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PERFORMANCE OF SOLID WASTE BY PRODUCT (PALM OIL CLINKER) AS PARTIAL COARSE AGGREGATE REPLACEMENT

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Thesis submitted in fulfillment of the requirements
for the award of the
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ABSTRAK

Kajian ini menerangkan eksperimen mengenai kesan penggantian klinker kelapa sawit (KKS) agregat terhadap sifat-sifat mekanikal konkrit yang terdiri daripada kebolehkerjaan, kekuatan mampatan dan kekuatan lenturan. Nisbah air simen yang paling sesuai bagi campuran untuk kajian ini diperoleh melalui campuran percubaan dan menghasilkan nisbah yang tetap iaitu 0.53. Peratusan KKS yang berbeza digunakan sebagai penggantian sebahagian agregat kasar yang terdiri daripada 0%, 5%, 10%, dan 15%. Setiap ujikaji adalah berdasarkan standard British. Kebolehkerjaan konkrit diuji dengan menggunakan ujian kemerosotan untuk menyemak ketekalan konkrit. Untuk kekuatan mampatan, sebanyak 36 kiub dengan saiz 150mm x 150mm x 150mm digunakan untuk menentukan kekuatan mampatan konkrit apabila menggantikan dengan 0%, 5%, 10% dan 15% KKS sebagai pengganti agregat kasar dalam konkrit. Kemudian, untuk jumlah kekuatan lenturan 36 prisma dengan saiz 150mm x 150mm x 750mm digunakan untuk menentukan kekuatan lenturan konkrit apabila menggantikan dengan 0%, 5%, 10% dan 15% KKS sebagai pengganti agregat kasar dalam konkrit . kekuatan mampatan dan lenturan telah dijalankan pada hari ke 7, 14 dan 28 untuk mendapatkan kekuatan konkrit. Semua ujian dibandingkan dengan konkrit normal. Kesimpulan yang dapat dibuat berdasarkan keputusan yang diperolihi ialah penggantian 10% dan 15% KKS mempunyai kebarangkalian untuk digunakan sebagai pengganti granit dalam industri pembinaan.

ABSTRACT

This research describes experimental studies on the effects of substitution of POC aggregates towards the mechanical properties of concrete which consist of workability, compressive strength and flexural strength. The most suitable water cement ratio for the mixture was obtained through trial mixtures and yielded a constant of 0.53. The different percentage of POC was use as partial coarse aggregate replacement which is consist of 0%, 5%, 10%, and 15% replacement by volume of granite. All of the testing were followed the British standard. The workability of concrete were tested by using slump test to check the consistency of freshly made concrete. For compressive strength, total of 36 cubes with size 150mm x 150mm x 150mm were used to determine the compressive strength of concrete when replace with 0%, 5%, 10% and 15% of POC as a replacement of coarse aggregates in concrete. Then, for flexural strength total of 36 prism with size of 150mm x 150mm x 750mm were used to determine the flexural strength of concrete when replace with 0%, 5%, 10% and 15% of POC as a replacement of coarse aggregates in concrete. Compressive and flexural strength were conducted at 7 days, 14 days, and 28 days to get the strength of concrete. All of the testing were compared with normal concrete. As the result were obtained, it can concluded that replacement of 10% and 15% POC had a probability to use as a granite replacement in construction industry.

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LIST OF ABBREVIATIONS

UMP	Universiti Malaysia Pahang
POC	Palm Oil Clinker
ASTM	American Society for Testing and Material
OPC	Ordinary Portland cement
ACI	American Concrete Institute
POCC	Palm Oil Clinker Concrete
NWC	Normal Weight Concrete
OHSA	Occupational Health and Safety Assessment
SSD	Saturated Surface Dry

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is a very strong and versatile mouldable construction material. It's well known as a composite static material that consist of aggregates, water and cement. Concrete is used in all types of construction, particularly commercial building, highway and residential building due to its great strength, affordability, durability, and versatility. Structures designed with concrete are more durable and can be engineered to withstand the natural disaster such as hurricanes, earthquakes, and also tornadoes. Due to fast growing construction industry, the demand for concrete has increased tremendously, causing deficiency of suitable raw material such as aggregate in concrete making process which lead to increases the construction cost. To alleviate this problem, engineers are not only challenged with the future homebuilding in terms of construction cost control but also the need to convert the industrial wastes to useful construction and building materials. One of such ways is to introduce industrial waste material into concrete. Such waste materials are wood chipping, silica fume, fly ash, crumb rubber, paper mill and palm oil clinker. The utilisation of these waste reduce the use of aggregate from natural sources and ensures sustainability.

Malaysia is one of the world largest producers of palm oil and generate significant amount of waste in the milling process. Palm oil mill in Malaysia incinerate palm oil waste to produce steam needed for the milling process. The waste product of incineration is palm oil clinker (POC). Instead of dumping the POC into environment, a better waste management option is to crush POC into desired sizes (coarse aggregate) and utilise it as aggregate to produce lightweight concrete. Currently, many research has been carried out in order to provide a strong and durable concrete with the utilising POC aggregate as full replacement to conventional fine and coarse aggregates. POC is a light solid fibrous material which when crushed has the potential to be used as aggregate in lightweight concrete. The density and the strength of POC falls within the requirements of the structural lightweight concrete (*Neville AM, 1995*). The used of POC in construction industry will results in reducing the cost of raw materials which directly reduce the cost of construction.

1.2 Problem Statement

Concrete has been used globally in the construction sector. It disclosed that, natural raw materials such as aggregate have become more limited. The demand for natural aggregate is on the increase due to rapid infrastructure development. Thus, finding an alternative material that can serve as a replacement for natural aggregate is important to reduce the high demand. Since, palm oil industries is the most popular agro-industries in Malaysia, it is a chance to review the effectiveness of those waste industrial products as aggregate replacement.

In order to overcome this problem, the study carried out to determine the behaviour of waste industrial products which is POC as aggregate replacement within suitable percent. The vital constraints on the utilization of those waste materials, it should fulfil the engineering requirement in term of physical properties of concrete. Besides that, tests ought to be done on the concrete to make sure that the concrete beyond the prescribed specifications in terms of durability and strength.

1.3 Objectives of Study

The main objectives of this study are as follows:

i. To determine the workability of concrete when added with different percentage of palm oil clinker as a replacement of coarse aggregates.

ii. To determine the compressive strength of concrete when added with different percentage of palm oil clinker as a replacement of coarse aggregates.

iii. To determine the flexural strength of concrete when added with different percentage of palm oil clinker as a replacement of coarse aggregates.

1.4 Scope of Study

The scopes of study of this study are as follows:

i. The material use are POC, Portland cement, aggregate and water using ratio 1:3.

ii. POC was crushed and sieved to the desired particle sizes. Particles in the range of 5–14 mm are considered as coarse aggregate.

iii. The dimension of cube and prism chosen for compressive test and flexural test are 150 x 150 x 150 mm3 and 100 x 100 x 750 mm3 respectively.

iv. The approach used in the mix design involved POC replacement of 0%, 5%, 10%,15%, of the total volume of coarse aggregates.

v. Control mix was prepared using natural aggregates, such as river sand for fine aggregate and granite stone for coarse aggregate.

vi. The specimens are tested at the age of 7, 14 and 28 days of curing referencing British Standard (BS 1881), and American Society for Testing and Materials (ASTM C).

1.5 Significance Of Propose Study

This researched give further understanding on Palm Oil Clinker (POC) substitution toward concrete physical properties. Beside, determine how far the performance of POC in the making of concrete for construction industry and the effect of POC use on concrete prism strength properties based on the workability, flexural strength and compressive strength.

Furthermore, positive findings from this study can facilitate to promote the utilization of POC as construction materials and thus are going to be able to employ the agricultural waste within the country such palm oil clinker as a natural sources of construction materials. Therefore, it would help to minimize the adoption of aggregate, as well as reduce the construction cost. The success of this study will not only introduce the potential of POC in construction but also tends to minimize the construction failure.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The rationale of studying a literature review was to seek out, learn, and analyse the body of literature which has been publish via journal article, convention articles, book, research paper and thesis. Earlier experiences on engineering properties of concrete and its performance within the existing application will likely be studied with the intention to analyse extra useful information associated to the construction endeavour. This chapter reviews the past relevant literatures, which include the characteristics of cement, coarse aggregate, fine aggregate, and water. Besides, the past researches on the industrial waste (palm oil clinker) that can enhance the strength of concrete in workability, flexural strength and compressive strength.

2.2 Concrete

Concrete is a composite material composed of coarse mixture bonded alongside a fluid cement which hardens over time. Concrete is totally demanded in construction as its low maintenance, high compressive strength and durability and its low cost have made concrete economically viable. Typically, concrete is a composite material which is made from cement, aggregate and water. Regularly, reinforcements and additives are include within the mixture to achieve the preferred physical properties of the completed material. . When these ingredients are mixed collectively, its form a fluid mass that is readily moulded into shape. The cement will bond these ingredient together to forms a hard medium concrete. In tradition, the composition of concrete is simple. However, the modern concrete is of complex mix, with intention to ensure the durability and longevity of concrete *(Branston, 2006).* Concrete continuously used for construction since ancient times. Modem day concrete application include home, basement, dams, streets, bridge, patios, plain cement tiles, kerbs, swimming pools, drain covers, lamp-posts, mosaic tiles, benches, balustrades, pavement blocks and many more.

2.3 Properties of Concrete

Amongst the several properties of concrete, the compressive strength is considered to be the most important and is taken as an index of its overall quality. Several other properties of concrete appear to be commonly related to its compressive strength such as workability and durability.

2.3.1 Workability

Workability is typically referred to as the ease with which a concrete can be mixed, placed, compacted and finished without excessive bleeding or segregation. The size or shape of aggregate, water content and level of hydration may influenced the degree of workability, but sometimes it's also influence by adding chemical additives.

