PERFORMANCE OF LIGHTWEIGHT CONCRETE USING PALM OIL CLINKER AS COARSE AGGREGATE

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ABSTRACT

Malaysia is one of the primary producers of palm oil in Asia and it is the second largest palm oil-producing country in the world. In this study, palm oil clinker (POC) aggregates were used as coarse aggregate replacement in lightweight concrete production. This study focused mainly on the physical properties of POC aggregate and the performance of fresh and hardened concrete mixture to identify the optimum content of replacement of POC as coarse aggregate in lightweight concrete to attain reasonable strength. The approach used in the mix design involved POC replacement of 0%, 33%, 67% and 100% of the content of coarse aggregates. Based on sieve analysis, the course aggregate was well graded. It was found that, as the percentage of replacement of POC increased, the workability of the fresh concrete and density of hardened concrete was decreased. This was due to the physical properties of POC aggregate which is porous, low specific gravity, low bulk density and high water absorption. The maximum compressive strength of the sample was 25.24MPa at 7 days and 27.89MPa at 28 days while splitting tensile strength and flexural strength achieved 5.12MPa and 3.98MPa. In this study, the optimum content of replacement of POC as coarse aggregate to achieve lightweight concrete was about 67% since the results from mechanical properties test comply with the requirement of structural lightweight concrete as stipulated in British Standard, BS 8110 : Part 2 : 1985, RILEM's functional classification of lightweight concrete, ASTM C330 and others previous study. Considering POC into lightweight concrete structure, it can be reduce the dead load thus saving the construction cost by reducing the size of columns, footings and other load bearing elements of a concrete structure.

Keywords: palm oil clinker,lightweight concrete, physical properties, workability and strength, optimum content.

1. Introduction

The utilization of waste by-products in concrete has garnered positive outcomes over the past few decades in terms of the cost savings and conservation of natural resources (Kanadasan, et. al, 2015). The development of sustainability should be provided prudently due to the exponentially increasing population in the world and it implies that the degrading of natural resources rapidly might affect the future generation (Han, 2012). This has resulted in an increase in research to develop alternative feed to reduce and maintain a non-excessive usage of natural sources (Kanadasan et. al, 2015). Therefore, researchers from the area of building and construction materials are trying to find an innovative solution to reduce the negative impact on the environment as well as to produce structural lightweight concrete. The idea is to use the solid waste from the agricultural and manufacture industries as coarse aggregate in lightweight aggregate concrete which will reduce the destruction of natural resources and demonstrate the proper management of solid waste (Nazmul et. al, 2016).

The use of POC in concrete is seen as recycling the agriculture waste, thus producing a suitable approach for sustainable construction. The cost of POC itself can be considered as "zero" as it is usually disposed of as a waste material without any economic value. Hence, when the cost factors are compared with the hardened properties of POC which is an abundantly available waste material and is obtained cheaply, generally it increases the cost efficiency by lowering the overall cost (Kanadasan et. al, 2015). Intermediate replacement levels produced good engineering to cost comparison values indicating the greater economic potential of POC to substitute aggregate.

Malaysia is one of the primary producers of palm oil in Asia. It is the second largest palm oil-producing country in the world, producing more than half of world's palm oil annually (Abutaha et. al, 2016). The residue of palm oil industries includes Oil Palm Shell (OPS) and Palm Oil Clinker (POC), empty fruit bunches, and palm oil mill effluent. Instead of dumping the POC into the environment, a better waste management option is to crush the POC into desired sizes and utilize it as aggregate to produce lightweight concrete. According to the British Standard, BS 8110-2, 1985 classified lightweight concrete as concrete having density of 2000 kg/m^3 or less. RILEM's functional classification of lightweight concrete, structural lightweight concrete is defined as having oven dry-density of less than 2000 kg/m^3 and compressive strength more than 15 N/mm^2.

