# The Effect of Oil Palm Shell as Coarse Aggregate Replacement on Densities and Compressive Strength of Concrete

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**Abstract.** Agricultural industrial wastes produced after extracting palm oil from palm fruits known as oil palm shell (OPS) are available in large quantities in Malaysia, Indonesia and other tropical countries. The palm industry has always been linked to the environment because it is a land intensive industry. Thus, these problems have driven researchers to figure out any possible solution. The aim of the study is to study the effect of OPS as coarse aggregate replacement on densities and compressive strength of concrete. The objectives of the study are (1) to examine the concrete with percentage of OPS replacement on wet properties; (2) to determine the relationship between densities of concrete and percentage of OPS replacement and; (3) to investigate the relationship between compressive strength of concrete and percentage of OPS replacement. At first, the OPS were cleaned from any impurities before it was used as concrete mix design. A set of laboratory tests including workability test, density and compressive strength test were conducted on normal weight concrete (NWC) made by coarse aggregate (crushed granite) as control sample and OPS concrete made by different percentage of OPS replacement from 10% to 40% at intervals of 10%. The corresponding water/cement (w/c) ratios used were 0.45 and 0.50 respectively for the defined mix proportions weight-batched. All samples were submerged for 7, 14 and 28 days as curing age. The result showed, the true slump was occurred from 0% up to 30% OPS replacement at w/c ratio of 0.45 while the true slump obtained at w/c ratio of 0.50 were only 0% to 20% OPS replacement. The densities of concrete with OPS decreases as the OPS replacement were increases. Similarly, for compressive strength, the trends of compressive strength decreases dramatically as the OPS replacement were increases. This shows that when the high quantity of OPS is used in concrete mix design, it has an impact on wet properties and it can potentially reduce the compressive strength of concrete.

## Introduction

The OPS is a waste product derived from palm oil mills. Waste disposal is growing and contributing to environmental pollution if no control measures were organized in the regions involved. Based on Table 1 shows that the types of waste contained in palm oil mills can be categorized as fronds, empty fruit bunches (EFB), palm pressed fibers (PPF), palm oil trunks (POT) and shell. The breakdown of waste from palm oil production was released in 2007 [1]. The waste of shell indicates the quantity of waste 4,506 ktonnes. The OPS is a one of the huge waste producing from palm oil extraction process. As a result, OPS which are light and naturally sized was ideal for substituting aggregates in OPS concrete construction and water absorption from OPS is high compared to normal weight aggregates (NWA). Based on previous study from [2], the increase of the porosity of the concrete depends on increasing voids in concrete.

The palm oil industry in Malaysia 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 [3]. However, it is also the main contributor to the nation's pollution problem, which includes the annual production of 2.6 million tonnes of solid waste in the form of OPS. In view of this country more produced oil palm based products such as cooking oil, and then the resulting waste will not be processed in industries such as OPS. The OPS can be used in the concrete mix to replace the aggregate in order to produce concrete. Then, the initiative to examine in more detail about the properties of this material is done to demonstrate its use in the construction industry.

Table 1: Types of waste contained in palm oil mills [1]

| Wastes | Quantity (ktonnes) |
|---|---|
| Fronds | 46, 837 |
| Palm pressed fibres (PPF) | 11, 059 |
| Palm oil trunks (POT) | 10, 827 |
| Shell | 4, 506 |

Malaysia is the second largest palm oil exporting countries in the world. The demand for vegetable oil in the international market is on the rise. Every year, palm oil industries produce large volume of oil palm shell (OPS) as waste material after the production of palm oil. Nearly 5 million hectares of palm oil trees is expected by the year 2020 in Malaysia alone [4]. This will increase the production of both palm oil and its wastes.

In many developed countries, due to the increasing cost of raw materials and the continuous reduction of natural resources, the use of waste materials is a potential alternative in the construction industry. Waste materials, when properly processed, have shown to be effective as construction materials and readily meet the design specifications. Both natural and artificial aggregates are used in the construction industry. Furnace clinker and sintered pulverized fuel ash aggregates, used in lightweight concrete are well known, but these artificial aggregates are limited in supply.

In developing countries where abundant agricultural and industrial wastes are discharged, these wastes can be used as potential material or replacement material in the construction industry. This will have the double advantage of reduction in the cost of construction material and also as a means of disposal of waste. It is at this time the above approach is logical, worthy and attributable.

The OPS are light and naturally sized; there are ideal for substituting aggregates in concrete construction. Being hard and of organic origin, they will not contaminate or leach to produce toxic substances once they are bound in concrete matrix. OPS concrete can potentially be utilized in concrete applications that require low to moderate strength such as pavements and infill panel for floorings and walls. The use of oil palm shell will result in concrete that is lighter because of low density [5].

A recent study identified where waste has the potential to be a source of renewable energy in the country to show such a large amount of forest and palm oil residues can be used for energy generation and also address environmental concerns over properly disposing of the waste. In 2005, Malaysian palm oil production is projected to reach approximately 15 million tonnes (301,000 barrels per day), which is very close to the actual value of 14.96 million metric tons recorded by [6] The rapid expansion of palm cultivation has raised concerns about the sustainability and environmental impact of palm plantations, in particular with regard to biodiversity, destruction of old growth rainforest and air pollution [7].

The palm industry has always been linked to the environment because it is a land intensive industry. Any unplanned development will lead to the degradation of the forest systems, loss of habitats including plants and animals, extreme land degradation and pollution (water and airborne) due to the use of large quantities of pesticides and herbicides required to maintain the plantation. The OPS is an organic waste that is easily available in Malaysia. Its use as a substitute aggregates in concrete can reduce the density of ordinary concrete as well as reduce environmental pollution. In this study, the OPS were used as coarse aggregate replacement that supplied from palm oil mill to study the effects of the OPS on compressive strength and wet properties of concrete.