In view that the strength of concrete is significantly and adversely littered with the presence of voids in the compacted mass, it's significant to attain a maximum viable density. This requires sufficient workability for very nearly full compaction to be viable utilizing a reasonable amount of work under the given conditions. The density and strength of concrete will greatly reduce with the presence of voids. Suitable level of uniformity and plasticity of concrete can obtain from concrete with good workability that will influence the quality of hardened concrete.

2.3.2 Strength

Strength is a measure of the amount of stress required to fail a material. The working stress theory for concrete design considers concrete as mostly suitable for bearing compressive load, this is why it is the compressive strength of the material that is generally specified. Since the strength of concrete is a function of the cement hydration process, which is relatively slow, traditionally the specifications and tests for concrete strength are based on specimens cured under standard temperature-humidity conditions for a period of 28 days. Typically, the tensile and flexural strengths of concrete are of the order of 10 and 15 percent, respectively, of the compressive strength. The reason for such a large difference between the tensile and compressive strength is attributed to the heterogeneous and complex microstructure of concrete. *(Mehta and Montero, 2006).*

Concrete has high compressive strength compare to its tensile strength. The compressive strength is the capacity of structure or material to resist loads tending to reduce size. It may be measured by way of applying force against deformation in a testing machine. The type of stress applied is not the only factor that effect compressive strength of concrete but it's also depend on the combination on various factors. The factor are include the proportion and properties of material, condition of curing and also the degree of compaction.

Concrete is a composite material, however, many of its characteristics do not follow the laws of mixtures. For instance, under compressive loading both the aggregate and the hydrated cement paste, if separately tested, would fail elastically, whereas concrete itself shows inelastic behaviour before fracture. Also, the strength of concrete is usually much lower than the individual strength of the two components. Such anomalies in the behaviour of concrete can be explained on the basis of its microstructure, specially the important role of the interfacial transition zone between coarse aggregate and cement paste *(Mehta and Montero, 2006).*

Additionally, the concrete curing process is also important and final step in making concrete gain more strength. It is the treatment of newly placed concrete during the period in which it is hardening so that it retain enough moisture to immunize shrinkage and resist cracking *(Lambert Corporation, 1999).* A proper curing extensively contributes to reduce the drying shrinkage and porosity of concrete, and consequently to gain better strength and higher resistance to physical or chemical attacks in aggressive environments. Thus, a compatible curing process such as spraying or sprinkling of water, water ponding (immersion), or covering with polythene sheet material is most important in order to produce strong and long lasting concrete.

2.4 Ordinary Portland Cement

A cement is a binder, a substance utilized in construction that sets and hardens and use to bind different materials together. The foremost necessary types of cement are used as a part within the production of concrete and mortar in masonry. There are many different applications and properties of cements for used in concrete including hydraulic cements, Portland and blended. Cement should place in dry condition and should be used within three month of the date manufacture and it is recommended that never use the cement has lump in it, otherwise will affect the strength of production.

Ordinary Portland cement (OPC) is that the most typical cement used in general concrete construction once there's no exposure to sulphates within the soil or groundwater. OPC is a grey colored powder. It's capable of bonding mineral fragments into a compact whole once mixed with water. This hydration process leads to a progressive strength development, hardening and stiffening.

2.4.1 Chemical Composition of Portland Cement

The main chemical components of ordinary Portland cement are calcium, silica, alumina and iron. Calcium is typically derived from alumina, marl or chalk while oxide, limestone and iron come from the sands, iron ores and clay. Other raw materials might include shells, shale and industrial by-products. Chemical contain of Portland cement as detailed by *Lim Ooi Yuan (2012)* is showed in Table 2.1 offer interval limitation of oxide in Portland cement.

Table 2.1 Estimate interval limitation of portland cement.

Oxide	**Content, %**
Calcium Oxide (CaO)	60 - 67
Silicon Dioxide (SiO_2)	17 - 25
Aluminium Oxide (Al_2 O_3)	3- 8
Ferric Oxide (Fe_2 O_3)	0.5 – 6.0
Magnesium Oxide (MgO)	0.5 – 4.0
Sodium Oxide (Na_2 O)	0.3 – 1.2
Sulphur Oxide (SO_3)	2.0 – 3.5

The constituents above forming the raw materials endure chemical reactions throughout burning and fusion, and mix to form the BOGUE compounds such as Tricalcium silicate (3CaO.SiO2), Dicalcium silicate (2CaO.SiO2), Tricalcium aluminate (3CaO.Al2O3) and Tetracalcium alumino-ferrite (4CaO.Al2O3.Fe2O3).

2.5 Aggregates

Aggregate is the granular material, such as gravel, sand, crushed blast-furnace slag, crushed stone, or construction and demolition waste that is used with a cementing medium to produce either mortar or concrete. Aggregates make up 60-75% of concrete so have a large influence of the properties of the concrete (ACI E1-07). There are two types of aggregates, which is fine and coarse aggregate. Fine aggregates can fit through a 3/8-inch sieve and are usually made of crushed stone or natural sand, while coarse aggregates can be up to 1.5 inches and are primarily made of gravel.

2.5.1 Fines Aggregate

Fine aggregates may be described into two major parts, which are natural sand and crushed stone or crushing gravel sand. In this study, river sand and crushed sandstone with fineness modulus of 1.78, that passed through a 2.36 mm BS 410 test sieve was used.

In concrete production, the size of fine aggregate is acceptable ranging between 4.75 mm to 75µm. fine aggregate consists of natural or manufactured particles ranging in size from 150 mm to 4.75 mm *(Mohamed Abdel et al., 2007).* According *Kwan et al., (2014)* the fine aggregate serves to mitigate the particle interlocking action when the fine and coarse aggregate are blended so that the fine aggregate is more than enough to fill in the voids within the coarse aggregate.

The use of river sand for a given workability requirement, reduce the water and/or super plasticizer demand, and thus allow a lower cement content and a lower water content to be adopted in the mix design. The use of river sand with lower silt and clay contents, would improve the quality control of the concrete production because the presence of too much silt and/or clay would adversely affect the workability and strength of the concrete produced.

Figure 2.1 Fine Aggregate

2.5.2 Coarse Aggregate

Coarse aggregates are particles greater than 4.75mm and it is consists of gravel, crushed stone or geosynthetic aggregate *(Mohamed Abdel et al., 2007)*, but generally range between 9.5 mm to 37.5 mm. normally, course aggregate occupies 2/3 of the total volume of aggregate in concrete. The concrete strength also can be effected by the surface texture and shape of course aggregate. The concrete strength is dependent on the size of aggregate *(Popovics, 1998)*. This was proven by the experiments carried out by (*Oh et al. 2002*). The result of the experiment showed that the size of 25 mm aggregate served lower strength as compared to 19 mm aggregate. Thus, it is clear that the shape and size of aggregate have significant influences in concrete strength.

Figure 2.2 Coarse Aggregate

2.6 Palm Oil Clinker

Palm oil clinker is a by-product of palm oil industry which normally being dumped abundantly as waste which caused to the undesirable effects to our environment sustainability. The by-product that is collected from inside the boiler is called clinker. The clinker has an irregular shape of 150 mm to 225 mm size and whitish grey in colour *(Zakaria, 1987).* The aggregates produced from clinker are lightweight, porous and irregular in shape, and consequently have low values of bulk density and specific gravity *(Omar and Mohamed, 2002).* The low specific gravity and high aggregate crushing value have made the potentiality of usage of POC as an alternative source of aggregate which has not required any pre-treatment or modification *(Kanadasan and Abdul Razak, 2015)* and this could lead to reduce the depletion of natural resources. In Malaysia, the development of using palm oil clinker as lightweight aggregate in construction industry, especially in structural application started about 30 years ago *(Kamaruddin ,2002).*

The physical properties such as water adsorption, moisture content and bulk density of POC are shown in Table 2.2 according to *Mohd Hilton, (2009).* POC and conventional coarse aggregate, such as gravel used in saturated surface dry condition.

Table 2.2 Physical properties of fine POC and Coarse POC

Physical properties	Fine	Crushed Stone
Specific gravity	2.17	2.60
Moisture content (%)	0.08	0.05
Water adsorption (%)	4.65	1.79
Bulk density (kg/m3)	863.65	1815.23
Fineness modulus	2.84	2.65

2.6.1 Collection and Preparation of Clinker

In the research of *Omar and Mohamed (1991),* all the clinkers taken from the burning boiler were in the form of hard clinker with large chunks size (Figure 2.3) need to be crushed into smaller size. The clinkers were first crushed by using hammer to a size that can be fit into grind machine. Then, a grind machine was used to crush all the clinkers to the required size. The clinker aggregates were then sieved using *BS 410* sieve size in order to segregate the aggregate to the required size. Clinkers with nominal size of 10 mm were used as a coarse aggregate in lightweight concrete mixture, replacing granite. For fine aggregate, those clinkers having a size below than 5 mm were used to replace sand.

Figure 2.3 POC collected from the palm oil mill

2.6.2 Mechanical Properties of Palm Oil Clinker Concrete (POCC)

Research on "analytical and experimental studies on composite slabs utilising palm oil clinker concrete" has been carried out by *B.S. Mohammed et al (2011).* In term of structural behaviour, the research found that, due to early loss of composite action between the concrete and the steel in the conventional concrete slab, the first crack was occurred late compared to the conventional concrete slabs. It was also found that, Palm Oil Clinker Concrete (POCC) slabs were lighter than the conventional concrete slabs by 18.3% and have very slightly lower structural properties than conventional concrete slabs due to the lower modulus of elasticity of the POCC. After the loss of the composite action, strain, end slip and deflection readings revealed obvious disturbance in their trend since the concrete and steel started to act separately. Based on the research, he conclude that the structural behaviour and the shear-bond strength of the POCC composite slabs are satisfactory and can be adequately used in the construction of composite slabs.

