.3: Detail of specimens

Batch	**Specimens**	**Coarse aggregate, kg/m^3**	**Steel reinforcement**
B1	6 cubes	1011CSA	
	3 slabs		3H12
B2	6 cubes	505.5 CSA	

	3 slabs	153.5 OPS	3H12
B3	6 cubes	307 OPS	
	3 slabs		3H12

A total of nine reinforced concrete slab formworks with dimensions of 500 mm long, 350 mm wide and 100 mm thick are prepared using plywood. The thickness of plywood used is 18 mm to make sure sufficient stiffness and durability during casting process. The dimensions of the cube and slab specimens are shown in the Figure 3.9 and Figure 3.10 respectively. The cube mould and slab formwork used for casting process are shown in Figure 3.11 and Figure 3.12 respectively.

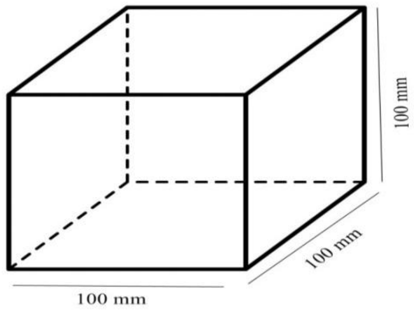

Figure 3.9: Cube with its dimensions

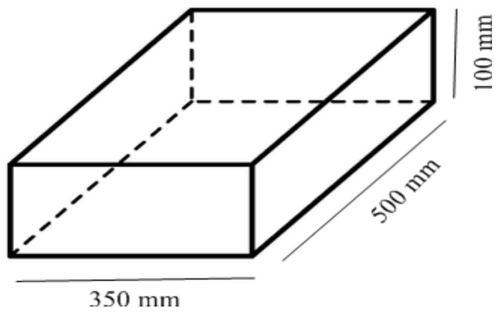

Figure 3.10: Slab with its dimension

Figure 3.11: Prepared cube mould

Figure 3.12: Prepared slab formwork

Three numbers of 12 mm diameter of high strength steel and 10 mm of mild steel are designed to reinforce the slab. The steel reinforcements are arranged to a distance of 150 mm between each other after considering the concrete cover of 25 mm size. The diagram of steel reinforcement arrangement is shown in Figure 3.13.The concrete covers are placed at every end of the reinforcements to protect the rebars from environmental effects to avoid their corrosion. In addition, concrete cover functions to provide thermal insulation which is useful to keep the reinforcement bars from fire. Figure 3.14 shows the concrete cover used in the steel reinforcements.

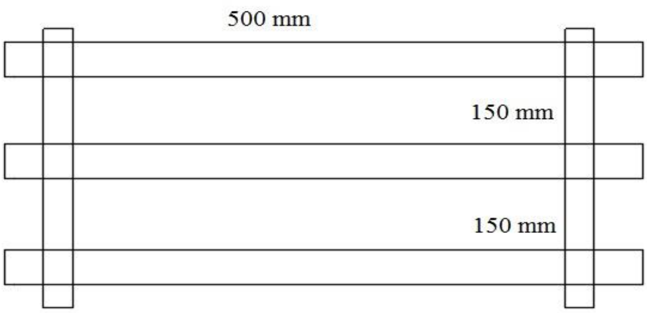

Figure 3.13: The schematic arrangement of steel reinforcement

Figure 3.14: The size of concrete cover used in this research is 25 mm

All equipments and materials required for the mixing process were prepared. The designed amount of cement and aggregates were mixed manually until they were fully blended. Then 70% from the required quantity of water was mixed with super plasticizer and added to the mix .The remaining water was added to the mixture and mixing process was continued until the concrete was mixed thoroughly. Fresh state of concrete after mixing process is shown in Figure 3.15.

Figure 3.15: Fresh state of concrete

The fresh concrete was poured into the moulds and the specimens were compacted using a poker vibrator machine as shown in the Figure 3.16. The benefits of using poker vibrator machine instead of manual compaction are it ensures the uniformity of compaction and faster rate of compaction can be done. The specimens were left to harden for about 24 hours before dismantling the moulds from the hardened concrete. Figure 3.17 and Figure 3.18 show the hardened cube and slab specimens before being dismantled from their moulds respectively.

Figure 3.16: Poker Vibrator which is used for compaction of concrete

Figure 3.17: Hardened cube before dismantling from mould

Figure 3.18: Hardened slab before dismantling from formwork

As discussed in the previous chapter, the curing of concrete is done to maintain mixing water in concrete during the early hardening process. Wet covering curing using wet gunny was applied in this research. The curing process on concrete took place for 7 and 28 days. Both cube and slab specimens were covered with gunny sacks which were wetted everyday to ensure the moisture of the concrete is kept constant. Figure 3.19 shows the concrete specimens which were cured using wet gunny.

Figure 3.19: Curing of concrete using wet gunny sack

3.4 SLUMP TEST

The procedures of concrete slump test are based on BS EN 12350-2-2009. This part of this British Standard describes a method for determination of slump of cohesive concrete of medium to high workability.

In a first step, required cone mould is prepared. The internal surface of the mould is cleaned before commencing the test. Then, the mould is placed on a smooth, horizontal, rigid and non-absorbent surface free from vibration and shock such as steel plate. Then the mould is held firmly against the surface below with funnel in position at the top whilst it is filled in three layers, each approximately one-third of the height of the mould when tamped.

Each layer is tampered with 25 evenly distributed strokes of the tamping rod over cross-section of the layer. After that the mould is filled to two-third full, and the second layer is rode with the same 25 strokes penetrating the top of the bottom layer. The concrete is heap above the mould and the top layer is rode with 25 strokes penetrating the top of the second layer. Further concrete may be added to maintain an excess above the top of the mould throughout the tamping operation. The top surface of the concrete is stroked off to the top of the mould. The mould is removed carefully by raising it in 5 to 10 s in the vertical direction. Immediately after the mould is replaced, the slump is measured to the nearest 5 mm by using ruler as shown in Figure 3.20.

Figure 3.20: Slump test for concrete

3.5 REVIEW ON CASTING PROCESS

During the casting process, full attention has been given to every batch of concrete in terms of its coarse aggregate replacements (50% and 100%). The whole attention is subjected to maintain the same effort, condition and steps were taken during process of casting.