Therefore, the aim of the study is to study the effect of OPS as coarse aggregate replacement on densities and compressive strength of concrete. The objectives of this study are as follows:

a) To examine the concrete with percentage of OPS replacement on wet properties.
b) To determine the relationship between densities of concrete and percentage of OPS replacement.
c) To investigate the relationship between compressive strength of concrete and percentage of OPS replacement.

The OPS as the waste material was derived from local palm mill that was located at Kulai, Johor Bahru. This study was conducted at Structure Laboratory (D04), Faculty of Civil Engineering, University of Technology Malaysia (UTM) Johor Bahru, Johor. The experimental tests that involved on this study are workability test (slump test) and compressive strength test. The limitation of this study only will be focused on wet properties (workability test and density) condition and compressive strength of the concrete. The study was focused on the influence of the use of OPS as a substitute for aggregate in the production of the concrete.

**Previous Studies**

As industrial waste material, one such alternative is OPS, which is a form of agricultural solid waste. OPS can be used as coarse aggregate on producing lightweight concrete. OPS concrete has higher porosity in itself due to higher water absorption [5]. Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet design requirement of a structures. The compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in units MPa (SI units). The previous studies from [5], and [8] their result from the experimental shown that the compressive strength of OPS concrete satisfies for lightweight structures. According to [8] the durability of OPS concrete influenced by curing conditions.

OPS that were used in this study only are wants to study the effects of OPS as coarse aggregate replacement on the compressive strength and wet properties of concrete. The alternative is to use industrial waste material as aggregates for construction. One of the solid waste products that have increasingly gained researchers' interest are OPS produced from the processing of palm oil. Palm oil industry is a fast-growing industry and economically it is able to become the backbone of the economy.

***Lightweight Concrete by Using Oil Palm Shell (OPS)*** OPS are a one of the huge waste producing from oil palm extraction process (Figure 1). As a result, the OPS which are light and naturally sized were ideal for substituting aggregates in lightweight concrete construction. Studies by [10] found that oil palm shells was the organic aggregate which is better impact resistance compared to normal weight aggregate. Besides, OPS contain many pores and the water absorption is high compared to normal weight aggregate. Increasing voids in concrete would probably increase the porosity of the concrete [2].

In order to prioritize the factors of operator reputation loss due to a corroded pipeline, the methodology of the study is as follows:

1. Gather the factors influencing stakeholders' perceptions that eventually contribute to the loss of an operator's reputation in the pipeline accident reports.
2. Sort the factors corresponding to the stakeholders and structure the decision-making problem into a hierarchical framework.
3. Design the questionnaire and input the responses in the AHP integrated software called Super Decision.
4. Make a pairwise comparison of elements at each hierarchy level with respect to each element on the preceding level.
5. Prioritize the factors and rank the reputation loss factors.

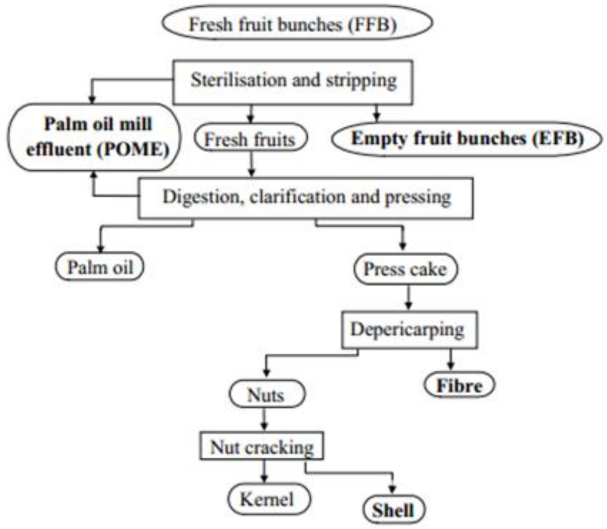



Figure 1 Simplified process flow diagram of an oil palm mill [9]

Generally, the shape of OPS aggregate varies irregular flaky shaped, angular, circular or polygonal which depend on the extraction method or breaking of the nut. Basri, Mannan and Zain (1998) found that the surface texture of the shell was fairly smooth for both concave and convex faces. Besides, the OPS can be classified as an organic aggregate which contains many pores and high water absorption. Mannan and Ganapathy (2002) showed that with OPS aggregate sizes ranging from 14 to 5 mm, water absorption for 24 hour was 23.30 % while water absorption by granite was 0.76% for 24 hour.

The mechanical properties of OPS concrete change depending on the physical properties of OPS. The established physical properties compared with normal weight aggregate (NWA) are specific gravity, thickness and shape, surface texture, loose and compacted bulk densities, air and moisture content, water absorption and porosity. According to [10] specific gravity of a material expressed as the ratio of the density of that particular material and that of water. They summarize the value specific gravity for OPS that were reported by previous researchers in Table 2. Specific gravity for OPS is around 1.17-1.62. The highest value of OPS was 1.62 by [11] who tried to use the OPS for soil stabilization. Meanwhile, [12], [5] and [13] was obtained the value of specific gravity was 1.17.

Table 2: Physical properties of OPS [10]

| Name of the author (year) | Specific gravity | Loose bulk density ($kg/m^3$) | Compacted bulk density ($kg/m^3$) | Moisture content (%) | Water absorption 24h (1h) (%) | Porosity (%) |
|---|---|---|---|---|---|---|
| Abdullah (1984) | - | - | 620 | - | - | - |
| Okafor (1988) | 1.37 | 512 | 589 | - | 27.3 | - |
| Okpala (1990) | 1.14 | 545 | 595 | - | 21.3 | 37 |
| Basri *et al.,* (1999) | 1.17 | - | 592 | - | 23.32 | - |
| Mannnan and Ganapathy (2002) | 1.17 | - | 592 | - | 23.32 | - |
| Teo *et al.,* (2006) | 1.17 | 500-600 | - | - | 33 | - |
| Ndoke (2006) | 1.62 | - | 740 | 9 | 14 | 28 |
| Jumaat *et al.,* (2008) | 1.37 | 566 | 620 | 8-15 | 238 | - |
| Mahmud *et al.,* (2009) | 1.27 | - | 620 | - | 24.5(10-12) | - |
| Alengaram *et al.,* (2010) | 1.27 | - | 620 | - | 25 | - |
| Gunasekaran *et al.,* (2011) | 1.17 | - | 590 | - | 23.32 | - |