2.6.3 Basic Material Properties of Normal Weight Concrete (NWC) and (POCC)

Based on the research of *Omar and Mohamed (1991),* the results of POCC and Normal Weight Concrete (NWC) properties in term of cube compressive strength, flexural tensile strength and indirect tensile strength were tabulated in Table 2.3.

Table 2.3 Basic Material Properties of NWC and POCC

Properties	**NWC**		**POCC**	
	Weight (kg)	Strength (N/mm2)	Weight (kg)	Strength (N/mm2)
Compressive Cube Strength (100 x 100 x 100 mm)	2.39	46.1	1.98	44.4
Flexural Tensile Strength (100 x 100 x 500 mm)	11.8	6.09	10.9	6.43
Splitting Tensile Strength (150 dia. x 300 mm)	12.2	3.31	11.1	3.17

The mean cube strength for the NWC is 46.1 N/mm2 compared to 44.1 N/mm2 of the POCC. The research found that the strength of lightweight concrete and the strength attained by the normal weight concrete is only have slightly different. For splitting tensile and flexural strength, the tests were implemented in accordance to British Standard *(BS 1881: Part 116 and 117)*. The mean modulus of rupture obtained for NWC are 6.1 N/mm2 and 6.4 N/mm2 for POCC. So, here we can see that it was found that POCC have higher rupture modulus compared to NWC. This could be due to higher cement content in palm oil clinker concrete mixture *(Omar and Mohamed, 2002)*. The splitting tensile strengths obtained for NWC and POCC are 3.31 N/mm2 and 3.17 N/mm2 respectively. Based on these results, it shows that the tensile strength of lightweight concrete is 4.4% lower than the tensile strength of normal weight concrete.

The result of the research also indicate that the POCC required 14% more total cementations contents than the corresponding NWC. In contrast, clinker mixture provides economic used of aggregate where about 37% of total aggregate content were saved in performing the same strength of POCC and NWC *(Omar and Mohamed, 2002).*

CHAPTER 3

METHODOLOGY

3.1 General

The experimental procedures, material use, preparation of materials, and apparatus, regarding this research will be discussed further in this chapter. This research was focused on workability, compressive strength and flexural strength using POC.

3.2 Experimental Program

This research was conducted to identify the best percentage of POC to replace coarse aggregate. There are 3 types of experiments that will be conduct which are slump test, compression test and flexural test.

The slump test were conducted to determine the workability of the specimens while the compression test to determine the compressive strength of specimens and the flexural test to test the flexural strength of the specimens. The arrangement of the experimental program can be summarized in the flow chart as shown in Figure 3.1.

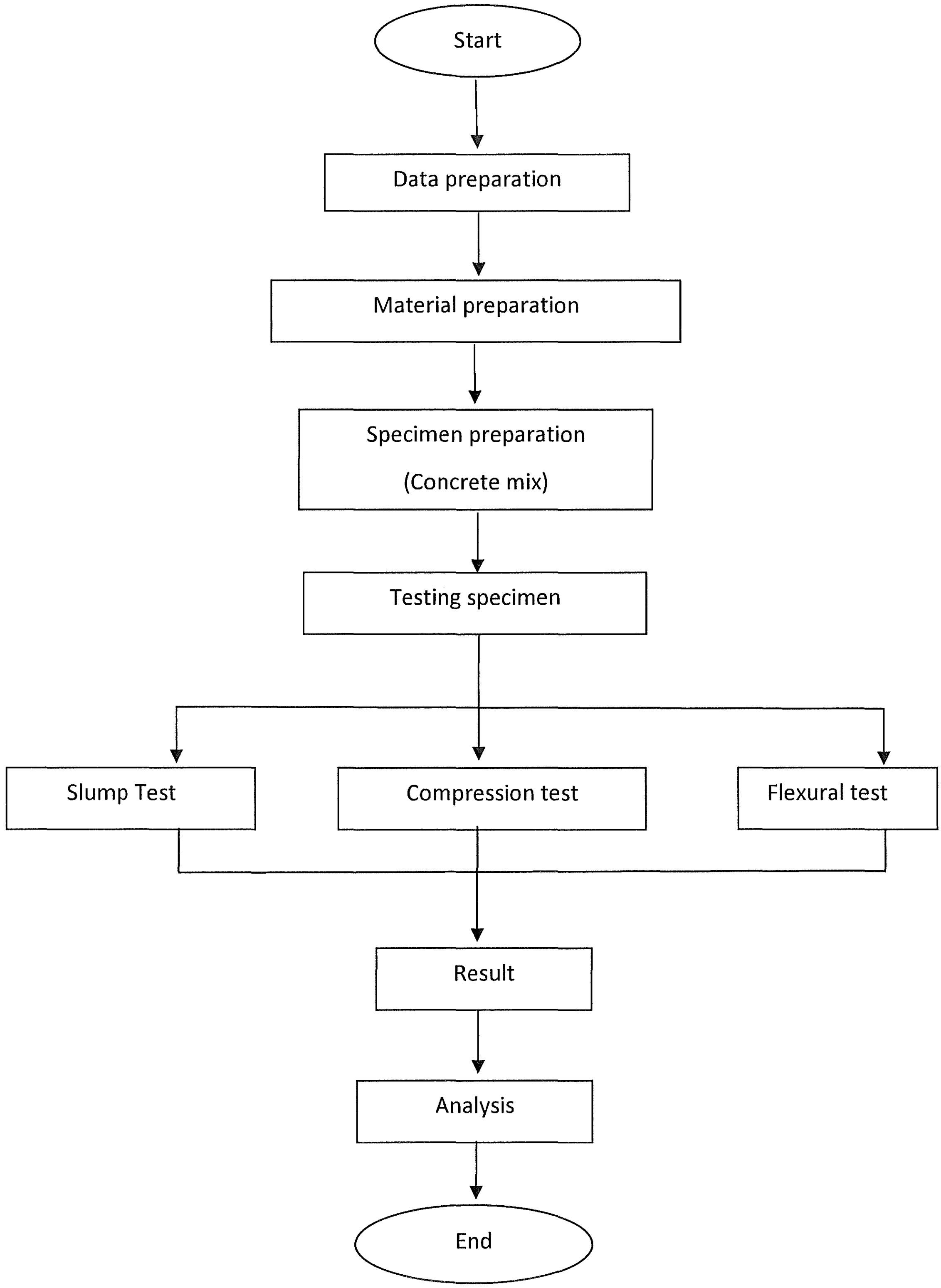

Figure 3.1 Flow chart of the experimental program

3.3 Selection Of Materials

The essential materials used in this research were cement, coarse aggregate, Water and POC. The depiction of each material is described in the following section.

3.3.1 Cement

The cement used for this research was the Ordinary Portland Cement (OPC) with brand name *Orang uat* certified to *MS 522-1 : 2007 (EN 197-1 : 2000), CEM I 42.5N / 52.5N and MS 522 : Part 1 : 2003. Orang kuat* cement brand is suitable for structural concreting, brickmaking, precast, and all general purpose applications where high strength is needed to improve productivity. *Orang kuat* is produced under stringent quality assurance, environmental management and health & safety systems and packed in 50kg paper bag as show in Figure 3.2. It is certified to *MS ISO 9001, MS ISO 14001* & Occupational Health and Safety Assessment Series *(OHSAS 18001).* The cement was kept in air tight packages and stored inside the laboratory. The purpose is to prevent the cement from being exposed to moisture and hardened before usage.

Figure 3.2 Ordinary Portland cement

3.3.2 Water

Water is used for mixing and curing process. Potable water is permitted to be used in concrete mixer without qualification testing. For other sources of water, associated testing frequencies and qualification requirements are established to identify the effects of the water source on strength and setting time when compared to control concrete made with potable water. For this research, the mixing water used was a potable drinking water from tap which is suitable for concrete work.

3.3.3 Fine Aggregate

In this study, the river sand is used as fine aggregate and it is shown in Figure 3.3. The role of river sand that act as fine aggregate is to fill the void between coarse aggregate. River sand is obtained by dredging from river beds. Since it has been subjected to years of abrasion and to years of washing, river sand consume a major characteristics that its particle shape is more or less rounded and smooth, also has a very low silt and clay contents. The characteristics of river sand would improve the workability of concrete compared to the use of alternatives such as crushed rock fine. Sieve test is carried out before concrete mix design to investigate the category of fine aggregate. River sand of size below 4.75mm with fines modulus of 2.66 was used as fine aggregate.

Figure 3.3 Fine Aggregate

3.3.4 Coarse Aggregate

In this research, the type of coarse aggregates used was crushed, angular aggregates with irregular surfaces and nominal size of 10 mm as shown in Figure 3.4. The coarse aggregates was sieving in order to fulfil the requirement of 100% retained on the 3/8 inch (9.5mm) sieve and 100% passing through the ½ inch (12.7 mm) sieve. For optimum compressive strength with low water/cement ratio and high cement content, the coarse aggregates were kept to the minimum size of 9.5 mm and the maximum size of 12.7 mm.

Figure 3.4 Coarse Aggregate

3.3.5 Palm Oil Clinker

Palm oil clinker used in this study were obtained from a palm oil mill factory which was located in Gambang, Pahang. The POC were collected in the form of large chunks from the mill and then manually crushed (Figure 3.5) into smaller pieces to ease the proceeding crushing process.

Figure 3.5 POC Manually Crushed

To implement the process of crushing POC pieces into aggregate, the manually crushed POC then crushed with a crushing machine (Figure 3.6). After that, POC aggregates were sieved to get the required size of Palm Oil Clinker Coarse aggregate

(Figure 3.7). For the purpose of this research the sieve size of ½ inch (12.7mm) and 3/8 inch sieve was used. The aggregates with nominal size of 10mm retained on the 3/8 inch sieve were used in the concrete mixtures.