The same condition is maintained throughout the casting process for every batch by reducing the external factors that may affect the mixing process. The intended factor is the consistency in the mixing process. This can be achieved by making sure that only one person did the specific works such as weighing the materials for the concrete mixes. In addition, the time for concrete mixing is ensured to be consistent for every batch and the compaction process using poker vibrator is operated by one person only. These manners help to keep the same condition for every batch of the concrete mixes.

3.6 COMPRESSION TEST

The cube specimens were tested for the compressive strength at the ages of 7 and 28 days in accordance to BS EN 12390-3-2009. The specimens were tested at the ages of 7 and 28 days to ensure that two-third of targeted strength and specific targeted strength were achieved respectively. This procedure is applied for control batch (B1). As for batches B2 and B3, this test was to study the effect of coarse aggregate substitution.

Testing was conducted immediately after the specimens were removed from the curing sacks. Before starting the test, the weight of specimens was measured and presented Table 3.4. Bearing faces of upper and lower bearing plates and of the specimen were wiped cleanly. The cube specimen was placed at the centre of the bearing plate. The compression machine used for this test is shown in Figure 3.21. The compression load was applied using compression machine at the rate of 0.3 $N/mm^2/s$. Three specimens were tested at each age to compute the average strength. The cube specimen the end of the test is shown in Figure 3.22. The results were recorded for further analysis.

Compressive strength is calculated using the equation $f_{cu} = \frac{P}{A}$

where f_{cu} = compressive strength (MPa)

P = maximum load carried by the specimen during test (N)

A = average cross-sectional area of the specimen (mm^2)

Table 3.4: Weight of cubes before compression test

Batch	Cube	Weight of cube at 7 days (kg)	Weight of cube at 28 days
B1	1	2.40	2.35
B1	2	2.35	2.30
B1	3	2.35	2.30
B2	1	2.15	2.20
B2	2	2.20	2.20
B2	3	2.20	2.15
B3	1	1.80	1.85
B3	2	1.90	1.80
B3	3	1.85	1.80

Figure 3.21: Compression Machine

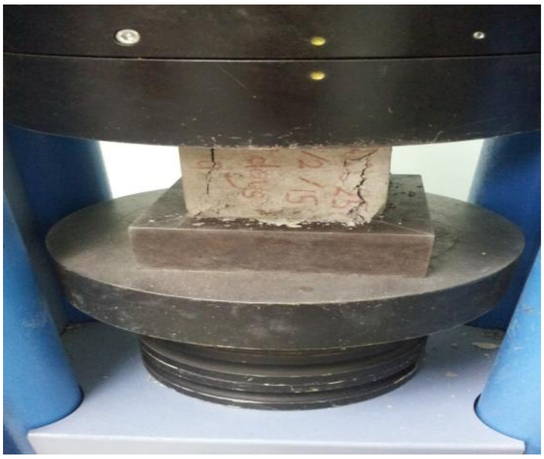

Figure 3.22: Cube specimen at the end of compression test

3.7 COMBINED BENDING AND SHEAR TEST

The combined bending and shear test was applied to the slab specimens to determine the maximum load that can resist by slabs before they fail under shear. The testing of slab was done using magnes frame. During the test, the behaviour of cracking failure for every batch of slab specimens was also observed. The LVDT or Linear Variable Differential Transformer is a type of well-established transducer that is installed to the specimen to measure the deflection. In this experimental test, five numbers of LVDTs are installed to the concrete slab for that reason. Hydraulic jack load functions to lift heavy load to the specimen. The data logger, an electronic instrument which connects to all LVDTs and load cell functions to record measurements at set interval over a period of time. Figure 3.23 shows the LVDT used in the research whereas Figure 3.24 and Figure 3.25 show the Hydraulic Jack Load and Data Logger machine respectively. The schematic diagram and actual experimental set up showing the location of the instruments for this test are shown in Figure 3.26 and Figure 3.27 respectively.

Figure 3.23: LVDT is used to measure the deflection of specimen

Figure 3.24: Hydraulic Jack Load is used to transfer load to the specimen

Figure 3.25: Data Logger is used to record the measurements of specimen

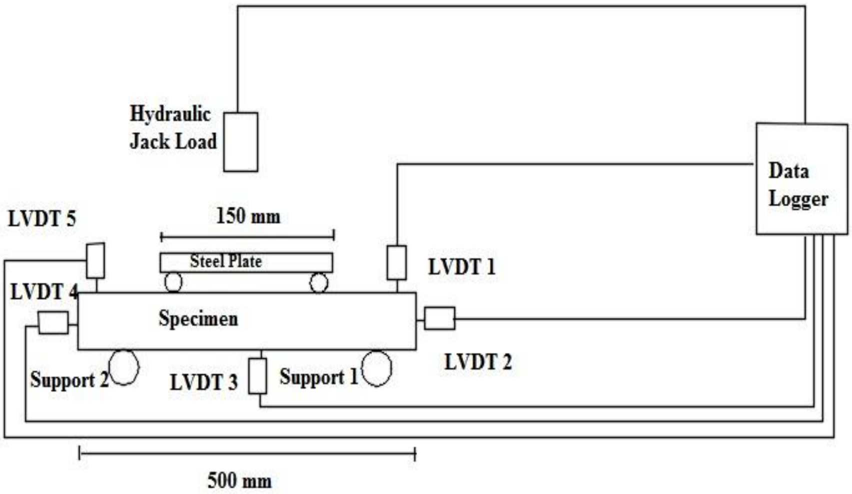

Figure 3.26: The schematic diagram arrangement for slab test

Figure 3.27: The actual diagram arrangement slab test

3.7.1 Testing Procedures

1. The location of supports and loading point on the surface of slab are indicated and marked.

2. Four LVDTs and a transducer are connected to the slab and data logger.

3. The load is applied to the specimen and each crack failure is traced using a marker pen.

4. The loads are applied continuously until the slab specimens failed.

5. No specific loading rate is set. The load reading is taken for each cracking load.

6. The maximum load is recorded for further analysis.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

This chapter focuses on the results obtained from the experimental work (as in Appendix A). The discussion starts with the compressive strength test and followed by combined bending and shear test results.

The behaviour of shear failure for the slab specimens under the combined bending and shear test is also discussed.

4.2 COMPRESSIVE STRENGTH TEST RESULTS

In this section, the compressive strength was determined using cubes of 100 mm × 100 mm × 100 mm. The test was carried out at 7 and 28 days for every batch. The 7 days test was aimed to determine whether the compressive strength has achieved two-third of the design strength of 30 MPa. Other than that, the early strength development of concrete can be seen by carrying out 7 days test of compressive strength. The coarse aggregate replacement is being referred as CAR in this whole research.