Before the OPS uses as a aggregate replacement in concrete, the material need to undergo treatment process to remove dust and oil coating. Manna and Ganapathy (2004) was listed six pre-treatment to remove impurities from aggregate. Following are the method suggested by them:

- Partial oxidation of organic aggregate;
- Water proofing;
- Neutralisation with alkali or precipitation of tannates, or sulphate treatment;
- Mixing with lime or calcium chloride for better performance of concrete as an accelerator;
- Microorganism treatment of aggregate by boiled water with ferrous sulphate;
- Removing oil coating with detergent and water.

Teo *et al.,* (2007) mentioned that to prevent the higher water absorption during mixing, the oil palm shell was pre-soaked for 24h in potable water prior to mixing and were in saturated surface dry (SSD) condition during mixing. An early 1984, research on OPS as a lightweight aggregate was conducted in Malaysia and the results of the research shows that the engineering properties of OPS in concrete are satisfactory.

***Wet Properties of Oil Palm Shell (OPS) Concrete*** Wet properties of concrete are very important part need to be considered. It can be included with workability test (slump test, compactor test), density and others. In this study the part of slump test for workability concrete and the density of concrete will be considered by replacing the percentage of OPS from 10% to 40% at intervals of 10%.

*Workability Test***.** Based on [15], it can be seen that, for both mixes workability of reduces as the of palm kernel shell (PKS) content increases. The workability of both mixes decreases with increase in the percentage replacement of granite by PKS. This is due to the increase the specific surface as a result of the increase in the quantity of PKS, thus requiring more water to make the specimens workable. The results obtained from the previous study by using the compaction factor test are presented in Table 3.

Table 3: Results of workability test (Compacting Factor) [15]

| Replacement (%) | 0 | 25 | 50 | 75 | 100 |
|---|---|---|---|---|---|
| Volume batch | 0.89 | 0.88 | 0.87 | 0.85 | 0.83 |
| Weight batch | 0.91 | 0.82 | 0.54 | 0.34 | 0.20 |

Similarly, the decrease of slump height in 20%, 30%, 40% and 50% oil palm shell (OPS) as percentage of OPS aggregate was increased was equally be attributed to water/cement ratio. With water/cement ratio of 0.5 used for all the mixes, the hydrated cement paste became more watery and less viscous (Figure 2). The rate of workability for OPS samples shows a relatively medium to high workability ranging from 28 to 50mm for slump height and 0.93 to 0.95 for compaction factor [16].

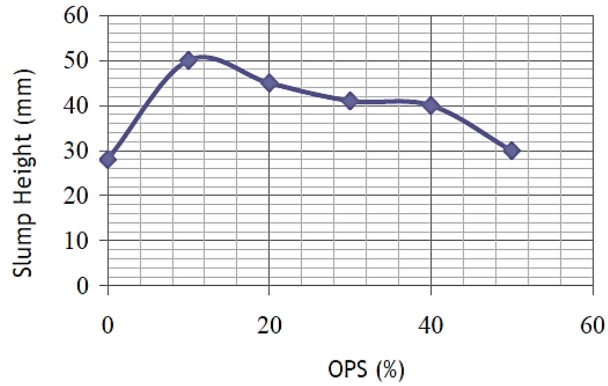



Figure 2: Slump test at different percentages of OPS [16]

*Unit Weight of Density***.** According to [17] stated that the density of the concrete produced has decreased with the increase in the percentage of OPS substitution with conventional coarse aggregate (crushed granite) as illustrated in Figure 3.

The density reduces as percentage inclusion of OPS increases vice versa (Figure 4). The range of densities for OPS concrete for 28 days was between 2230 -1925 kg/m$^3$ while in contrast, 0% OPS concrete (control concrete) has a density of 2476 kg/m$^3$. The highest density was recorded for 0% OPS of 2476 kg/m$^3$, while the least density was recorded for 50% OPS with 1925 kg/m$^3$ as mentioned by [16].

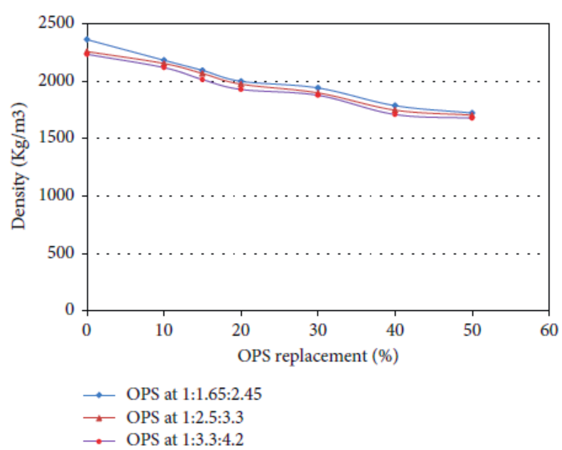



Figure 3: Density of OPS at three mix ratios [17]

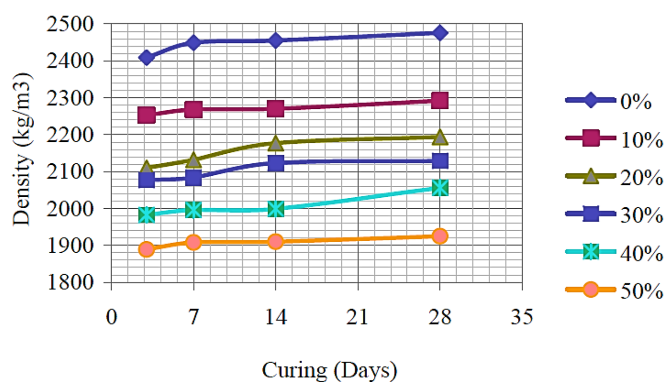



Figure 4: Densities of cubes for different percentages of OPS [16]

Daneshmand and Saadatian (2011) also stated that not all of OPS concrete samples air dry fully satisfied the structural lightweight concrete requirement, with only 28 days 50% OPS concrete sample been within the density limit of 2000 kg/m$^3$ for structural lightweight concrete, even though 10%, 20%, 30% and 40% OPS samples could be considered as partial lightweight concrete, but not fully lightweight concrete.