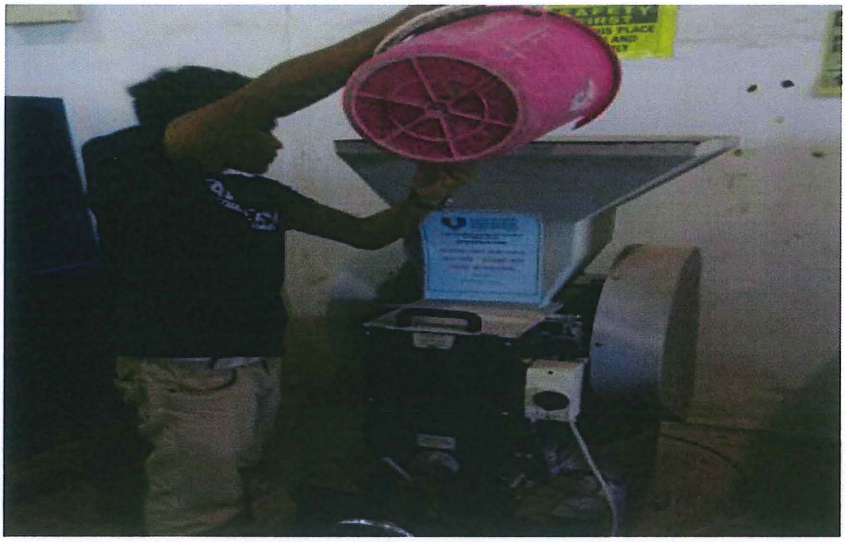

Figure 3.6 Crushed POC using crushing machine

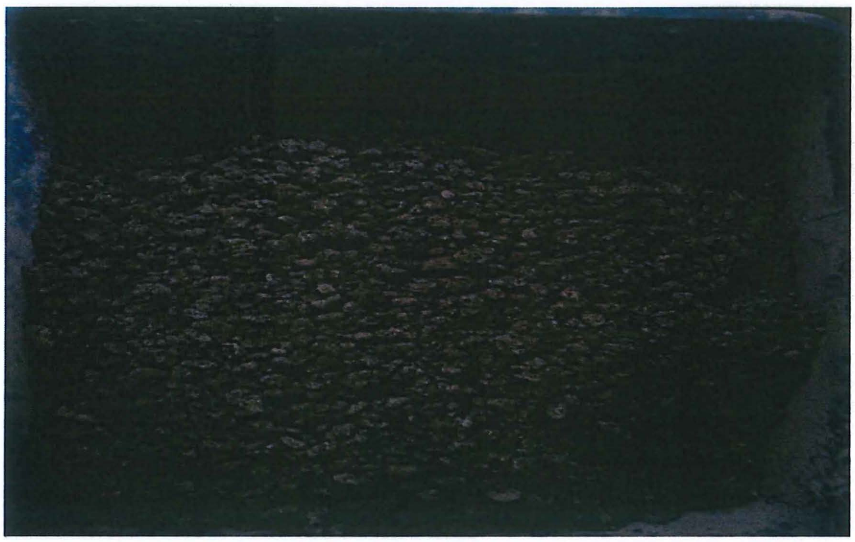

Figure 3.7 Palm Oil Clinker Aggregates

3.4 Sample Preparation

In order to produce a good sample, it is important to follow the sequence in mixing and casting the sample.

3.4.1 Mix Design

The mix design in this research is in accordance to the method published by the Department of Environment, United Kingdom (years 1988) to produce Grade C25/30 concrete with a slump range of 100 ± 25 mm. This study was conducted for coarse aggregate replacement. The percentage of POC replacement used are 0%, 5%, 10% and 15% of the total volume of coarse aggregates. Fresh and hardened properties of concrete were determined for the different replacement percentages and compared with the control mix. Details of the proportion for the constituent materials for all mixes are presented in Table 3.1.

Table 3.1 Mixture proportion for different level replacement of POC

Replacement Level (%)	W/C Ratio	Mix proportion (Kg/m3)			
		Cement	Fine Aggregate	Coarse Aggregate	
			Sand	Granite	POC
0	0.53	52.5	95	125.88	-
5	0.53	52.5	95	119.59	4.11
10	0.53	52.5	95	113.29	8.25
15	0.53	52.5	95	107.00	12.32

3.4.2 Mixing Process

The mixing of concrete was carried out by using a standard concrete mixing procedure. The concrete were mixed either manually or using the mechanical mixer depending on the batch sizes. All the materials were weighted according to the proportions in the design mixes before the mixing process.

The coarse and fine aggregates initially prepared in a Saturated Surface Dry (SSD) condition before mixing. Specimen preparation involved the dry mixing of the cement and aggregate using a pan mixer for three minutes to obtain a homogenous mix, followed by three more minutes of mixing with 70% of the total water added to the mixture. Afterward, the remaining water was added and mixing was continued for another five minutes to complete the whole mixing process. The fresh density was measured and a workability test was performed on the mix. The same mixing procedure was implemented for all the mixes to ensure consistency.

characteristics of concrete improve with the age of concrete curing as long the hydration process is not stopped. Meaning, the more strength of the concrete can be obtained if the longer curing time is taken. There were few type of curing method that can be used such as water curing, membrane curing, application of heat and miscellaneous. In this research, the curing method used is water curing as shown in Figure 3.8. The sample cured for 28 days in order for the samples to achieve desirable strength.

Figure 3.8 Curing Process

3.5 The Principles of Parameter Used

For testing the concrete, a few of parameters are used . In this study, the parameters involved are as follows:

i. Compressive strength

A specified material can sustain without fracture under a gradually applied load which is can be definite as the maximum compressive strength or maximum compressive stress. Compressive strength is very important value for structures designed.

ii. Workability

Workability is the relative easiness with which concrete can be mixed, transported, moulded and compacted. Also can be defined as, the amount of energy to overcome abrasion while compacting.

iii. Density

The density of hardened concrete was determined according to British Standard *(BS 1881-114:1983)*. After curing for the specified numbers of days, the samples were removed from the curing tank and wiped dry with a cloth to get rid of the excess curing water trapped inside and on the surface of the porous concretes. After drying, the samples were weighed with electronic weighing scale. The concrete density, in (kg/m3) was calculated by dividing the weight of the concrete divide with the mould volume.

3.6 Testing Sample

The test that was conducted in this study is Slump test, Compressive strength test and Flexural test.

3.6.1 Slump Test

Referring to Figure 3.9, to measure the workability of fresh concrete slump test were used. The test was conducted using a mould named slump cone or Abrams cone. A hard non-absorbent surface prepared to place the cone. The cone filled with concrete in three layers of equal volume. Each layer is compacted with 25 strokes using a tamping rod. At the end of the last stage, concrete is struck off flush to the top of the mould. The mould lifted carefully on vertical upwards, so as not to disturb the concrete cone.

Figure 3.9 Slump test

In accordance with British Standard *(BS 1881: Part 102)*, generally, there were three types of slump obtained which were true slump, shear slump or collapse slump (Figure 3.10). If a shear or collapse slump is achieved, a fresh concrete should be taken and the test must be repeated. A collapse slump refer to the concrete collapsed completely which an indicated the mix is too wet or that it is a very high workability mix achieved, for which slump test is not appropriate. Then, in a shear slump the top portion of the concrete slips sideways and shears off while in a true slump the concrete is keeping more or less to shape which is simply subsides,. Only a true slump is of any use in the test.

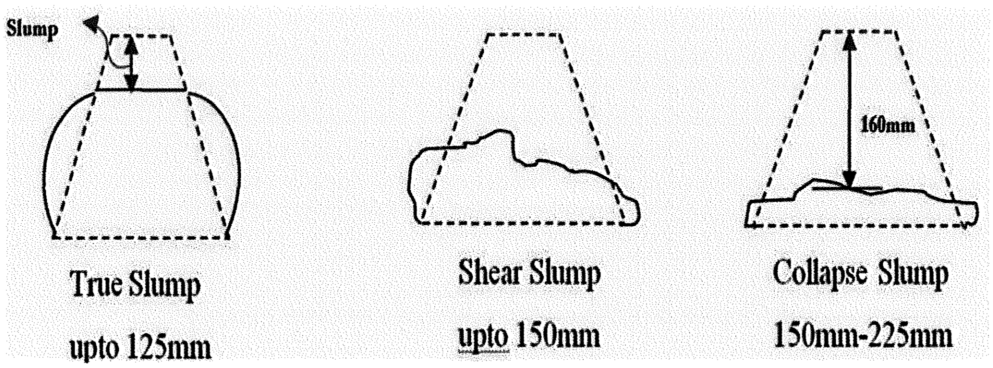

Figure 3.10 Type of slump test
Source: M.L. Gambhir (2009)

The properties of fresh concrete which is indicated by the amount of useful essential internal work to fully compact the concrete without segregation or bleeding during the finished product. There are some main factors affecting workability of the concrete, like water content used, temperature of the concrete mix, method of concrete placement, method of concrete transmission, nature of aggregate particles, humidity of the environment, aggregate grading, and mode of compaction.

3.6.2 Compressive Test

Main objective of compressive test is to obtain the compressive strength of the specimen by analysing the maximum load acted on the specimen. By this single test, we can judge that whether concreting has been done properly or not. Compressive strength testing machine which located in concrete laboratory was used to conduct this test. The compressive strength of POC concrete was obtained by crushing 150 x 150 x 150 mm cubes sample at 7, 14 and 28 days. The mean value obtained from the 3 cubes was then taken as the cube compressive strength for each concrete mixes. The tests were performed in accordance with British Standard (*BS 1881-116: 1983)*. The compressive strength tests at the age of 7, 14 and 28 days were carried out for the purpose of studying the strength development of the POC concrete.