4.2.1 Compressive Strength Value

Table 4.1 until Table 4.3 show the results of compressive strength at 7 and 28 days for each batch. Meanwhile, Table 4.4 give the average compressive strength, $f_{cu,ave}$ for each batch. The compressive strength results of cube test with and without the addition of OPS aggregate showed variant strength. Through the tables, it can be seen that the replacement of coarse aggregate with 50% contributed to reduction in strength. This is shown for B2 cubes while further replacement at 100% contributed to further strength reduction (B3 cubes). This occurred at 7 and 28 days aged. When comparing the average compressive strength for these three cubes (Table 4.4), it can be seen that batch B1 had the highest compressive strength average at both 7 and 28 days age of testing then followed by batch B2 and B3 respectively. As mentioned in the previous chapter, batch B1 is a control concrete while batch B2 is 50% OPS + 50% CSA and batch B3 is 100% OPS. Hence, it can be concluded that increasing the percentage replacement of OPS gave lower compressive strength to concrete.These results are due to the fact that OPS has weaker properties when compared to conventional coarse aggregate.

However, when referring to the previous work by Okafor and Basri (2003), they stated that minimum requirement to produce structural lightweight concrete OPS is strength of 17 MPa, meanwhile the compressive strength for 50% coarse aggregate replacement was 18.48 MPa. Therefore the half replacement of OPS as coarse aggregate in the concrete is possible to produce lightweight concrete OPS.

Table 4.1: Compressive strength, f_{cu} for B1

Age of testing (days)	**f_{cu} (MPa)**		
	Cube 1	**Cube 2**	**Cube 3**
7	33.96	30.38	29.73
28	43.85	42.21	42.36

Table 4.2: Compressive strength, f_{cu} for B2

Age of testing (days)	**f_{cu} (MPa)**		
	Cube 1	**Cube 2**	**Cube 3**
7	16.70	15.83	15.43
28	17.23	20.07	18.13

Table 4.3: Compressive strength, f_{cu} for B3

Age of testing (days)	f_{cu} (MPa)		
	Cube 1	**Cube 2**	**Cube 3**
7	11.66	11.45	11.64
28	14.29	13.63	13.68

Table 4.4: Average Compressive strength, $f_{cu,ave}$

Concrete batch	$f_{cu,ave}$ (MPa)	
	At 7 days	**At 28 days**
B1	31.36	42.81
B2	15.99	18.48
B3	11.58	13.68

Figure 4.1 shows the relationship between $f_{cu,ave}$ and percentage of coarse aggregate replacement. The findings showed that the compressive strength at 28 days age of testing for the control specimens meet the targeted strength of 30 MPa. However, the compressive strengths start to decrease at 50% CAR and is further decreased at 100% CAR. This observation occurred at both 7 and 28 days.

To better observe the comparison of compressive strength for each coarse aggregate replacement, a histogram was presented to determine the percentage reduction of compressive strength when compared to the control cubes from B1 batch. From the histogram (Figure 4.2), it can be seen clearly that for 50% coarse aggregate replacement, the compressive reduced to 49% and 64% at 7 and 28 days age of testing respectively. Meanwhile for the full replacement of coarse aggregate, the compressive strength reduced to 57% and 70% at 7 and 28 days age of testing respectively.