***Oil Palm Shell (OPS) Replacement on Compressive Strength of Concrete*** The compressive strength of the concrete is the most common performance measure used by the engineer in designing buildings and other structures. Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet design requirement of a structures. The compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in units MPa (SI units). Mannan and Ganapathy (2002) was uses OPS as a coarse aggregate. From their study found that OPS concrete achieve compressive strength of up to 20 MPa with water/cement ratio of 0.40 and with usual laboratory curing. Meanwhile, [8] highlighted that OPS concrete can be a good alternative which can help to overcome the overdependence on depletable resources due to compressive testing of OPS concrete. The result from their experimental showed that the compressive strength of the OPS concrete satisfies for lightweight structures.

Besides, [18] reported that the compressive strength OPS concrete for 28 days 23% higher than natural lightweight concrete. Normal range for structural lightweight concrete is 17-35 MPa [12]. Shafigh *et al.,* (2011) also found that the compressive strength, splitting tensile and flexural strength of OPS concrete was higher efficiency factor than clay lightweight concrete.

Furthermore, durability performance determines the variability of OPS concrete to be used in practical application. Durability of an aggregate of it is resistance to wear, moisture penetration, decay and disintegration. According to [8] stated that durability of OPS concrete influenced by curing conditions. Besides, [10] and [5] mentioned that OPS concrete has higher porosity in OPS itself due to higher water absorption. Thus, replacement of the aggregate with OPS would increase the sound transmission loss and possible use for acoustic purpose such as noise barrier because sound transmission loss of concrete depends on densities of specimen and pores inside the concrete.

However, the concrete compressive strengths with the 15% OPS substitution as shown in Figure 5 are between 17.01 N/mm$^2$ and 17.7 N/mm$^2$ at the age of 28 days for different mix proportions of concrete and it satisfies the structural requirement of lightweight concrete as reported by [17].

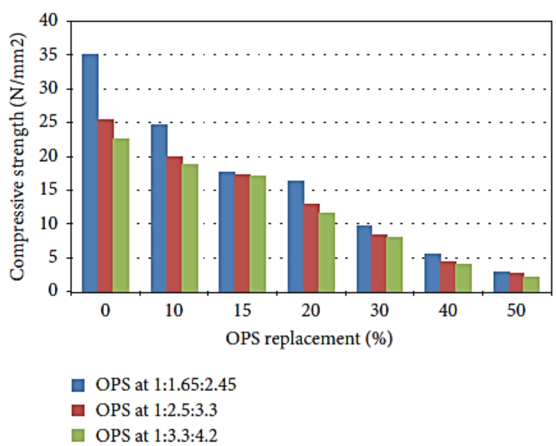



Figure 5: Comparison of compressive strength of OPS at28 days of curing (1 : 2.5 : 3.3) [17]

Studies by [15], they concluded that palm kernel shell concrete (PKSC) batched by volume replacement or weight replacement of coarse aggregate with PKS show similar trends in the variation of strength (Table 4 and Table 5) with increase in percentage replacement. The loss of strength per increase in percentage replacement by PKS is higher for weight-batched concrete than for volume batched concrete as shown in Figure 6. PKS concrete batched by volume performed better than that batched by weight.

Table 4: Compressive strengths of volume-batched PKSC (N/mm$^2$) [15]

| Age at testing(days) | Palm kernel shell replacement (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 25 | 50 | 75 | 100 |
| 7days | 15.00 | 12.11 | 9.34 | 8.71 | 3.10 |
| 14days | 18.69 | 14.52 | 13.02 | 12.70 | 6.88 |
| 21days | 19.65 | 15.30 | 14.42 | 14.31 | 7.87 |
| 28days | 21.80 | 16.64 | 15.00 | 15.18 | 10.37 |

Table 5: Compressive strengths of weight-batched PKSC (N/mm$^2$) [15]

| Age at testing(days) | Palm kernel shell replace-ment (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 25 | 50 | 75 | 100 |
| 7 | 16.25 | 11.61 | 4.67 | 1.56 | 0.93 |
| 14 | 18.84 | 13.24 | 6.16 | 1.87 | 1.00 |
| 21 | 20.91 | 14.82 | 7.21 | 2.19 | 1.34 |
| 28 | 24.02 | 16.33 | 7.89 | 2.82 | 1.84 |

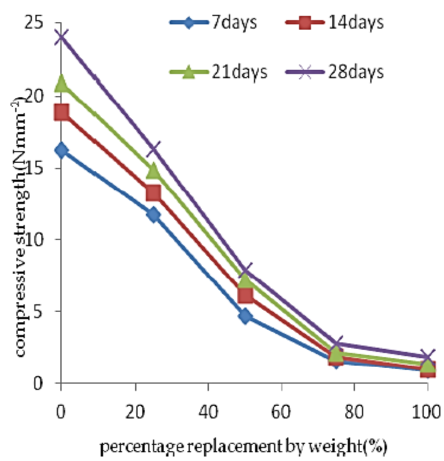


Figure 6: Variation of compressive strength with palm kernel shell content by weight [15]

## Methodology

In this study, the OPS were washed with potable water and after that it were left under the shed for air-drying process (Figure 7). When the OPS fully dried, sieve analysis were conducted to remove the fibre and to obtain the particle size distribution. This study was involved for NWC and OPS concrete mix design. For NWC mix design preparation were based on crushed aggregate (crushed granite), fine aggregate (natural river sand), cement and water. NWC was considered as no OPS content because NWC was created as a control concrete in this study while for the OPS concrete were designed with OPS content by 10%, 20%, 30% and 40% respectively.