Figure 3.11 Compressive Strength Test

The compressive strength tests at the age of 7, 14 and 28 days were carried out for the purpose of studying the strength development of the POC concrete. The load was applied slowly and continuously increased until the resistance of the specimen's breaks down and cannot sustained load anymore. The results were recorded and the maximum load that is applied to the specimens was being noted to bring out in the report.

3.6.3 Flexural Test

Flexural capacity or flexural strength, known as modulus of rupture, fracture strength or bend strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique.

The tests were carried out in accordance with British Standard (*BS 1881-117: 1983*) at the age of 7, 14 and 28 days. The mean value calculated from the test results is then taken as the indirect tensile strength. The flexural strength represents the highest stress experienced within the material at its moment of rupture. Figure 3.12 show the Flexural test for 5% POC concrete sample.

Figure 3.12 Flexural Strength Test

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

The emissions results for each test are presented in this chapter. These results are utilized to determine properties of concrete with POC as partial replacement of coarse aggregate or granite and evaluate optimum ratio of POC in modified concrete. All the tests conducted were in accordance with the methods described in chapter three and the results displayed include slump height, maximum load, maximum compressive strength and maximum flexural strength. The results generated at this stage of the study formed a set of data of modified concrete that was further used in the analysis and comparison with control concrete.

4.2 Slump Test

Concrete slump test were used to determine the consistency of fresh concrete. The consistency or stiffness of the concrete shows the fluidity of the concrete indicating how much water has been used in the mix, and is often measured by concrete slump. There were three types of slump which is true slump, shear slump and collapse slump. Table 4.1 and Figure 4.1 shown variation in slump for 0%, 5%, 10% and 15% of mix proportion of POC replacement with coarse aggregate.

Table 4.1 Slump test

Percentage Replacement, (%)	Slump Height, (mm)
0	64
5	66
10	71
15	79

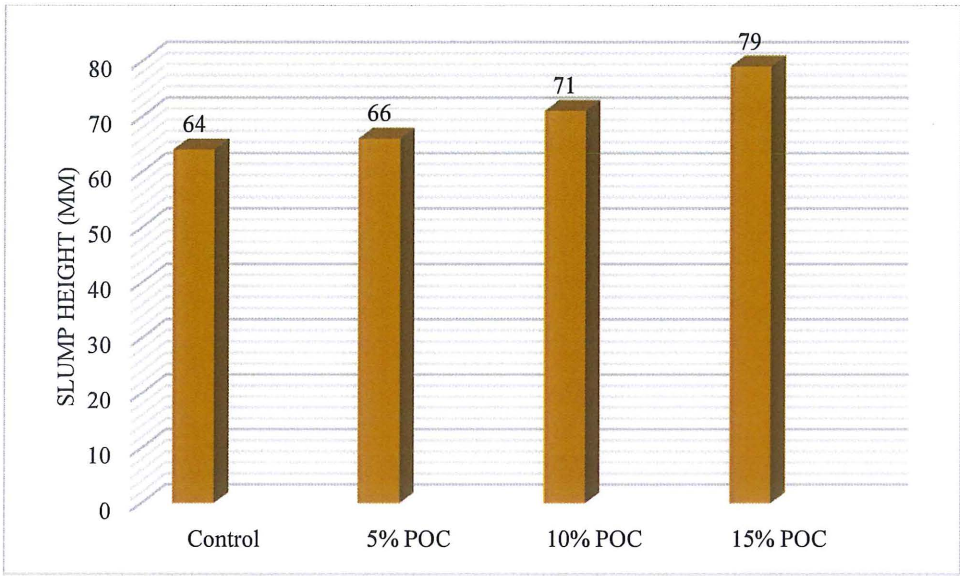

Figure 4.1 Slump Test for all mix proportion

Figure 4.1 shown the increasing value of slump height from 0% replacement mix proportion to 15% replacement mix proportion. The result shows the shear slump type for all specimens. The height of slump for requirement were range between 50-100mm. It can be seen that the highest value was 79 mm, which goes to 15% replacement mix proportion while the lowest value was 64 mm that obtained from control mix proportion. The increasing in slump height is due to the POC particle shape and rough surface, as well as the spiny broken edges. The irregular shape of POC resulted in higher surface area increasing the demand for extra paste volume to ensure good workability. In terms of workability, the higher the slump value, the higher the amount of water and as a result the mixture is more fluid for working the concrete and finishing. Therefore, 15% replacement mix proportion was found to be the highest workability among the other mix proportion.

4.3 Compressive Strength Test

Compressive Strength Test indicates the major compressive strength which was carried out according to American Society for Testing and Material (ASTM C-39). The sample cubes with the dimension of 150 mm x 150 mm x 150 mm were tested. The sample cubes were cured in water and tested for compressive strength at the curing age of 7, 14 and 28 days. The compressive strength average was taken from the result of three sample cubes. Table 4.2, Table 4.3 and Table 4.4 show the result of average compressive strength of the different POC replacement sample cubes with curing period of 7, 14 and 28 days. The effects of replacement of granite with POC on average compressive strengths of the different POC replacement sample cubes with curing period of 7, 14 and 28 days are shown in Figures 4.2, Figure 4.3 and Figure 4.4 respectively.

Table 4.2 Compressive Strength Test for 7 days curing period

Percentage Replacement, (%)	Load, (kN)	Compressive Strength, (Mpa)
0	621.526	28.424
5	404.509	18.208
10	305.145	13.351
15	221.361	10.352

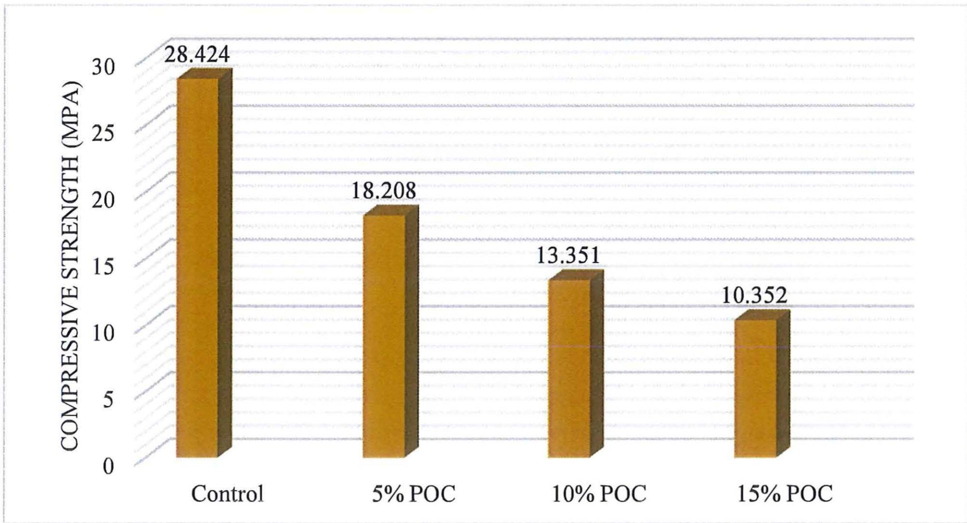

Figure 4.2 Compressive Strength Test for 7 days curing period

Table 4.3 Compressive Strength Test for 14 days curing period

Percentage Replacement, (%)	Load, (kN)	Compressive Strength, (Mpa)
0	736.968	34.112
5	531.619	23.541
10	354.270	16.060
15	276.732	12.164

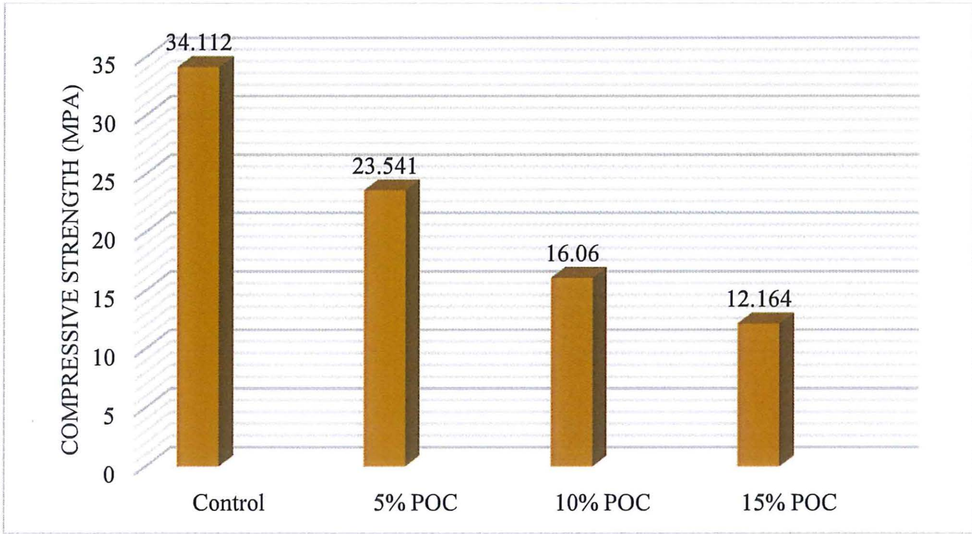

Figure 4.3 Compressive Strength Test for 14 days curing period

Table 4.4 Compressive Strength Test for 28 days curing period

Percentage Replacement, (%)	Load, (kN)	Compressive Strength, (Mpa)
0	793.028	39.185
5	660.110	29.141
10	360.673	15.896
15	316.672	13.873