POC is a by-product from palm oil shell incineration. It is a light, solid, and fibrous material, which may be used as a potential lightweight aggregate for concrete when crushed. Previous studies have shown that POC is a suitable lightweight aggregate replacement in concrete. The benefit of using POC as lightweight aggregate is the reduced dead load of concrete structures without much loss in the strength of the structure (Abutaha et. al, 2016). This condition is possible because lightweight concrete can reduce the dead load by as much as 35% and still provide the structural strength (Omar et. al, 2002). Studies have reported that lightweight concrete improves thermal and acoustic insulation and fire resistance, makes construction easier and reduces self weight (Mun, 2007). According to Kanadasan and Abdul Razak, utilization of POC reduces the cost and energy usage and lowers carbon emission.

Nowadays, demand for concrete in construction industry is very high. This situation leads to increase the cost of construction. This interest is a result of various factors such as the ever increasing cost of raw materials and the continuous depletion of natural resources resulting in the shortage of building materials to meet the demand of the rapidly growing world population (Abutaha et. al, 2016). According to statistics and construction demand 2015 – 2016 by CIDB Malaysia, the national average aggregate price for 2014 was RM38.23 per tonne, an increase by 28.0% over RM29.86 per tonne in 2013.

To overcome this problem, construction industry should find the alternative to reduce the cost such as using the waste materials. The utilization of waste by-products in concrete has garnered positive outcomes over the past few decades in terms of the cost savings and conservation of natural resources (Kanadasan et. al, 2015). This alternative would ensure the preservation of our natural resources by mitigating the depletion of rock outcrops that are usually quarried and crushed to be used as aggregate for construction work. As a result, many researchers are determined to identify the uses of various waste materials for sustainable development (Abutaha et. al, 2016). According to National Biomass Strategy 2020: New Wealth Creation for Malaysia's Palm Oil Industry, eighty million tonnes of dry solid biomass waste was yielded in 2010 by the oil palm industry in Malaysia and is expected to rise up to 85–110 million tonnes by 2020. Because of this reason, the aim of this research is to produce concrete from waste materials by using palm oil clinker (POC) as coarse aggregate. Hence, it is a suitable approach for sustainable construction.

This study is aimed to determine the behaviour of lightweight concrete by replaced POC as coarse aggregates. The physical properties of POC such as sieve analysis, bulk density, specific gravity and water absorption test are carried out before making the concrete mix. The approach used in the mix design involved POC replacement of 0%, 33%, 67% and 100% of the total volume of coarse aggregates. The parameters investigated in this study include the slump for the fresh properties, as well as the density analysis, compressive strength tests, splitting tensile strength test and flexural strength test at 7 and 28 days for the hardened properties. All the results were compared to the control mix.

2. Materials and Test Methods

This research examined the physical properties of POC and mechanical properties of fresh and hardened concrete. There four set of samples represent different percentage of palm oil clinker as partial replacement in coarse aggregate to identify the optimum content of strength – weight ratio for 0%, 33%, 67% and 100% replacement of POC.

2.1. Materials

Ordinary Portland cement (OPC) were used as binder throughout the experimental work. The cement was stored at normal room temperature of 25°C with 85% relative humidity for maintaining the quality. In addition, a superplasticizer (SP) based on polycarboxylate type was used in all mixes. The dosage of superplasticizer using was kept constant with total amount of 1.5% of weight of cement for all concrete mixtures in order to increased the workability of mixed concrete.

Local mining sand with a maximum nominal size of 4.75 mm, specific gravity of 2.65 and fineness modulus of 2.70 was used as fine aggregate. POC were collected from a local crude palm oil mill. Then POC crushed in the laboratory and sieved by mass passing BS410 sieve for nominal sizes 20mm to 5mm as shown in Figure 1. In addition, crushed granite as normal coarse aggregate with a maximum nominal size of 20 mm was used in this study.

Figure 1. POC before and after crushed to nominal sizes

2.2. Physical properties of POC

Sieve analysis covers the determination of the particle size distribution of crush granite and POC coarse aggregates by sieving as per requirement of JKR 20800-0183-14. The test method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The important of data been collected through the sieve procedures is the calculation of fineness modulus of aggregates. Bulk density is the mass of the unit volume of bulk aggregate material. The term volume includes the volume of the individual particles and the volume of the voids between the particles. Bulk density is used in weight and volume batching. In this test, the specific gravity of POC is measure to study the strength or quality of the material and water absorption test is to determine the water absorption of aggregates. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed to satisfy most of the absorption potential.