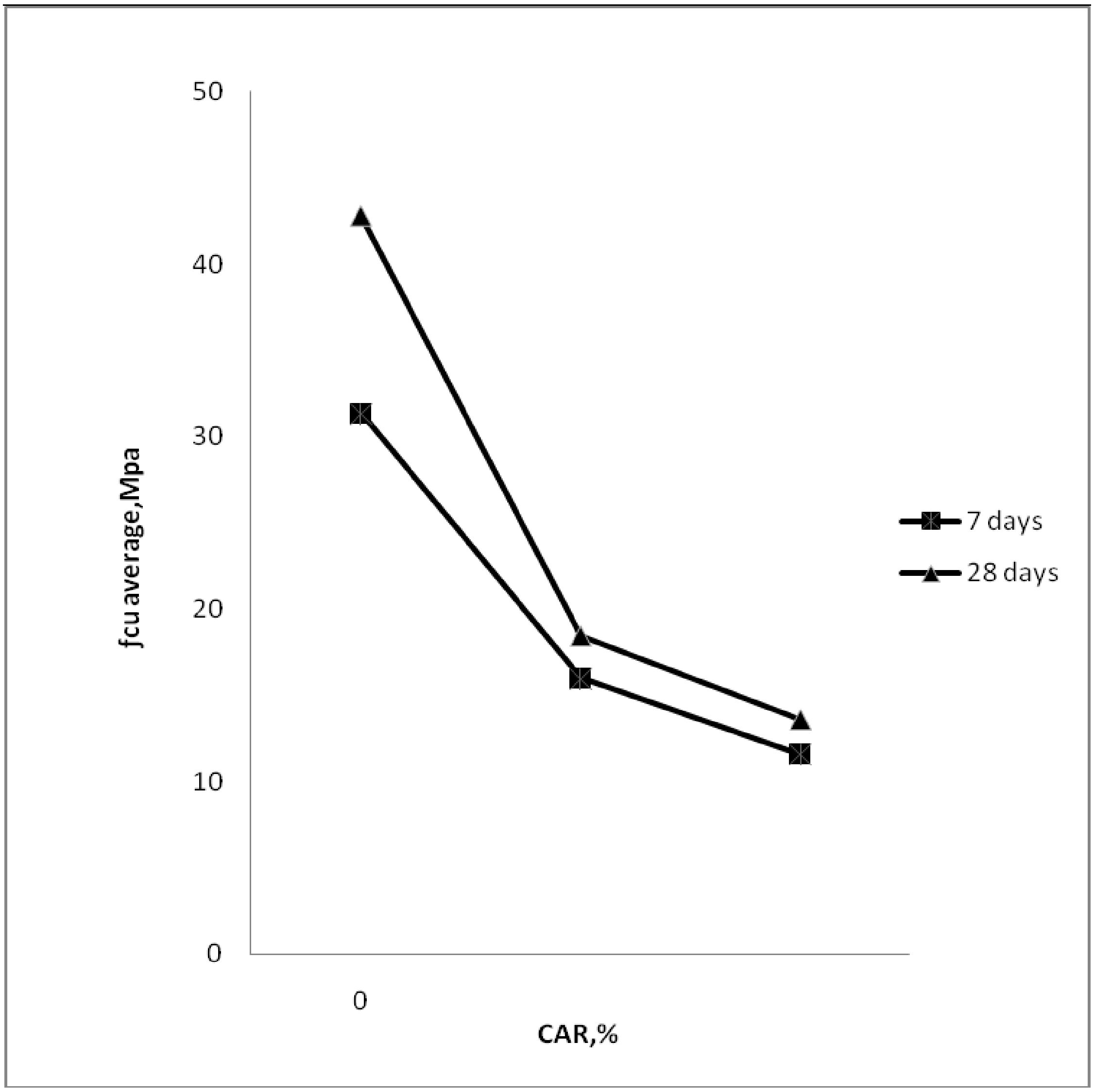

Figure 4.1: Relationship between $f_{cu,ave}$ and CAR

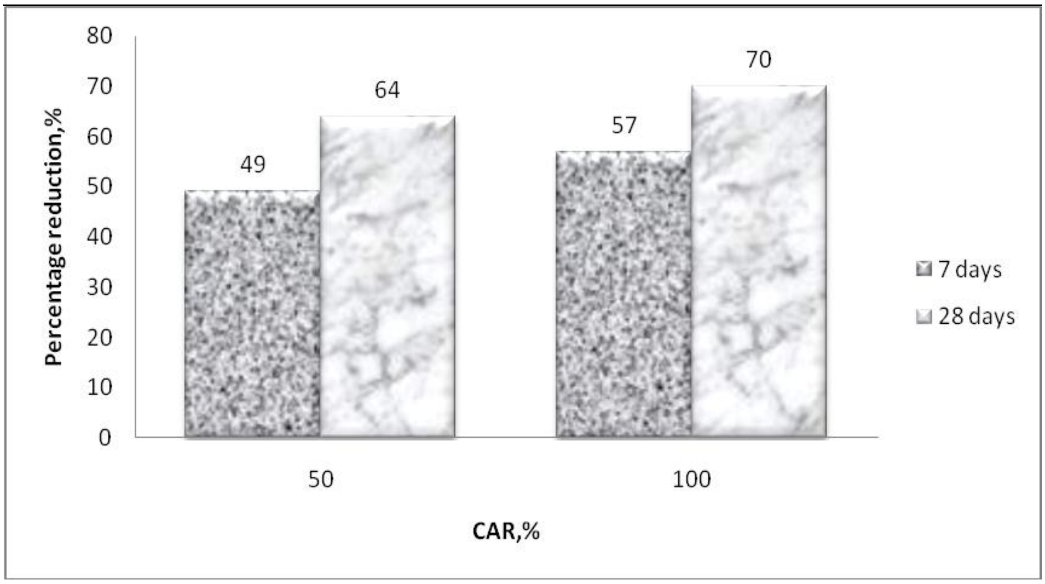

Figure 4.2: Relationship between percentage reductions with CAR

4.2.2 Failure Mechanism of Cube

In this section, the failure mechanism of cubes were discussesd. The failure cracks were generated under pure unaxial compression loading, and it showed that the pattern of failure cracks are approximately parallel to the direction of load.The comparison was made between the plain concrete cubes with the OPS concrete cubes.It showed that the crack openings for plain concrete were greater than the concrete with the addition of OPS aggregate. At higher level of coarse aggregate replacement which was 100%, the failure mode showed less cracking development and small cracking opening when compared to the lower replacement of aggregates. However, most of the specimens showing the same crack patterns for each batch. The specimens before testing is shown in Figure 4.3 whereas the failure mode for cube batch B1, B2 and B3 are shown in Figure 4.4 (a), (b) and (c) respectively.

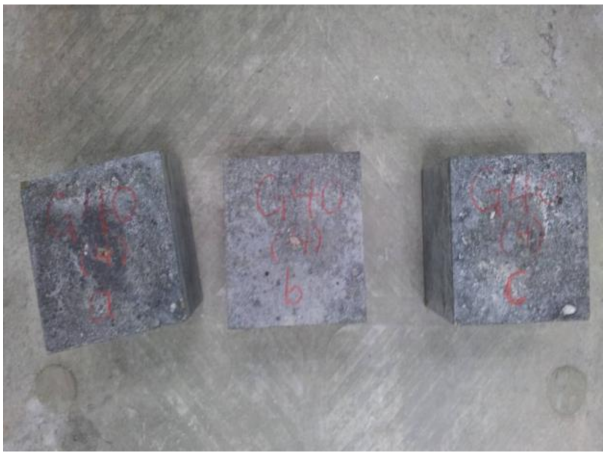

Figure 4.3: Cubes before compression test

(a) (b) (c)

Figure 4.4 (a),(b) and (c): Cubes after compression test for batch B1, B2 and B3 respectively

4.3 COMBINED BENDING AND SHEAR TEST RESULTS

In this section, combined bending and shear test was carried out using slabs of size 350 mm × 500 m × 100 mm. The test was carried out at 28 days. The first part of this section discussed the relationship between load and mid-span deflection of specimens, followed by the relationship between load and CAR and the relationship between ultimate load and CAR. The last part of this section discussed the failure mechanism of the slab.

4.3.1 Relationship between load and mid-span deflection

During the test, the mid-span deflection was recorded for every loading increment. At each loading increment during the test, the cracking was observed by visual inspection and traced with a marker pen to get the clear picture of the cracking pattern.

Figure 4.5 shows the curve pattern for control (B1) specimens. The deflection curves were diverged as early as the applied load reached 15 kN for specimen 1 and specimen 3 and reached 40 kN for specimen 2. After the load, specimens 1 and 3 showed steeper gradient when compared to specimen 2. The curve for specimen 2 was extended to higher ultimate load compared to the other two specimens. This batch may had possessed some errors due to the unusual value obtained. It might be the errors during the process of compaction which this batch was not properly compacted compared to the other two batches. In addition, the maximum deflection of specimen 1, 2 and 3 were 5.79, 4.12 and 4.59 mm respectively. The results showed that the bigger the loading applied to the slab, the greater the deflection would be.