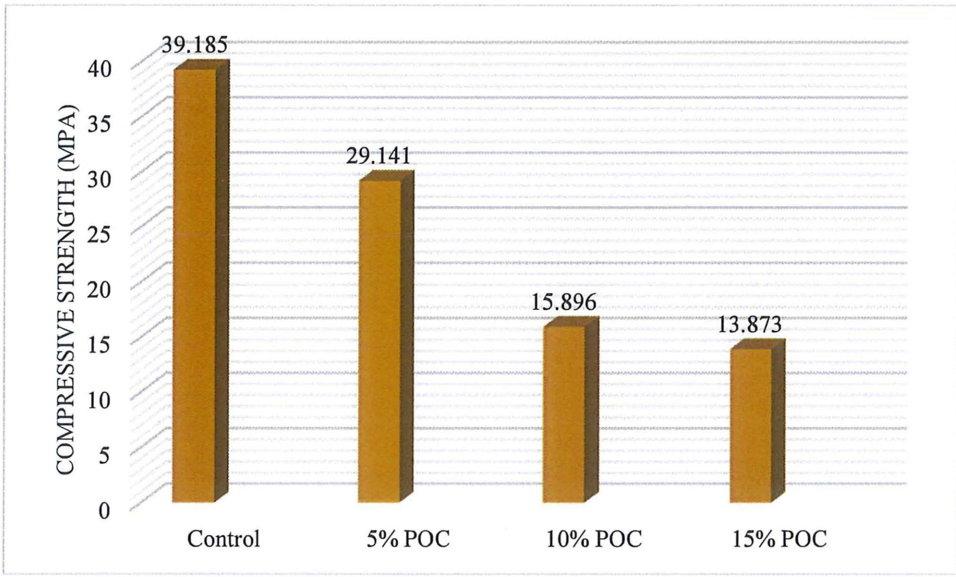

Figure 4.4 Compressive Strength Test for 28 days curing period

The test results indicate that increasing POC replacement caused a decrease in load and compressive strength of the concrete. It can be clearly observed that a clear downward trend in both load and compressive strength for all graph of 7, 14 and 28 days curing period. For 7 days curing period, the load and compressive strength was highest at 0% replacement of granite with POC concrete which were 621.526 kN and 28.424 Mpa respectively and the minimum value recorded at 15% replacement of granite, which the load and compressive strength were obtained to be 221.361 kN and 10.352 Mpa respectively. At 14 days curing period, the highest load and compressive strength goes to 0% replacement of granite with POC concrete, which found to be 736.968 kN and 34.112 Mpa while the lowest value goes to 15% replacement of granite with POC concrete, which the load was 276.732 kN and compressive strength was 12.164 Mpa. Then, for 28 days curing period the highest value of load and compressive strength was presented to be 793.028 kN and 39.185 Mpa, respectively at 0% replacement of granite with POC concrete. Conversely, the lowest value of load, 316.672 kN and compressive strength, 13.873 Mpa goes to 15% replacement of granite with POC concrete at 28 days curing period.

This reduction in load and compressive strength may be attributed to the pore structure induced by POC addition. As the portion of POC content increases, the specific area increases, thus requiring more cement paste to bond effectively with the POC. Since the cement content remains the same, the bonding is therefore inadequate. The load and compressive strength reduces as a consequence of the increase in percentage of POC content. It can be observed that the 28 day curing period compressive strength for 5% and 10% replacement of granite with POC concrete were above the specified value of 15 Mpa, which are 29.141 Mpa and 15.896 Mpa respectively. Therefore, the concrete produced in this study can be classified as lightweight concrete British Standard *(BS 8110, 1997)* as shown in Table 4.5.

Table 4.5 Recommended grade of concrete

Grade	Characteristic strength, Mpa	Concrete class
7	7.0	Plain concrete
10	10.0	
15	15.0	Reinforced concrete with lightweight aggregate
20	20.0	Reinforced concrete with dense aggregate
25	25.0	
30	30.0	Concrete with post tensioned tendons
40	40.0	Concrete with pre tensioned tendons
50	50.0	
60	60.0	

Source: BS 8110 (1997)

Based on inspection of many specifications, it has been noted that compressive strength is very important property of concrete. However, the workability and bond are also make a great significant affect. The result of overall compressive strength or maximum strength with concrete consist of POC portion indicate change occur in compressive strength with different percentage of POC replacement of coarse aggregate shown in table and figure below. Table 4.6 and Figure 4.5 shown the maximum load result while Table 4.7 and Figure 4.6 shown the maximum compressive strength.

Table 4.6 Maximum Load of Compressive Strength Test in kN

Curing Period, (Day)	Percentage Replacement, (%)			
	0	5	10	15
7	621.526	404.509	305.145	221.361
14	736.968	531.619	354.270	276.732
28	793.028	660.110	360.673	316.672

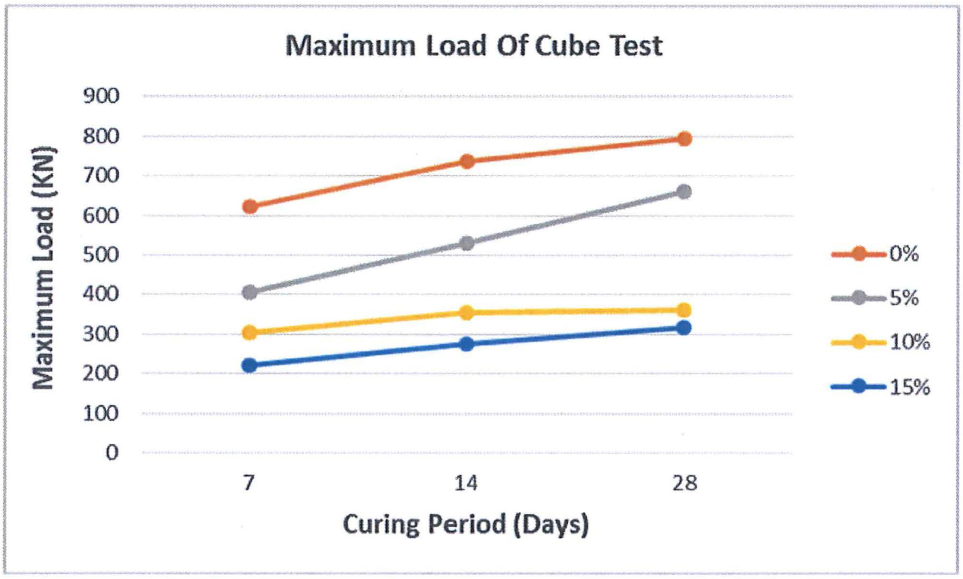

Figure 4.5 Maximum Load of Compressive Strength Test in kN

Table 4.7 Maximum Compressive Strength of Compressive Strength Test in Mpa

Curing Period, (Day)	Percentage Replacement, (%) 0	5	10	15
7	28.424	18.208	13.351	10.352
14	34.112	23.541	16.060	12.164
28	39.185	29.141	15.896	13.873

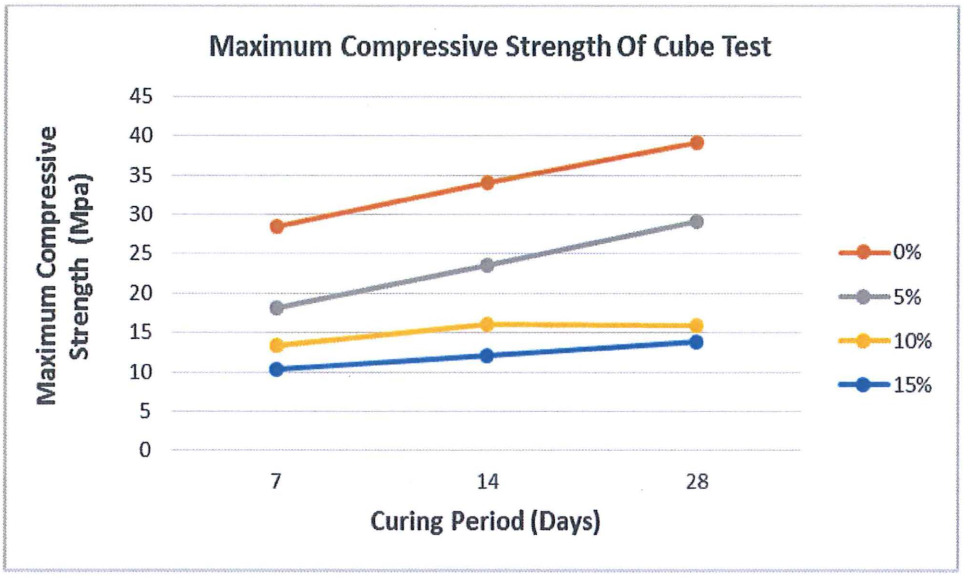

Figure 4.6 Maximum Compressive Strength

The maximum load for all four different mix proportions shown in the Table 4.6 and Figure 4.5 above over curing period of 7 days, 14 days and 28 day under water curing. Meanwhile, Table 4.7 and Figure 4.6 display the maximum compressive strength for all four different mix proportions over curing period of 7 days, 14 days and 28 day under water curing. Based on the result shown, it is clear that the maximum load and compressive strength increased over the curing period. All four mix proportion displayed the same pattern for both maximum load and compressive strength graph, which indicate to be gradually increased from day 7 to day 28 of curing period. It can be clearly perceived that the control specimen which is 0% replacement of granite with POC concrete has highest value for both maximum load and compressive strength among all three mix proportions, which found to be 793.028 and 39.185 respectively. Then, followed by 5%, 10% and 15% of mix proportion at 28 days curing period. Meanwhile, the specimen of 15% replacement of granite with POC concrete of 28 days curing period obtained the lowest maximum load of 316.672 kN and the lowest compressive strength of 13.873 Mpa among all mix proportions.

4.4 Flexural Test

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, is defined as a material's ability to resist deformation under load. The size of specimen use was 100mm x 100mm 750mm and test were conducted for different POC ratio with ratio of 5 %, 10% and 15% replacement of granite with POC concrete from the basic concrete grade C25/30 at the curing period of 7 days, 14 days and 28 days. Table 4.8 and Figure 4.7 shows the effects of POC on flexural strength of 0% replacement of granite with POC concrete (Control concrete).