2.3. Preparation of Concrete Mix Design

Concrete mix design is the procedure by the proportions of constituent materials are suitably selected so as to produce concrete satisfying all the required properties for the minimum cost. In this study, DOE method by British Department of Environment is used to design the concrete mix. POC0 was the control sample while POC33, POC67 and POC100 were replacement with POC course aggregate. The sample used in this study is 150 x 150 x 150 mm cube for density analysis and the compression test, 100mm diameter x 200mm height dimension of cylindrical for splitting tensile strength test and 500 x 100 x 100 mm dimension of prismatic for flexural strength test. Table 1 shows the concrete mix specimens and proportion. Compression test are prepared for the laboratory testing on 7 days and 28 days curing period meanwhile density analysis, splitting tensile strength test and flexural strength test are testing only on 28 days.

Table 1. Mix propotion of concrete (kg/m^3)

Mix No	Cement	Water	Superplasticizer	Fine Aggregate	Course Aggregate	POC
POC0	340	170	5.1	722	1229	0
POC33	340	170	5.1	722	823	242
POC67	340	170	5.1	722	406	491
POC100	340	170	5.1	722	0	733

There are three stages in mixing concrete. The first stage were weighted and mixed cement, fine and coarse aggregates until all the constituents are mixed uniformly. The second stage, the POC were added slowly and uniformly to ensure the POC clumped together. The third stage was measured water and added superplasticizer. Than mixed thoroughly until a homogeneous mix is obtained.

2.4. Tests on Fresh and Hardened Concrete

The slump test is prescribed in BS1881-102,1983 and was conducted for determining the workability of fresh concrete. In this research, the density test for the concrete cubes samples for wet and dry density were tested under the BS1881-114,1983. Compression test following BS1881-127,1990 was a qualitative measure for other properties of hardened concrete on mechanical property and fracture mechanism by compressing until reaching the ultimate strength. Splitting tensile strength test was used to determine the indirect tensile strength of the concrete. The test was carried out in accordance with BS 1881-117,1983 on cylindrical specimens were loaded sideway at a constant rate of 900kPa/min splitting tensile stress until they failed. Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. In this research, the prisms specimens were conducted two point loading according to the guideline of BS1881-118,1983. The test machine was operated in net deflection of the beam increased at a constant rate until it failed or to the deflection of L/150, whichever came first.

3. Result and Discussion

3.1. POC Physical Properties

The sieve grading of crush granite and Palm Oil Clinker course aggregate as shown in Figure 2 was in range requirements which is in upper boundary and lower boundary grading for coarse aggregate as per requirement of JKR 20800-0183-14. It shows that the aggregate are well graded. This result will contribute to excellent interlocking, less voids and friction at many points. Well graded material should be used for achieving good bond stress. Grading of coarse aggregates are important consideration for getting maximum strength of concrete and significant both economically as well as technically.

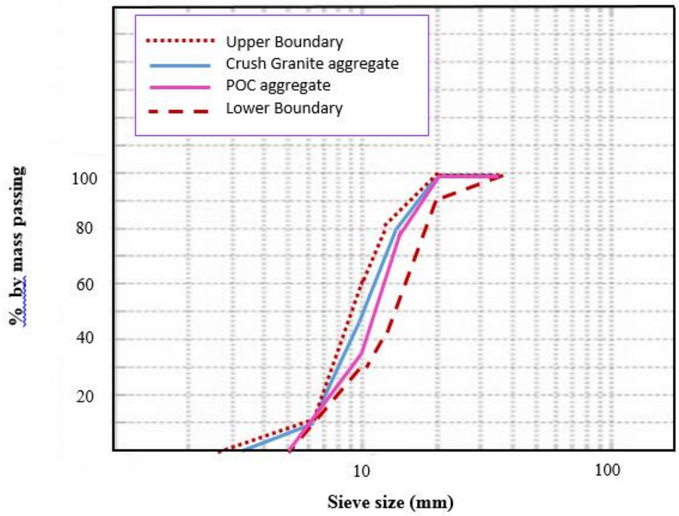

Figure 2. Grading of crush granite and Palm Oil Clinker course aggregate

In this study, the fineness modulus for crush granite aggregate and palm oil clinker are 3.61 and 3.81 respectively. Typical values for course aggregate is range from 5.5 to 8.0. This is due to the crushing, which produced more fine rather than course particles. However the plotted line is within the range as per requirement of JKR 20800-0183-14 and suitable for this study to replace POC as coarse aggregate.