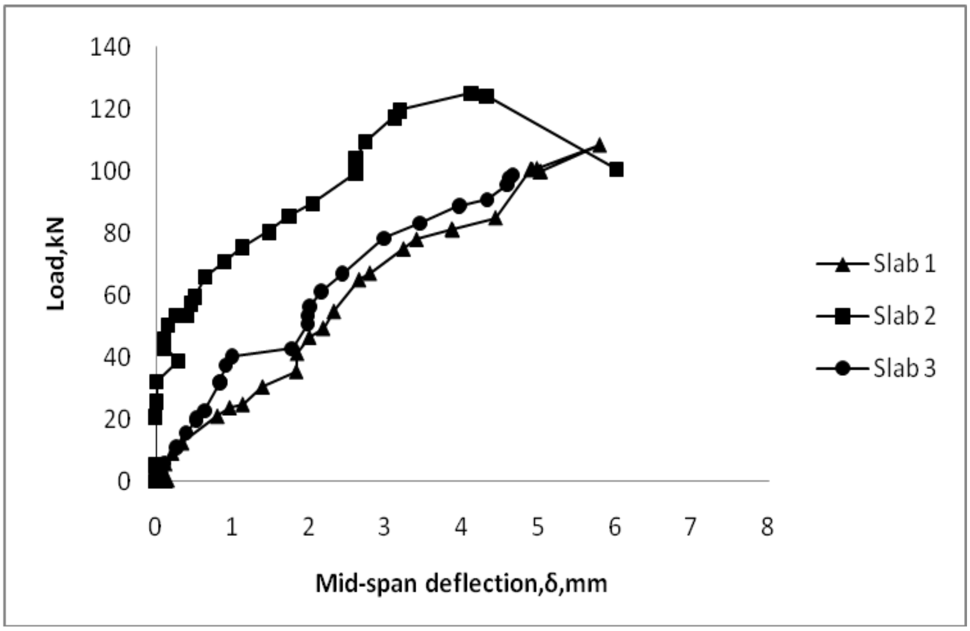

Figure 4.5: Relationship between load and mid-span deflection of slabs B1

Figure 4.6 shows the curve patterns produced for the B2 specimens. The deflections for three specimens showing the same behaviour until reaching the maximum failure load. The curve of specimen 1, 2 and 3 diverged when the applied load reached about 18, 9 and 11 kN respectively. The ultimate deflection for the specimen 1, 2 and 3 were 2.65, 5.73 and 5.68 respectively. When comparing to the previous discussed batch, batch B2 yielded lesser strength.

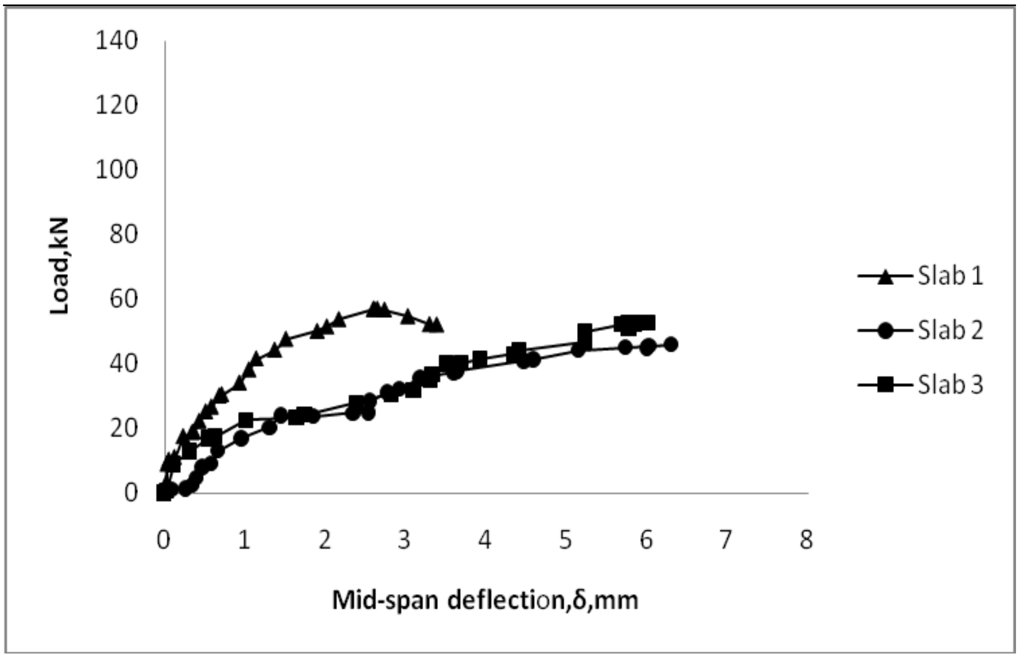

Figure 4.6: Relationship between load and mid-span deflection of slabs B2

Figure 4.7 represents the curve patterns for B3 specimens. The curve of specimen 1,2 and 3 diverged when the applied load reached about 2, 4 and 1 kN respectively. The deflections for specimen 1, 2 and 3 were 6.54, 5.27 and 7.03 mm respectively.This B3 batch showing less improvement in strength when compared to the other two batches. This was due to greater increment of CAR in B3 batch.