Table 4.8 Flexural Test for Control concrete

Curing Period, (Day)	Load, (kN)	Flexural Strength, (Mpa)
7	27.707	6.213
14	33.550	7.477
28	31.237	7.017

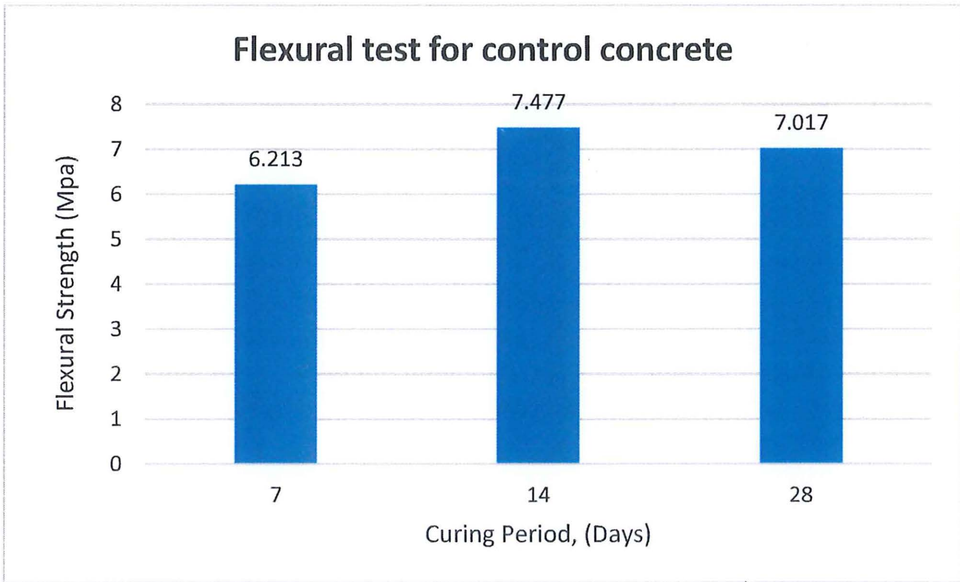

Figure 4.7 Flexural Test for Control concrete

The result showed the load and flexural strength of test for control concrete between the 7 days and 28 days of curing period. It can be perceived that both increased from day 7 to day 14 of curing period and then dropped slightly by 0.46 Mpa from day

14 to day 28 of curing period. At 7 days curing period, it shown the lowest of load and flexural strength value obtained among the other curing period, which the load and compressive strength were 27.707 kN and 6.213 Mpa, respectively. The highest value of load and compressive strength goes to 14 days curing period, 33.550 kN and 7.477 Mpa, respectively.

The other variations of effects of concrete with POC content on flexural strength were shown in Table 4.9, 4.10, 4.11 and Figures 4.8, 4.9 and 4.10, respectively for 5%, 10% and 15% replacement of granite with POC concrete on 7, 14 and 28 days curing period.

Table 4.9 Flexural Test for 5% of POC Concrete

Curing Period, (Day)	Load, (kN)	Flexural Strength, (Mpa)
7	27.570	6.150
14	32.463	7.182
28	37.383	8.753

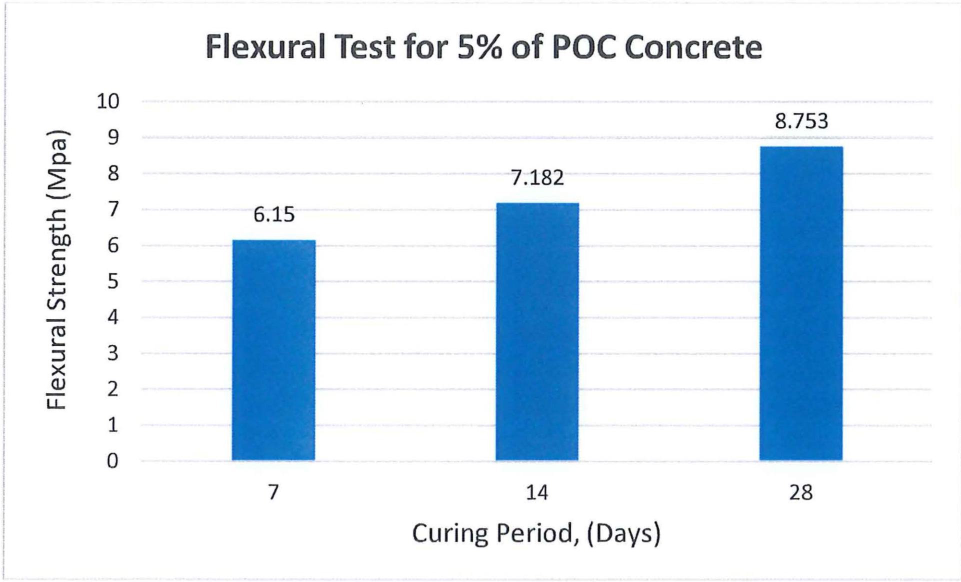

Figure 4.8 Flexural Test for 5% of POC Concrete

Table 4.10 Flexural Test for 10% of POC Concrete

Curing Period, (Day)	Load, (kN)	Flexural Strength, (Mpa)
7	18.743	4.187
14	23.113	5.188
28	27.630	6.173

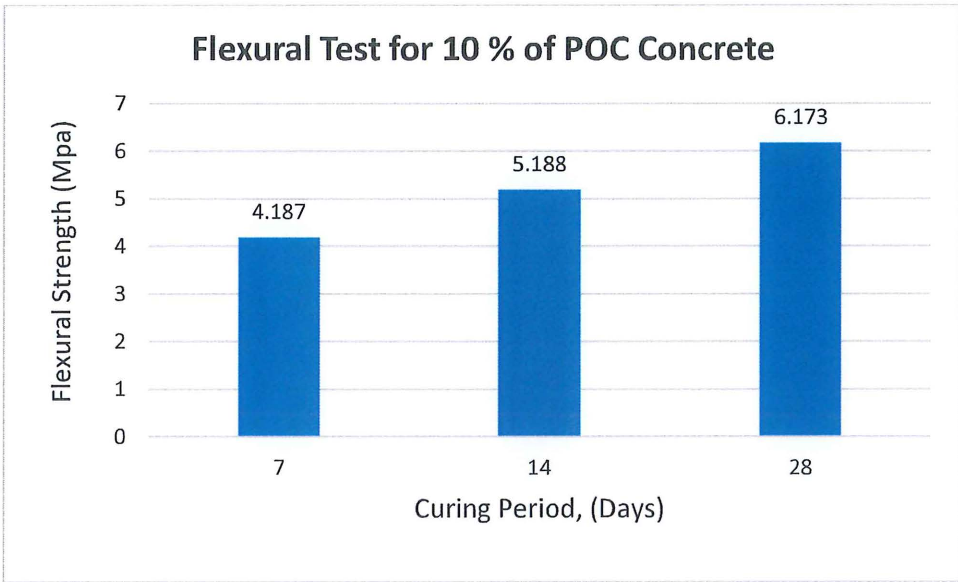

Figure 4.9 Flexural Test for 10% of POC Concrete

Table 4.11 Flexural Test for 15% of POC Concrete

Curing Period, (Day)	Load, (kN)	Flexural Strength, (Mpa)
7	15.323	3.441
14	21.527	4.762
28	22.897	5.067

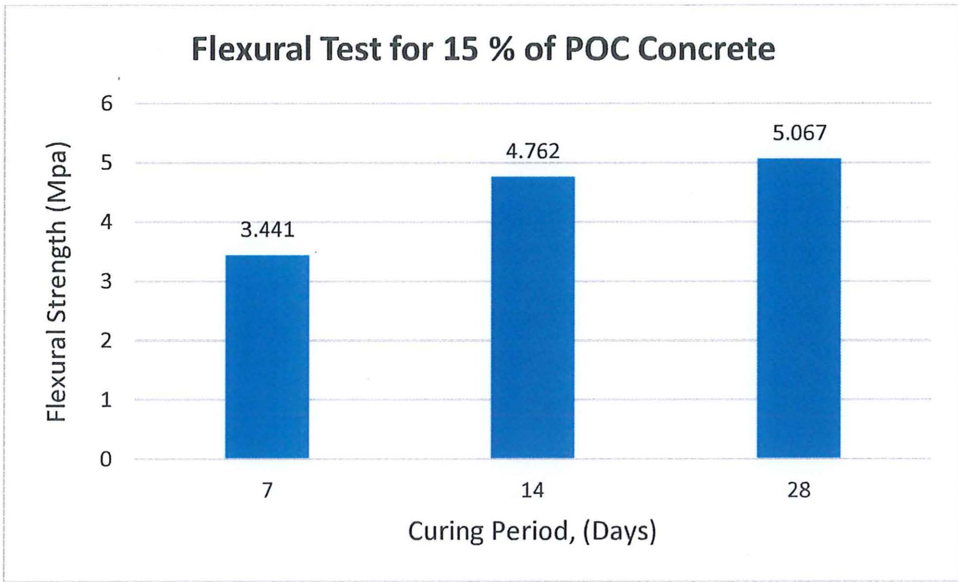

Figure 4.10 Flexural Test for 15% of POC Concrete

In general, the flexural strength increase with increasing curing period for all mix proportions. It can be observed that in these three mix proportion, the load and flexural strength were increased reasonably. The results above describe the specimen with 5%, 10% and 15% replacement of granite with POC concrete were found to be the highest value of load and flexural strength at 28 days curing period. Contrariwise, the lowest value of load and flexural strength goes to 7 days curing period for these three mix proportion. Table 4.9 and Figure 4.8 shown load and flexural strength at 28 days curing period were found to be 37.383 kN and 8.753 Mpa, respectively for 5% replacement of granite with POC concrete. Then, Table 4.10 and Figure 4.9 describe for 10% replacement of granite with POC concrete, the highest value of load and flexural strength was obtained from 28 days curing period, which were 27.630 kN and 6.173 Mpa respectively. Last but not least, from Table 4.11 and Figure 4.10, it can be seen that for 10% replacement of granite with POC concrete, 28 days curing period presented the highest value of load that was 22.897 kN while the flexural strength was 5.067 Mpa.