Table 2 shows the physical properties of Crush Granite Aggregate and POC aggregate. The bulk density, specific gravity and water absorption result for crushed granite aggregate is 1815 kg/m^3, 2.70 and 1.79%. However, the bulk density specific gravity and water absorption result for POC is 733 kg/m^3, 1.76 and 5%. For bulk density less than 1120 kg/m^3 are specified as lightweight concrete. POC was in this characteristic and as specified in BS812: Part 2: 1975, for structurally satisfactory, density of aggregates are between 700-1400 kg/m^3. Natural aggregates have specific gravity between 2.4 and 3.0 while POC was lower specific gravity value were gave the requirement for designing the mixture of lightweight concrete. Normally, aggregate having low specific gravity are generally weaker than those with higher specific gravity values. Based on FIP Manual of lightweight aggregate concrete, generally the water absorption of lightweight aggregates varies from 5% to 30% in 24 hours. Since POC is a porous aggregate, it will allow high amount of water to fulfill the pores compared to solid aggregates.

Table 2. Physical Properties of Crush Granite Aggregate and POC Aggregate

Properties	Crush Granite Aggregate	POC Aggregate
Bulk density (kg/m^3)	1815	733
Specific Gravity	2.70	1.76
Water Absorption (%)	1.79	5

3.2. Mechanical Properties of Fresh Concrete Mixture

3.2.1. Slump Test

From the result obtained in Figure 3, the slump test of the fresh concrete was in the range of 20 mm to 30 mm where the result are equal to slump value in mix design 10-30mm. The control samples is the highest of slump value while the replacement of POC as coarse aggregate is lower value than control samples.

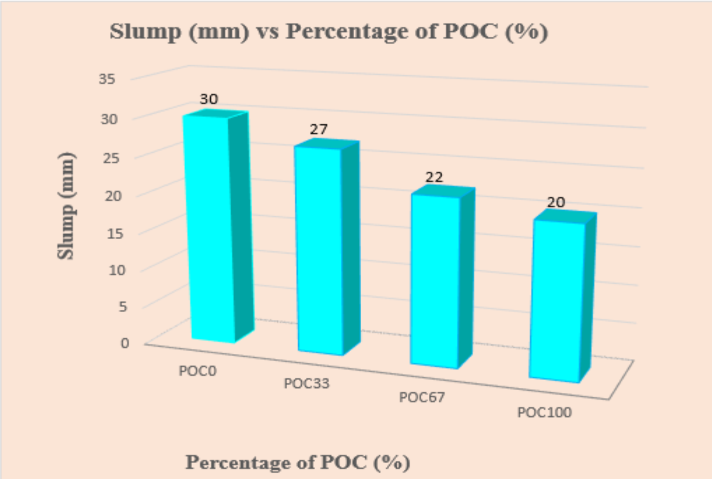

Figure 3. Graph Slump (mm) vs Percentage of POC (%)

As the percentage of replacement of POC as coarse aggregate increased, the workability of the fresh concrete was decreased. This was due to the content of POC in the fresh concrete contains lot of void and absorbed more water where reduced the slump value. Overall, the slump value of these samples indicates that the workability of concrete where in low range.

3.3. Mechanical properties of hardened concrete mixture

The mechanical properties of POC investigated in this study are density analysis, compressive strength, splitting tensile strength and flexural strength. The results obtained for all mechanical properties of different concrete mixes investigation were presented in Table 3.

Table 3. Mechanical properties of different concrete mixes.