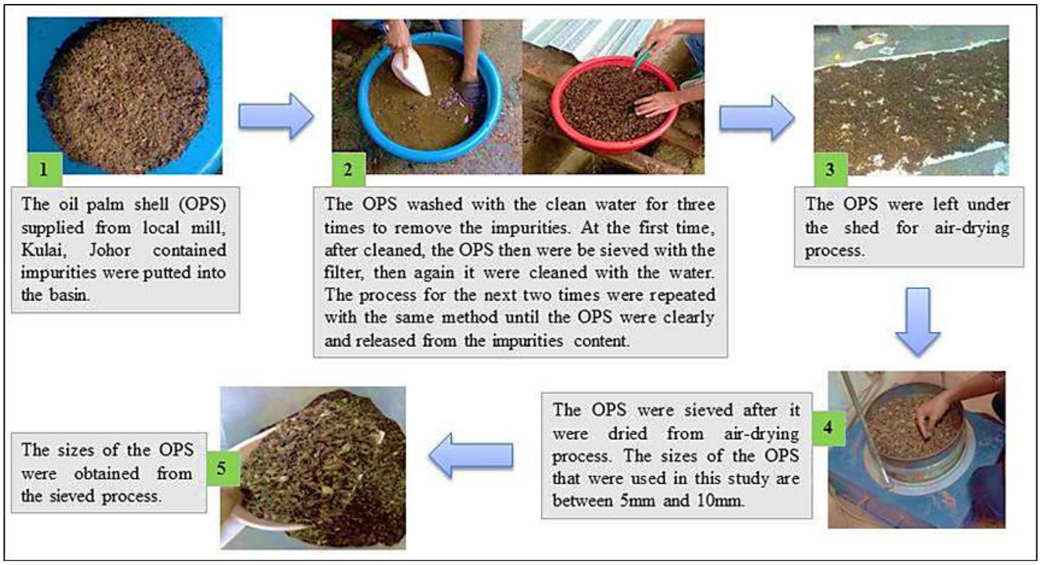



Figure 7: The process to remove the impurities content

Type I Malaysian Ordinary Portland Cement (OPC) based on ASTM accordance to BS EN 1991 was used as a binder for NWC and OPS concrete. Since OPS were used as a replacement material of course aggregate, the size of OPC was used between of 5mm to 10mm in the production of OPS concrete. The natural river sand was assumed to use with 60% percent passing by mass with 600 µm sieve as fine aggregate accordance to ASTM C33. Meanwhile, the crushed stone with nominal size less than 10mm will be used as coarse aggregate of a control specimen for this study. The ordinary tap water was selected for the mixing of the concrete. The quality met the requirements of MS 528: 1985 or BS 3148: 1959; that is, it was free from any particles content and contaminants. The concrete mixer was used to mix all the ingredient includes fine and coarse aggregate, OPS, water and cement as shown in Figure 8.

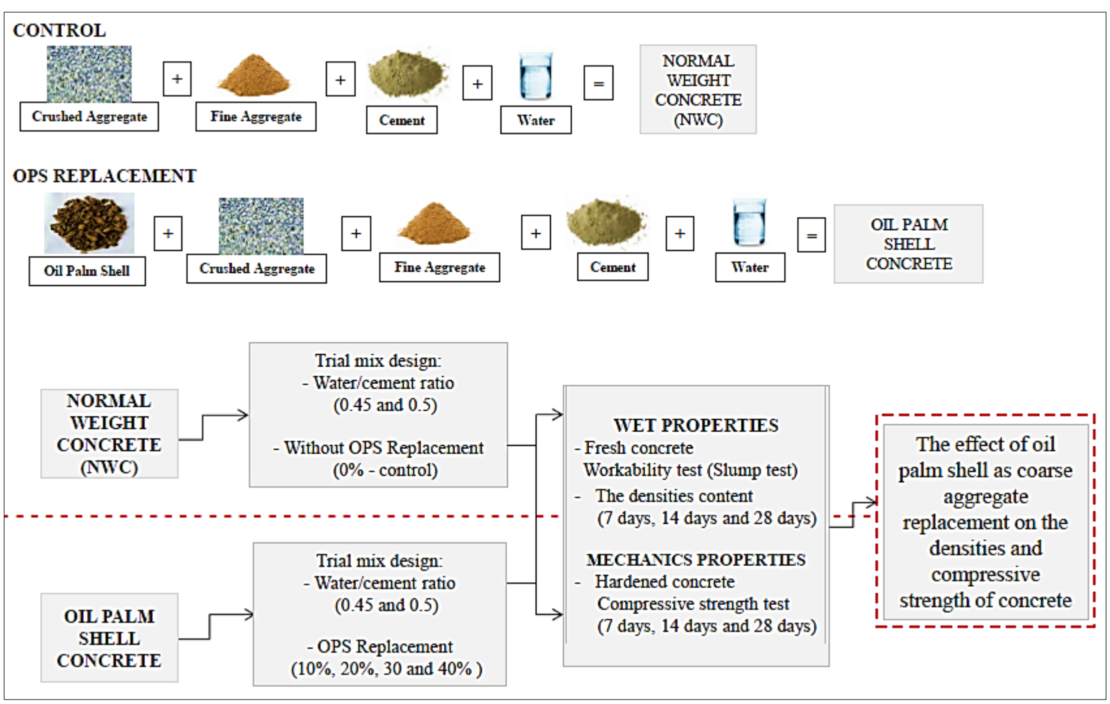



Figure 8: Operational framework

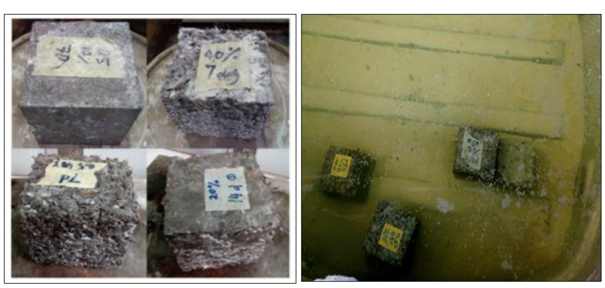
Concrete mix design was used for designing the normal mixes that published by [19]. The summaries of calculation on concrete mix design for w/c ratio at 0.45 and 0.50 as shown in Table 6 by using weight method were used in this study. The value of OPS were used in kilogram (kg) that were obtained based on the total coarse aggregate of normal mixes by multiplying with the percentage of OPS replacement.