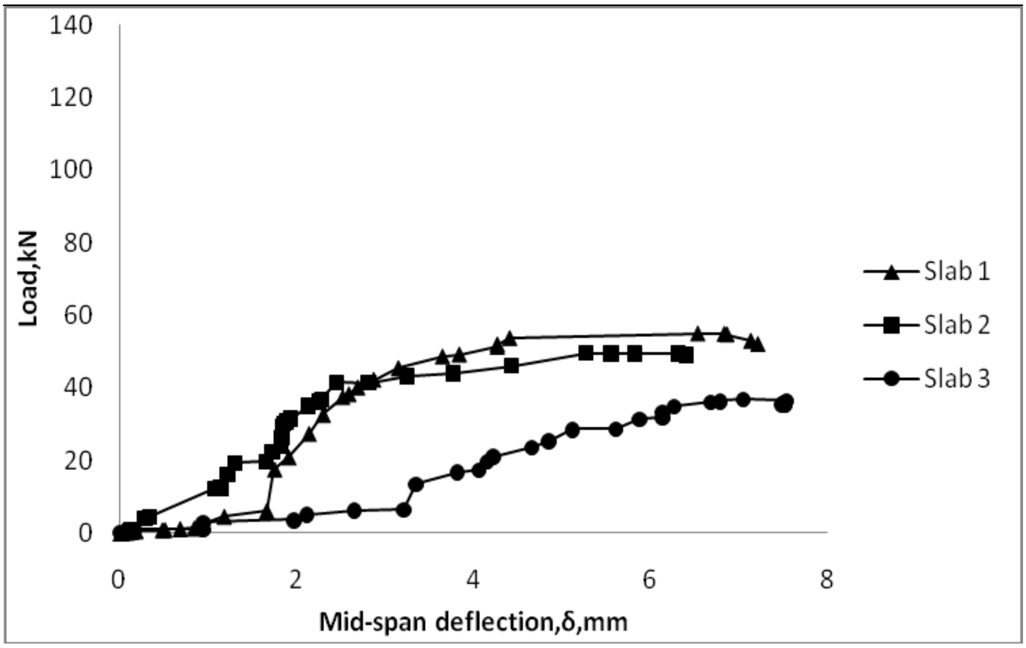

Figure 4.7: Relationship between load and mid-span deflection of slabs B3

4.3.2 Relationship between first cracking load and CAR

The first cracking load for each batch of slabs were observed and marked to compare the values. Figure 4.8 shows the relationship between first cracking load and CAR. The curve pattern shows that the first cracking load decreased when the percentage of CAR increased. For B1 batch, the first cracking load for slab 1, slab 2 and slab 3 are 70.92, 41.39 and 40.01 kN respectively. Meanwhile, for B2 batch, the first cracking load for slab 1, slab 2 and slab 3 are 29.44, 24.31 and 23.74 kN respectively. For B3 batch, the first cracking load for slab 1, slab 2 and slab 3 are 22.87, 23.14 and 18.4 respectively

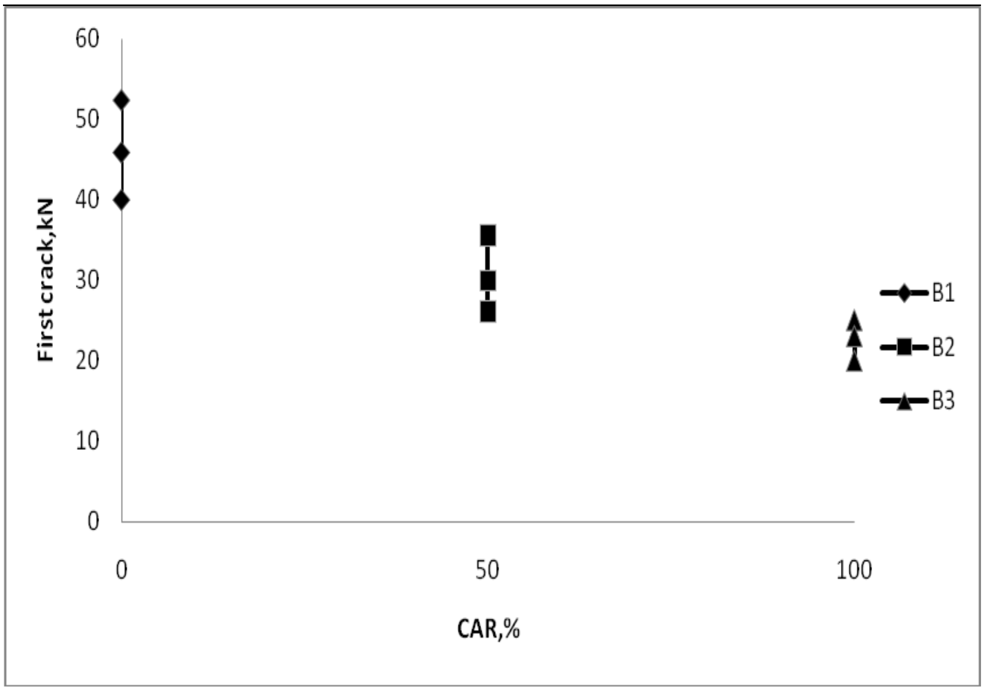

Figure 4.8: Relationship between first cracking load and CAR

The histogram upon the percentage reduction of first cracking load of CAR of 50% and 100% is presented in Figure 4.9. For 50% CAR, the first cracking load reduced to 49% when compared to the control specimens meanwhile for 100% CAR the percentage reduction of first crack was 58%. The first cracking load, if variant when compared between OPS specimens and control may show the effect of OPS aggregate in the concrete. It can be clearly seen that the 100% replacement of coarse aggregates gave higher value of first cracking load.

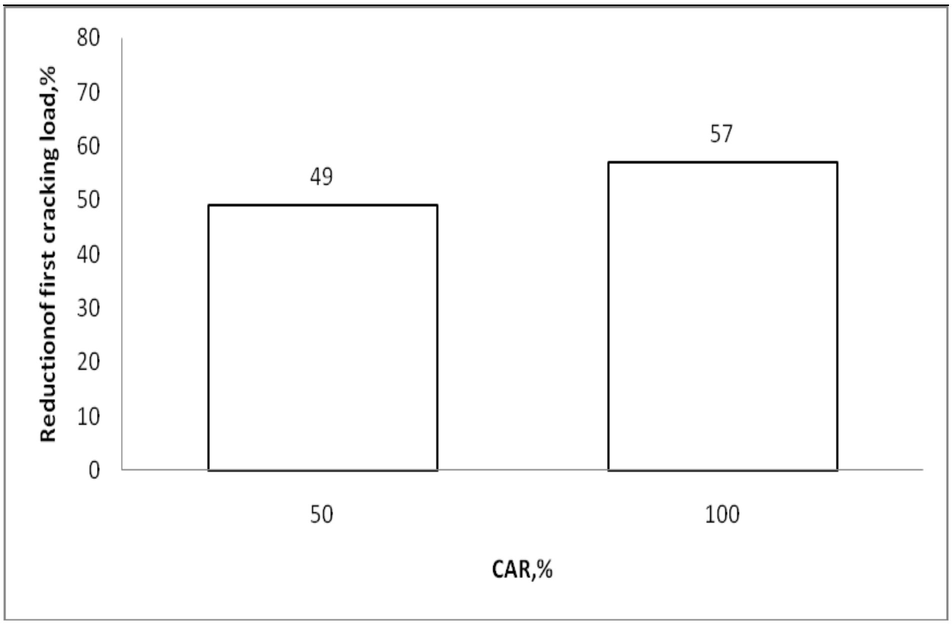

Figure 4.9: Relationship between percentage reduction and CAR for first cracking load

4.3.3 Relationship between ultimate load and CAR

An ultimate load is the amount of load applied to a component beyond which the component will fail. Figure 4.10 shows the relationship between ultimate load and coarse aggregate replacement (CAR) for the three batches of specimens. From the graph, batch B1 showed the highest ultimate load which were 108.23 kN, 124.91kN and 95.75 for sample 1,2 and 3 respectively. The ultimate load produced by batch B2 were 57.04 kN, 45.08 kN and 52.34 kN for sample 1,2 and 3 respectively while batch B3 yielded ultimate load of 54.88 kN, 49.45 kN and 36.80 kN for sample 1,2 and 3 respectively.It can be clearly shown that increasing percentage of CAR in the concrete specimens reduced the ultimate load. The average ultimate load computed for three specimens for CAR percentages of 0, 50 and 100% were 109.63, 51.49 and 47% respectively. By comparison with the control specimens, 50% and 100% of CAR produced 47% and 37% reduction in ultimate load respectively.