Mix No	Density (kg/m^3)		Compressive Strength (MPa)		Splitting Tensile Strength (MPa)	Flexural strength (MPa)
	Wet	Dry	7 days	28 days		
POC0	2418	2317	29.15	32.35	5.37	4.21
POC33	2317	2213	25.24	27.89	5.12	3.98
POC67	2124	1994	24.27	25.98	4.60	3.72
POC100	2056	1929	19.97	21.56	4.28	3.33

3.3.1. Density Analysis

British Standard, BS8110-2,1985 and RILEM's functional classification of lightweight concrete classified that lightweight concrete as concrete having density less than 2000 kg/m^3. In this study, wet density of all mixes and dry density of POC0 and POC33 are classified as normal weight concrete while POC67 and POC100 of dry density can be classified as lightweight concrete because the density is less than 2000 kg/m^3. The highest reduction of wet and dry density compared to POC0 is about 14% - 17% which shows that the total dead load could be reduced by replacing the normal weight concrete with lightweight concrete.

Figure 4 shows that increasing of POC as course aggregate were decrease of concrete density. It was because of physical properties of POC in high water absorption and porosity and low density.

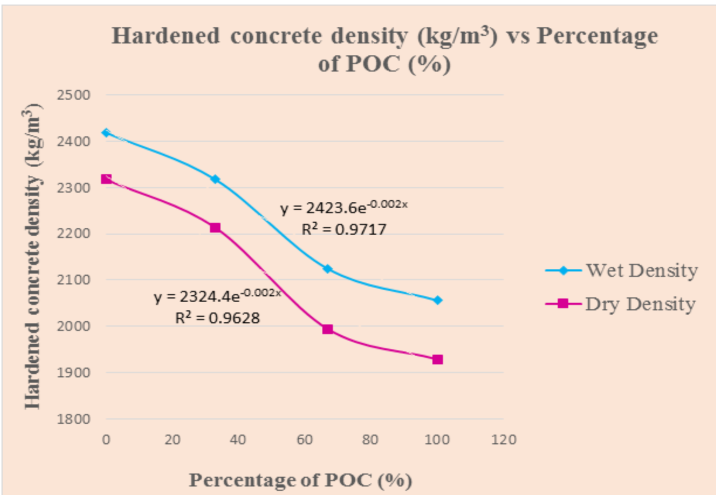

Figure 4. Concrete density (kg/m^3) for different percentage of POC (%)

3.3.2. Compressive Strength

Compressive strength of concrete mixes results shown in Table 3 and Figure 5 was increased with the age of concrete at 7 days curing period about 29.15 MPa to 19.97 MPa respectively to percentage increment of POC and 28 days curing period about 32.35Mpa to 21.56Mpa respectively to percentage increment of POC. It was found that the strength of concrete with POC replacement is decrease 14% to 33% with the addition of POC. It was because of physical properties of POC in low specific gravity were reduce the strength of concrete. However all the value of compressive strength are reliable for lightweight concrete according to RILEM's functional classification of lightweight concrete having compressive strength more than 15MPa and ASTM C330 has a minimum 28 day compressive strength of 17 MPa.

Figure 6 illustrates the typical failure mode of control and POC replacement concrete. It can be classified in satisfactory failure because equal cracking of all four exposed faces with little or no damage (top and bottom) in contact with the platens and also the cracking were vertical zigzag pattern.

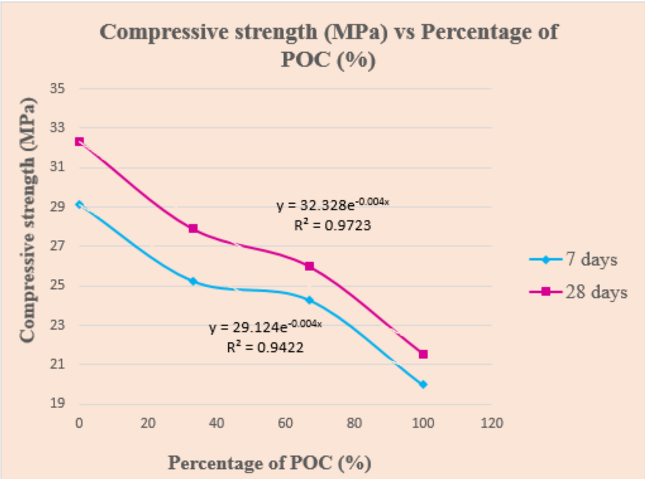

Figure 5. Compressive strength (MPa) for different percentage of POC (%)