Table 6: Mix design concrete for w/c ratio at 0.45 and 0.50

| **W/C ratio** | **% OPS** | **Cement (kg)** | **Water (kg)** | **Fine Aggregate (kg)** | **Coarse Aggregate (kg)** | **OPS (kg)** |
|---|---|---|---|---|---|---|
| **0.45** | 0 (control) | 7.15 | 3.22 | 9.02 | 13.51 | 0.00 |
| | 10 | 7.15 | 3.22 | 9.02 | 12.16 | 1.35 |
| | 20 | 7.15 | 3.22 | 9.02 | 10.81 | 2.70 |
| | 30 | 7.15 | 3.22 | 9.02 | 9.46 | 4.05 |
| | 40 | 7.15 | 3.22 | 9.02 | 8.11 | 5.40 |
| **0.50** | 0 (control) | 6.44 | 3.22 | 9.02 | 13.94 | 0.00 |
| | 10 | 6.44 | 3.22 | 9.02 | 12.55 | 1.39 |
| | 20 | 6.44 | 3.22 | 9.02 | 11.16 | 2.79 |
| | 30 | 6.44 | 3.22 | 9.02 | 9.76 | 4.18 |
| | 40 | 6.44 | 3.22 | 9.02 | 4.18 | 5.58 |

The corresponding water/cement ratios used were 0.45 and 0.5 respectively. In each mix proportion, the percentage of OPS replacement used were 0%, 10%, 20%, 30% and 40%. For comparison, 0% OPS replacement has been used as a control specimen for this study. The various mixes design were carried out to know the wet properties such as slump value and densities content for w/c ratio at 0.45 and 0.50 performances. In addition, it is also to investigate the relationship between compressive strength of concrete and the percentage of OPS replacement. The mixtures were casted in 100mm x 100mm x100mm mould cube as recommended by ASTM C39. Every sample needs three specimens to provide average results.

After completing mix the concrete, workability of concrete were conducted immediately to test concrete performance. It was conducted with slump test where concrete were be investigated what types of slump it will be categorized according to BS 1881: part 102: 1983. For cube mould, the inner cubes surface were be coated with oil to prevent the concrete from sticking and when the concrete hardens, the process of opening a concrete will become quick and easy. The cubes were casted by filling the mould in three layers. Each layer need to compact normally with 25 blows by using the steel rod. Then, all specimens were leaved in the mould for at least 24 hours under ambient temperature. After that, the hardened concrete were removed from the mould and transferred into a curing container that consists of clean water (Figure 9). The curing processes were made in 7 days, 14 days and 28 days.



(a) (b)

Figure 9: (a) Some of hardened concrete produced and (b) curing process

The densities of concrete were determined to fulfill the aim and objectives that have been set as recommended by ASTM C138. The sample cube cured from 7 days, 14 days and 28 days were removed from the curing container. Before weighed the sample by using weighing machine (Figure 10), the sample is needed to dry first for a few minutes. Then, the readings of weighed concrete are recorded and repeated the same method for all concrete samples. The densities of concrete can be calculated using the following formula:

$$\text{Density (kg /m}^3\text{)} = \frac{\text{Sample weight (kg)}}{\text{Sample volume (m}^3\text{)}}$$

Figure 10: The concrete cube sample is weighed

Curing has a strong influence on the properties of hardened concrete with proper curing were increase durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicers. The improvement is rapid at early ages but continues more slowly thereafter for an indefinite period. After curing process was completed in 7 days, 14 days and 28 days, the samples were tested with the compressive strength machine accordance to ASTM C39. The compressive strength of hardened concrete was tested by using the compressive machine in the laboratory.

**Data Analysis**

According to the tests that were carried out on samples of concrete by using the OPS as the coarse aggregate replacement for the concrete, this chapter will explain in detail about the data and the results that has been obtained. The types of tests on samples of concrete are the workability test, unit weight of density test and the compressive strength test. The test results on densities and compressive strength of concrete are based on the activities curing at 7 days, 14 days and 28 days. The results obtained from previous studies by [16], and [17] were compared.

***Workability Test*** In investigation of wet properties of the concrete, the workability test on fresh concrete were used method of slump test. Slump test is a test that is often done on fresh concrete and it is simple and most practical way to measure the workability of concrete. Height slump which has been designed around 30 mm to 60 mm. The results obtained from the slump test for two different of w/c ratio condition at 0.45 and 0.50 are presented in Table 7. It was determined that with an increasing the replacement percentage of the OPS, the value of slump was increased.

The highest slump value occurred in 40% of OPS replacement for both w/c ratio which are 80mm at 0.45 w/c ratio and 120mm at 0.50 w/c ratio. The classification type of slump can be classified based on the slump value. The amount of the OPS added to influence the workability of fresh concrete as can be observed in Figure 11.