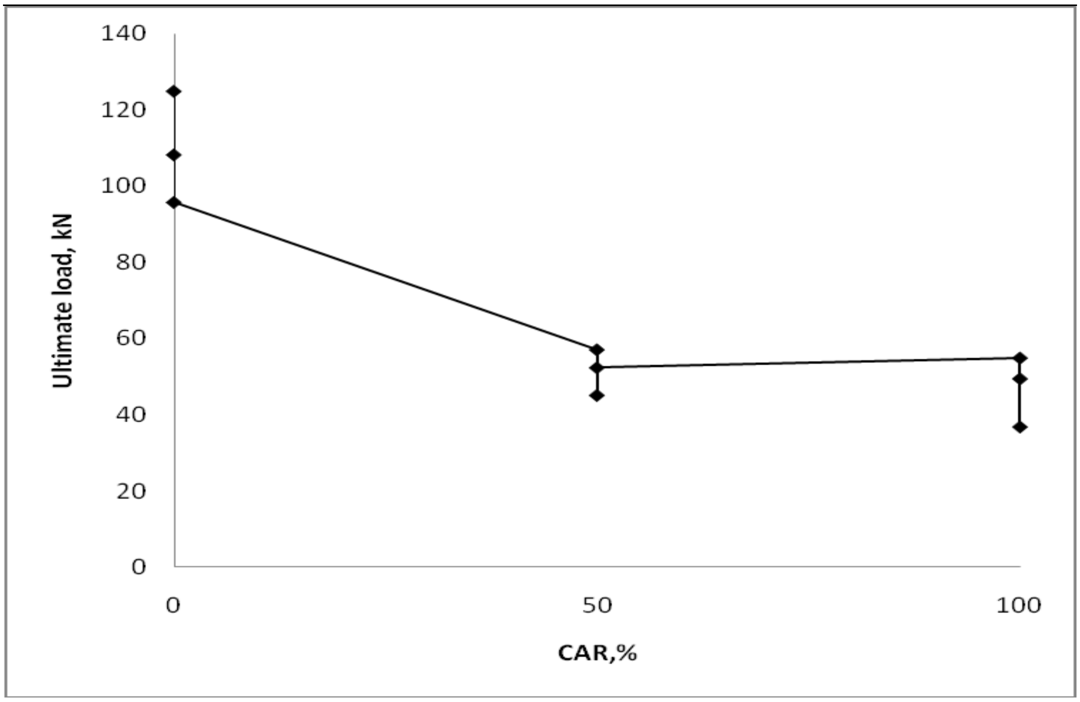

Figure 4.10: Relationship between ultimate load and CAR

4.4 FAILURE MECHANISM OF SLAB

Failure mechanism of slab specimens is discussed in this section. The failure mode of the specimens for B1, B2 and B3 were shown in Figure 4.11 (a), (b) and (c) respectively. Figure 4.13 and Figure 4.1. For the control specimens (B1), the slab deflected during the early loading increment but without any sign of visible cracks. Upon reaching the first crack load which for the specimen 1, 2 and 3 which were 70.92, 41.39 and 40.01 respectively, crack started to form at the flexural region. As the applied loading was subsequently increased, the cracks were getting wider followed by more cracks developed in the flexural region. The specimens started to fail when the maximum load reached. The failure was a diagonal shear and assisted with a loud sound.

The similar behaviour shown by specimens B2 and B3 where the first crack of the OPS specimen started to develop in the flexural region. For specimen B2 the first cracking loads for the three samples were 29.44, 24.31 and 23.74 kN whereas for specimen B3 the first crack load were recorded as 22.87, 23.14 and 18.4 kN. The diagonal crack initially started at the support then propagated diagonally into the flexural crack.

A visual inspection for each slab was made to compare the specimen behaviour between control and OPS specimens. From the results, varying the OPS content in the slab samples produced varying shear force strength. It can be clearly said that increasing the percentage of OPS as a replacement for conventional coarse aggregate will gradually decreased the shear of the concrete.