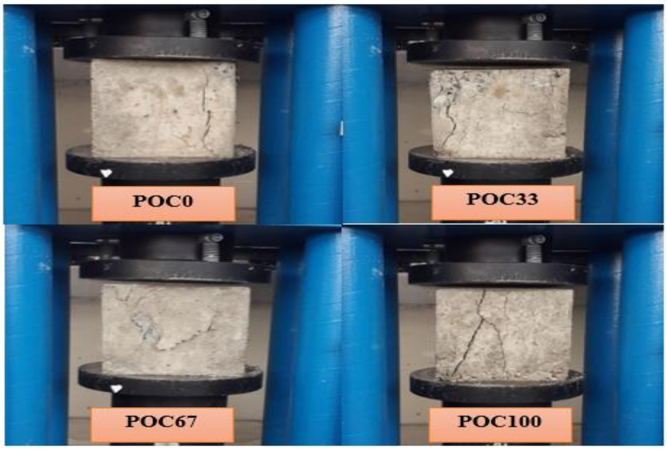

Figure 6. Typical failure pattern of control and POC replacement concrete cube

3.3.3. Splitting Tensile Strength

Table 3 and Figure 7 shows the results of Splitting tensile strength with increasing amount of POC at the age 28 days. Based on the result obtained, the splitting tensile strength was in the range from 5.37MPa to 4.28MPa and reduced 5 to 20% compared to control sample. According to ASTM: C330, a minimum splitting tensile strength of 2.0 MPa is a requirement for structural grade lightweight aggregate concrete.

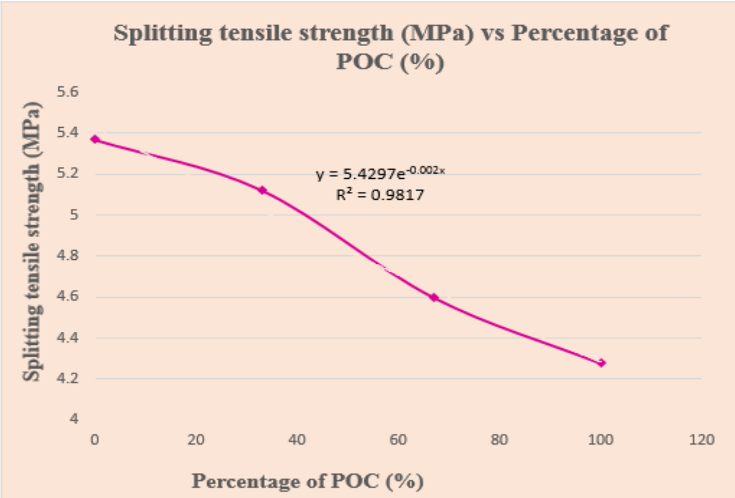

Figure 7. Splitting tensile strength (MPa) for different percentage of POC (%)

Figure 8 illustrates the typical failure pattern of control and POC replacement concrete. Based on the failure mode, overall all the samples have a similar pattern which is the fracture initiation on the surface near the loading distributing boundary. The unavoidable presence of aggregate imperfection, voids, imperfect bonding, and micro cracks certainly provide plenty of sites for stress concentrations and thus argue for failure to initiate in the interior of the cylinder.

Figure 8. Typical failure pattern of control and POC replacement concrete cylindrical

3.3.4. Flexural Strength

Flexural strength vs percentage of POC replacement in concrete in Figure 9 shows that the downward trend is proportional to the addition of POC. According to Holm and Bremmer, the flexural strength of high strength lightweight aggregate concrete under continuous moist curing, is generally in the range of 9–11% of the compressive strength. Based on Shetty MS. Concrete technology theory and practice was reported that for concrete having a compressive strength of more than 25 MPa, the flexural strength is 8-11% of the compressive strength.