Table 7: Results of workability test (slump test)

| Water cement ratio: 0.45 | | |
|---|---|---|
| **OPS %** | **Height (mm)** | **Type of slump** |
| 0 | 20.00 | True slump |
| 10 | 5.00 | True slump |
| 20 | 5.00 | True slump |
| 30 | 7.00 | True slump |
| 40 | 80.00 | Collapse slump |
| **Water cement ratio: 0.50** | | |
| **OPS %** | **Height (mm)** | **Type of slump** |
| 0 | 25.00 | True slump |
| 10 | 5.00 | True slump |
| 20 | 15.00 | True slump |
| 30 | 90.00 | Collapse slump |
| 40 | 120.00 | Collapse slump |

The w/c ratio at 0.45 and 0.50, the conventional concrete without OPS replacement gave the slump value of 20mm and 25mm which are can be classified as true slump. The workability of fresh concrete started to be collapse slump type at 30% and 40% when the OPS replacement is increased. The slump value for w/c ratio at 0.45 from 10% up to 30% of OPS replacement produced lower value of slump. It can be classified as true slump and achieve high workability while at 40% of OPS replacement, the slump value is high and produced collapse slump type.

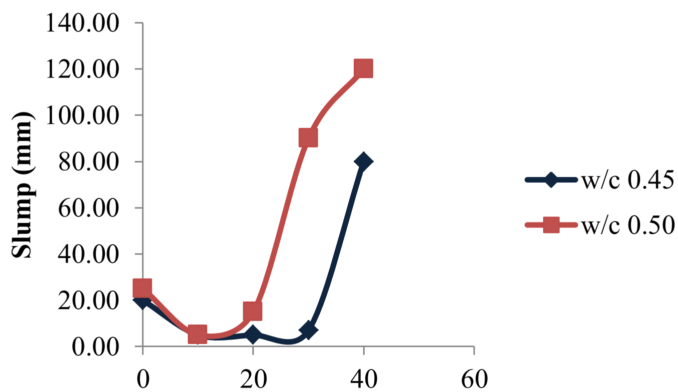



Figure 11: The trend of slump heights with different percentages of OPS

The results were differences from [16], and [17] as shown in Table 8. The normal concrete based on slump value obtained from researchers are 28 mm and 62 mm. The percentages of difference for w/c ratio obtained in this study at 0.45 are 29% and 68% while w/c ratios at 0.50 are 11% and 60%. For slump value based on OPS replacement, only [16] recorded the results where the slump value were decreases as the OPS replacement were increases.

Table 8: Comparison on percentage of slump value from previous study

| **Researches** | **OPS Replacement** | **Previous Results (Slump Value)** | **Difference by Percentage (%)** | |
|---|---|---|---|---|
| | | | **w/c 0.45** | **w/c 0.50** |
| Daneshmand and Saadatian (2011) | 0% | 28mm | 29 | 11 |
| Sobuz *et al.,* (2014) | 0% | 62mm | 68 | 60 |

***Unit Weight of Density*** The densities for w/c ratio at 0.45 and 0.50 are presented in Table 9 and Table 10 respectively. The values of densities were weighted after curing at 7 days, 14 days and 28 days. The densities of all samples were determined to find the possibility of structural concrete component. Densities of three samples were determined to which the average was taken to determine the actual density of each sample.

Table 9: Densities of concrete for w/c ratio at 0.45

| Day | OPS % | Sample | Weight (kg) | Volume ($m^3$) | Density ($kg/m^3$) |
|---|---|---|---|---|---|
| | 0 | 0 A1 | 2.368 | 0.001 | 2368 |
| | 10 | 10 A2 | 2.237 | 0.001 | 2237 |
| | 20 | 20 A3 | 2.102 | 0.001 | 2102 |
| 7 | 30 | 30 A4 | 1.918 | 0.001 | 1918 |
| | 40 | 40 A5 | 1.578 | 0.001 | 1578 |
| | 0 | 0 B1 | 2.375 | 0.001 | 2375 |
| | 10 | 10 B2 | 2.158 | 0.001 | 2158 |
| | 20 | 20 B3 | 2.070 | 0.001 | 2070 |
| 14 | 30 | 30 B4 | 1.848 | 0.001 | 1848 |
| | 40 | 40 B5 | 1.658 | 0.001 | 1658 |
| | 0 | 0 C1 | 2.402 | 0.001 | 2402 |
| | 10 | 10 C2 | 2.190 | 0.001 | 2190 |
| | 20 | 20 C3 | 2.087 | 0.001 | 2087 |
| 28 | 30 | 30 C4 | 1.905 | 0.001 | 1905 |
| | 40 | 40 C5 | 1.677 | 0.001 | 1677 |

The percentage of 0% from the table above represented as the conventional concrete. The densities of concrete without OPS replacement increasing 1.42% based on curing activities from 7 days up to 28 days. The density of the OPS concrete produced has decreased with the increase in the percentage of OPS substitution except the density of NWC as illustrated in Figure 12. To begin with, at the replacement level of 0% of OPS substitution at 28 days, the density of the concrete was 2402 $kg/m^3$. At 10%, up to 40% levels of OPS substitution, the density were decreased respectively from 2190 $kg/m^3$, 2087 $kg/m^3$, 1905 $kg/m^3$, and 1677 $kg/m^3$ for the w/c ratio at 0.45.

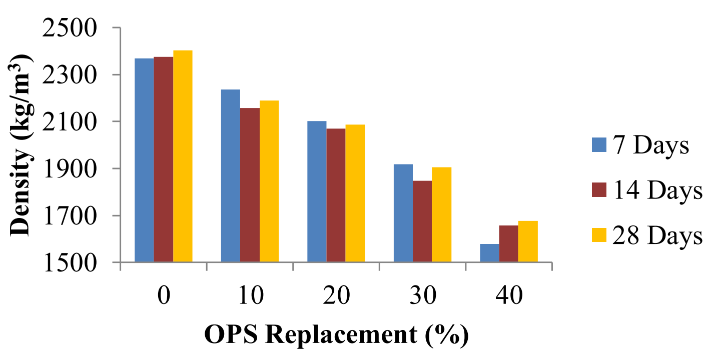



Figure 12: The density trend of OPS at 7 days, 14 days and 28 days for w/c ratio at 0.45

Furthermore, the lightweight concrete has a density below 1850 $kg/m^3$. At the 40% OPS replacement, the densities obtained for 7 days, 14 days and 28 days are 1578 $kg/m^3$, 1658 $kg/m^3$ and

1677 kg/m$^3$ which are below than 1850 kg/m$^3$. This consequently results to the production of structure lightweight concrete. However, in this case as mentioned from the workability test result, the type of slump occurred at 40% OPS replacement was collapse slump which meant produced low workability of concrete. Hence, 40% OPS replacement cannot be classified as lightweight concrete although the result of densities was lower than required. Next, the percentage from 10% up to 30% mostly shown it is above than 1850 kg/$^3$ of densities content. An expected weight for control concrete was produced 2402 kg/m$^3$ at 28 days of concrete higher than 1850 kg/m$^3$, thus implying that 0% OPS sample concrete is considered as NWC.