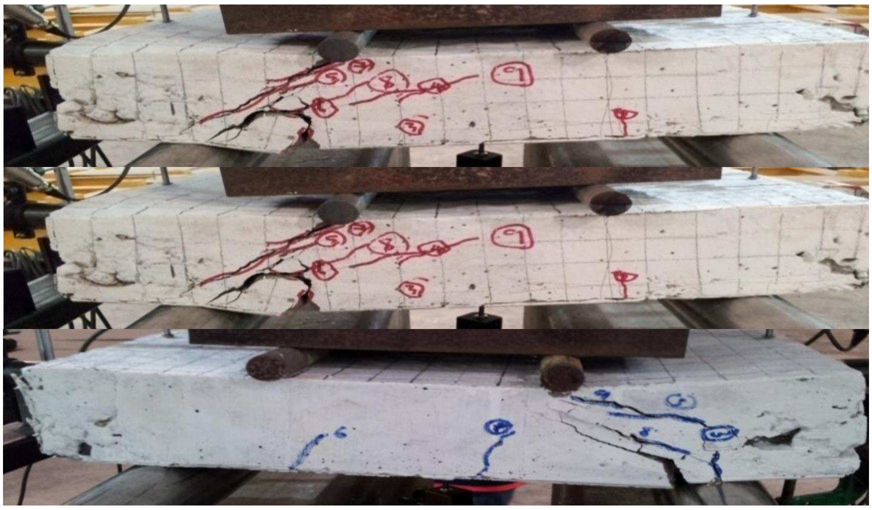

Figure 4.11(a): Failure mode of slabs B1 after testing

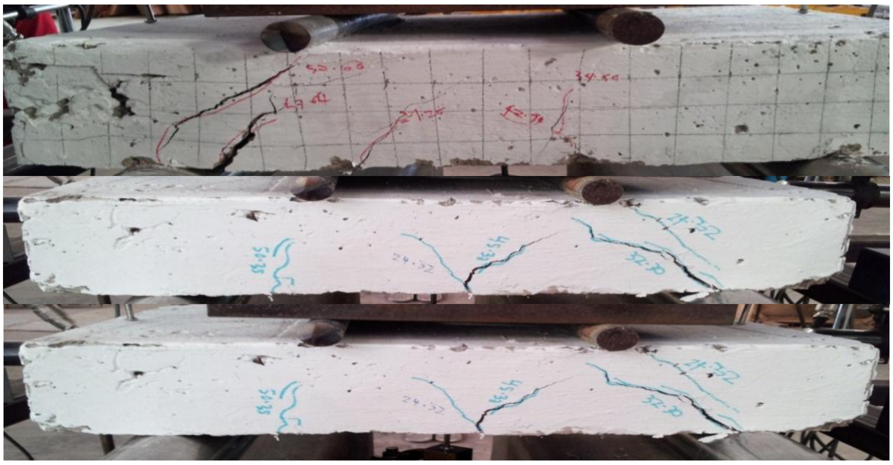

Figure 4.11(b): Failure mode of slabs B2 after testing

Figure 4.11(c): Failure mode of slabs B3 after testing

Based on the observation of the failure mode on the three batches of specimens, it can be concluded that all of them failed at the flexural region. Therefore it can be said that the cracking was in shear mode.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses a general overview on the experimental test results for the research. Conclusions are drawn up based on the findings in order to meet the research objectives. Last but not least, a few recommendations are proposed for the use in future research.

5.1 CONCLUSIONS

The conclusions are made as follows:

i. The experimental test on cubes showed that the increasing the addition of OPS into the concrete lower the compressive strength. Therefore, oil palm shell is a potential coarse aggregate replacement in concrete.

ii. The experimental tests on slab proved that the addition of OPS into the gives no significant effect to the structural behaviour of the concrete.

5.2 RECOMMENDATIONS

The recommendations for future investigation are:

i. As in this study, the OPS aggregates were left untreated before being used for casting process. Therefore it is recommended to pre-treat the OPS before using because it contains dust and oil coating. The previous work mentioned that some of the pre-treatment processes are waterproofing, sulphate treatments and removing oil coating with detergent and water (Mannan & Ganapathy, 2003).

ii. Treating OPS aggregates using Polyvynyl alcohol (PVA) helps to achieve better performance of the resulting concrete.

iii. The casting process of concrete in this study was made manually. Therefore it is recommended that future work for casting process is done using mixer to ensure the uniformity of concrete mixes for every batch.

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APPENDIX A

Table A1: Details of Testing Results for Slabs

Batch	CAR, %	First cracking load, kN	Ultimate load, kN	Ultimate deflection, δ, mm
B1	0	70.92	108.23	5.79
B1	0	41.39	124.91	4.12
B1	0	40.01	95.75	4.59
B2	50	29.44	57.04	2.65
B2	50	24.31	45.08	5.73
B2	50	23.74	52.34	5.68
B3	100	22.87	54.88	6.54
B3	100	23.14	49.45	5.27
B3	100	18.40	36.80	7.03

APPENDIX B

Design Shear Strength of reinforced concrete slab

Table B1: Specification of Parameters Used in The Shear Strength Design

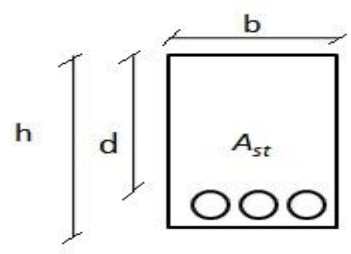
Properties	Symbol	Value
Characteristic strength of steel reinforcement	f_{yk}	500 N/mm^2
Unit weight of concrete	γ	25 kN/m^3
Diameter of steel bar	Φ	12 mm
Concrete cover	c_{nom}	25 mm
Loading span	L	500 mm
Area of steel reinforcement	A_{st}	339.29 mm^2
Thickness of slab	h	100 mm
Width of slab	b	350 mm

1. DESIGN ANAYSIS

$$d = h - c - 0.5\ \Phi_{bar}$$

$$= 100mm - 25mm - 0.5(12mm)$$

$$= 69mm$$



$$A_{st} = \frac{\pi d^2}{4}$$

$$= \frac{\pi(12)^2}{4}$$

$$= 113.10\ \text{mm}^2$$

For 3 steel reinforcements,

$= 113.10 \times 3$

$= 339.29$ mm^2

2. FORCES ANALYSIS

$F_{st} = 1.0\, f_{yk}\, A_{st}$

$= 1.0\ (500)(339.29)$

$= 169645\ N$

= 169.65 kN

3. ACTIONS AND ANALYSIS

$$d = \frac{100x}{2}$$

$$69 = \frac{100x}{2}$$

$x = 1.38$ mm

$z = d - x$

$= 69 - 1.38$

$= 67.62$ mm = 0.0673 m

$W = \gamma bh$

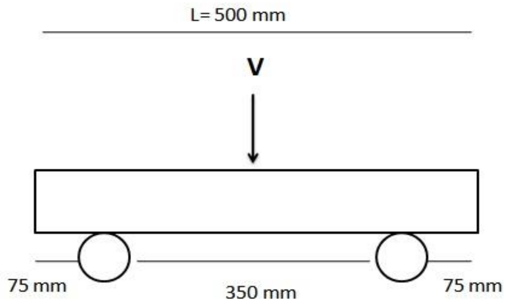
$= 25\text{kN/m}^3 \times 0.35\ \text{m} \times 0.10\ \text{m}$

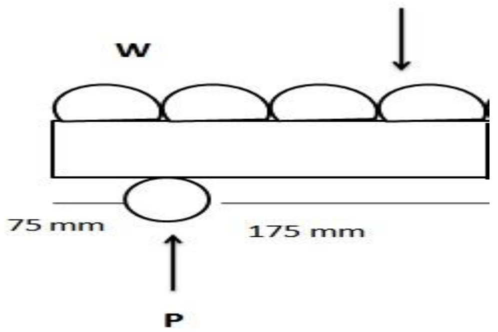
$= 0.875\ kN/m$

$M = F_{st.}$ z

$= 169.65(0.0673)$

$= 11.47\ kNm$





$\Sigma M_P = V_x + W_x$

$11.47 = V(175\text{-}75) + 0.875(0.125)$

$= 113.61$ kN