Based on Table 3, the flexural strength is between 4.211 to 3.325MPa and it comply the flexural strength is 9-11% of the compressive strength. Therefore POC aggregate can be replaced crush granite aggregate in structural.

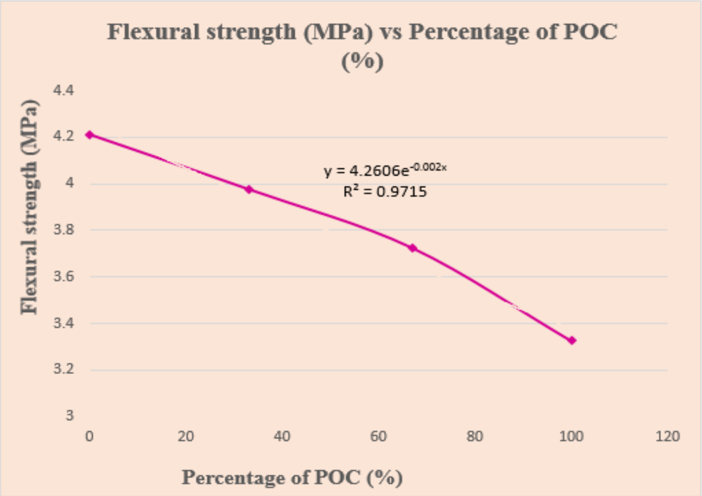

Figure 9. Flexural strength (MPa) for different percentage of POC (%)

Figure 10 illustrates the typical failure pattern of flexural strength test. From the observation, there were no horizontal cracks which indicated that there were no occurrences of bond failure. Vertical flexural cracks were observed in the constant-moment region and final failure occurred due to crushing of the compression concrete with significant amount of ultimate deflection.

Figure 10. Typical failure pattern of control and POC replacement concrete prism

3.4. Optimum content of strength – weight ratio

After various lightweight concrete analysis in this study, the optimum content of strength – weight ratio in replacement of POC as coarse aggregate to achieve lightweight concrete was about 67%. At this percentage of POC replacement it was comply that all the characteristic of lightweight concrete stated by British Standard, BS 8110-2, 1985, RILEM's functional classification of lightweight concrete, ASTM C330 and others previous study.

Since the mechanical properties of the concrete was density of less than 2000 kg/m^3, compressive strength more than 15MPa, minimum splitting tensile strength of 2.0 MPa and flexural strength in the range of 9–11% of the compressive strength, that was proved that the concrete was classified in lightweight concrete and can be used for making structural concrete elements.

The advantage of structural lightweight concrete not only have similar strength as normal weight concrete but it also contribute to saving the construction cost and reduced the dead load by reducing the size of columns, footings and other load bearing elements of a concrete structure.

4.0 . Conclusions

The results obtained and the observation made in this study draw some conclusions. it can be concluded that :

i. Based on sieve analysis, crush granite aggregate and POC course aggregate are in the envelope of well graded as per requirement of JKR 20800-0183-14. This result will contribute to excellent interlocking, less voids and friction at many points. The fineness modulus for crush granite aggregate is 3.61 while palm oil clinker is 3.81. This might due to the crushing work produce more fine aggregate rather than course aggregate. However it is in range as per requirement of JKR 20800-0183-14 and suitable for this study to replace POC as coarse aggregate.
ii. POC aggregate have low bulk density and specific gravity. However POC aggregate was high in water absorption. All the properties was reduced the density of concrete.

iii. The inclusion of POC significantly affected the workability of concrete. It has been found that the workability of concrete mixes decreased with the increase of POC.
iv. The compressive strength, splitting tensile strength and Flexural strength shows the decrease of strength proportional to the addition of POC aggregate. However it comply all the classification for lightweight concrete properties.
v. The optimum content of strength – weight ratio in replacement of POC as coarse aggregate to achieve lightweight concrete was about 67% where at this percentage it was comply that all the characteristic of lightweight concrete stated by British Standard, BS 8110 : Part 2 : 1985, RILEM's functional classification of lightweight concrete, ASTM C330 and others previous study.

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