The maximum load results obtained in Table 4.12 and Figure 4.11 while maximum flexural strength results shown in Table 4.13 and Figure 4.12 that revealed in the form of graphical variation, where in the maximum load and flexural strength were plotted against the curing period.

Table 4.12 Maximum Load of Flexural Test in kN

Curing Period, (Day)	**Percentage Replacement, (%)**			
	0	5	10	15
7	27.707	27.570	18.743	15.323
14	33.550	32.463	23.113	21.527
28	31.237	37.383	27.630	22.897

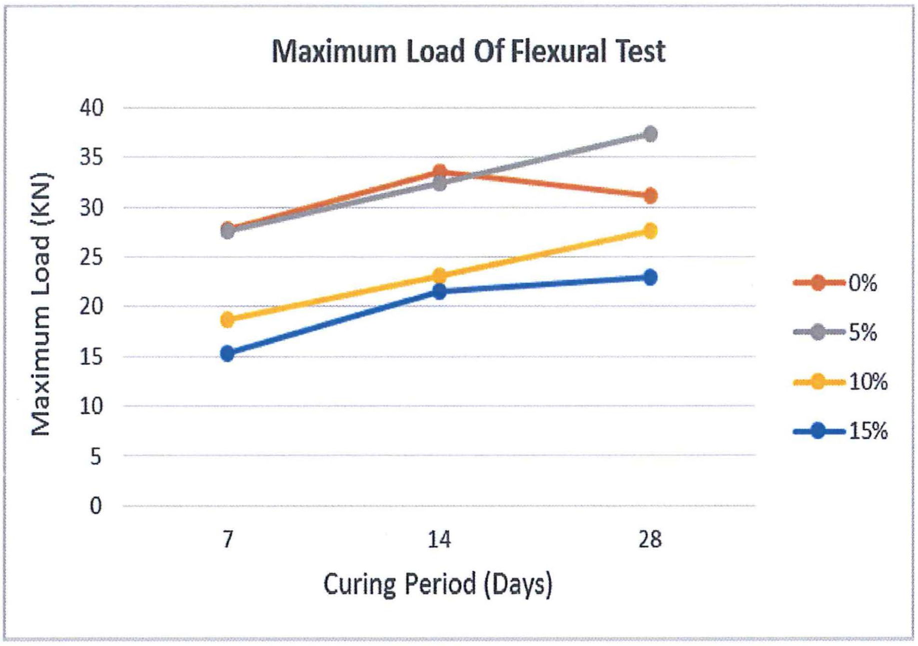

Figure 4.11 Maximum Load of Flexural Test in kN

Table 4.12 and Figure 4.11 displayed maximum load for all mix proportion. From the graph, it can be observed that 0% replacement of granite with POC concrete maximum load was increased from day 7 to day 14 of curing period and it decreased at day 28. For the other mix proportion, the maximum load was gradually increased properly until day 28 of curing period. At 28 days curing period, specimen 5% replacement of granite with POC concrete, recorded the highest maximum load, which was 37.383 kN among the other mix proportion. Meanwhile, specimen 15% replacement of granite with POC concrete was reported to be the lowest maximum load, 22.897 kN.

Table 4.13 Maximum Flexural Strength of Flexural Test in Mpa

Curing Period, (Day)	Percentage Replacement, (%)			
	0	5	10	15
7	6.213	6.150	4.187	3.441
14	7.477	7.182	5.188	4.762
28	7.017	8.753	6.173	5.067

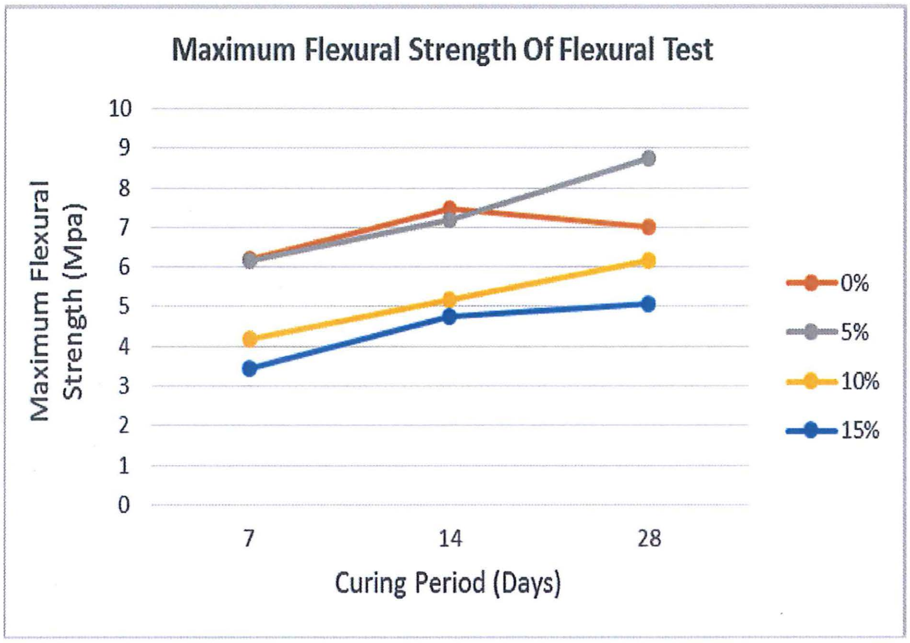

Figure 4.12 Maximum Flexural Strength of Flexural Test in Mpa

The experimental results of the maximum flexural strength for all mix proportion are described in Tables 4.13 and graphically were shown in Figure 4.12. It can be observed from the graph on Figure 4.12 that the specimens of 0% replacement of granite with POC concrete was slightly increased to day 14 of curing period and then it decreased by 0.46 Mpa from day 14 to day 28. Generally, to get the true maximum strength the result should be continuous increase until day 28. The reasonable cause for this reduction maybe due to the cement that was used for this mix proportion. The cement used for control mix in this study was the old cement that available in laboratory, which was exposed to the air for a long time. For other three mix proportion of 5%, 10% and 15%, the different condition of cement was used. The cement used for these three mix proportion were new that arrived from factory at that moment. So that, the condition of cement possibly effect the strength of this mix proportion and caused the reduction of flexural strength. From the results, it is noticed that the specimen of 5% and 10%

replacement of granite with POC concrete increased until day 28 with almost the same pattern. Meanwhile, the specimen of 15% replacement of granite with POC concrete also increased from day 7 to day 14 and slightly increased to day 28. At day 28, 5% replacement of granite with POC concrete mix proportion presented the highest maximum flexural strength value, 8.753 Mpa, and the lowest strength value presented by 15% replacement of granite with POC concrete mix proportion, 5.067 Mpa.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study is aimed on conducting a complete research on palm oil clinker (POC), a waste from the palm oil mill production stages to be assimilated in concrete for structural and other applications. As it would be the first and novel study on the exploitation of POC in concrete, deeper and complete characterisation studies were required. This chapter provides the conclusions of the study and the proposed recommendations for future study. The study covers the replacement of coarse aggregate with POC in concrete. Main tasks of this study were to determine properties of concrete with POC as partial replacement of coarse aggregate and evaluate optimum ratio of POC in modified concrete.

5.2 Conclusions

The potential application of this study is to reduce the production of coarse aggregate further reduce natural sources from being running low, solve the disposal problem of numerous POC produced as well as reduce the construction cost.

This study offers a further environmental benefit by using agro-waste material. This will lead to a reduction in the supply of such waste material, thus decreasing their environmental impact and easing the problems associated with the disposal of waste material to landfill. Economically, this study also benefits the construction industry from lower production cost due to the ready availability and low cost of industrial waste material.

The following conclusions can be drawn from this study:

i. This study showed that the compressive strengths of the specimen 10% and 15% of mix proportion at days 28 are 15.896 Mpa and 13.873 Mpa, respectively, which have a very high potential to delights as lightweight concrete since the value of compressive strengths are within 15-10 Mpa according to British Standard (BS 8110, 1997). Meanwhile, the specimen 5% of mix proportion at days 28 was found to be 29.141 Mpa, which not practically defined as lightweight concrete.

ii. The results of compressive and flexural tests showed that the optimum ratio for this study was found to be the specimen 15% replacement of granite with POC concrete due to the results of compressive and flexural strengths at day 28 curing period, which classified as lightweight concrete.

From this study, there exists a high potential for the use of POC as coarse aggregate replacement with certain portion in the production of lightweight concrete. It can be concluded that POC can be successfully used in the lightweight concrete as coarse aggregate replacement. Therefore, the development of existing information and identification of waste materials to be used in making concrete will provide a valuable contribution in the environmental sustainability of the industry.

5.3 Recommendations For Future Study

For further research purpose, some recommendations as follows can be made in order to improve the research of palm oil clinker aggregates in the development of lightweight concrete.

i. Higher percentage substitution of POC aggregates in concrete can be conducted in order to determine whether there will be further reduction of strength in concrete or possess a particular strength with more POC content.

ii. A study on the characteristic of the POC aggregates can be done to determine the suitability of these aggregates as construction materials.

iii. Different sizes of POC aggregates can be used in the research to determine the mechanical properties of the concrete.

iv. The mix proportion of concrete can be diversified by using other types of cement replacement material, admixtures or water-binder ratio to observe the physical and strength changes.

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