The actual weight of both coarse aggregate and OPS aggregate that were used can be possibility to make the reason of lightweight concrete. As shown from the table and figure above, an increase in percentage of OPS replacement can leads to a decrease in the air and dry density of the concrete if not considered the workability test results. However since the OPS is lighter in weight than coarse aggregate, as coarse aggregate is been replaced at different percentages, resulting to a lesser amount of coarse aggregate in the mix, absorption of cement paste is greatly reduced as the OPS do not properly bond with cement, this reduces the overall density of concrete, thus leading to the making of lightweight concrete.

Table 10: Densities of concrete for w/c ratio of 0.50

| Day | OPS % | Sample | Weight (kg) | Volume (m$^3$) | Density (kg/m$^3$) |
|---|---|---|---|---|---|
| | 0 | 0 D1 | 2.367 | 0.001 | 2367 |
| | 10 | 10 D2 | 2.282 | 0.001 | 2282 |
| 7 | 20 | 20 D3 | 2.108 | 0.001 | 2108 |
| | 30 | 30 D4 | 1.830 | 0.001 | 1830 |
| | 40 | 40 D5 | 1.637 | 0.001 | 1637 |
| | 0 | 0 F1 | 2.367 | 0.001 | 2367 |
| | 10 | 10 F2 | 2.250 | 0.001 | 2250 |
| 14 | 20 | 20 F3 | 2.105 | 0.001 | 2105 |
| | 30 | 30 F4 | 1.835 | 0.001 | 1835 |
| | 40 | 40 F5 | 1.632 | 0.001 | 1632 |
| | 0 | 0 G1 | 2.367 | 0.001 | 2367 |
| | 10 | 10 G2 | 2.293 | 0.001 | 2293 |
| 28 | 20 | 20 G3 | 2.098 | 0.001 | 2098 |
| | 30 | 30 G4 | 1.863 | 0.001 | 1863 |
| | 40 | 40 G5 | 1.730 | 0.001 | 1730 |

For densities at w/c ratio of 0.50, the percentage of 0% from the table above also represented as the conventional concrete. The densities of concrete without OPS replacement increasing 0% based on curing activities from 7 days to 28 days. Based on Figure 13, the density of the concrete produced has decreased with the increase in the percentage of OPS substitution with control coarse aggregate. The replacement level of 0% of OPS substitution at 28 days, the density of the concrete was 2367 kg/m$^3$. At 10%, 20%, 30% and 40% levels of OPS substitution, the density has decreased respectively from 2293 kg/m$^3$, 2098 kg/m$^3$, 1863 kg/m$^3$, and 1730 kg/m$^3$ for the w/c ratio at 0.50.

Similarly with case of 40% OPS replacement at w/c of 0.45, the density for w/c ratio at 0.50 is also the same case where 40% of the OPS replacement was below than 1850 kg/m$^3$. It cannot be classified as lightweight concrete because the workability test was shown it was collapse slump. The rest from 10% up to 30% also were unconsidered as lightweight concrete because their densities are more than 1850 kg/m$^3$. The conventional concrete with 0% OPS replacement can be categorized as NWC.

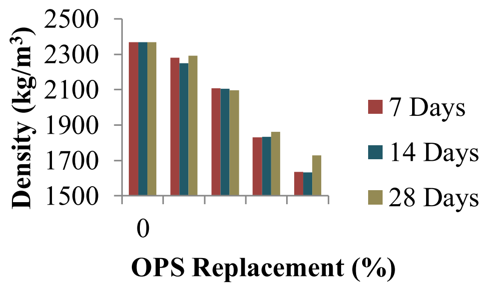



Figure 13: The density trend of OPS at 7 days, 14 days and 28 days for w/c ratio at 0.50

The comparison both of w/c ratio at 0.45 and 0.50 were shown in Figure 14 according to the relationship of density and the percentage of OPS replacement. The percentages of 10% up to 30% OPS replacements are cannot considered as the lightweight concrete because the densities are more than 1850 kg/m$^3$. The density from the percentage OPS replacement needs to be lower than 1850 kg/m$^3$. Then, it can be required being as lightweight concrete properties.

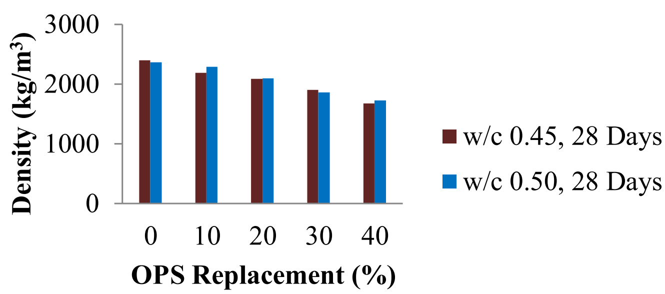



Figure 14: Densities versus OPS replacement pattern

In Table 11 was shown the comparison on densities from previous studies and results obtained in this study. According to [16], they were used w/c ratio at 0.50 in their mix design of concrete while [17] were used w/c at 0.45 for their studies. The range differences at w/c ratio 0f 0.45 was between 0.46% and 6.05%. The slightly difference can be concluded at 10% OPS replacement. Based on w/c ratio at 0.50, the range differences was between 0.04% and 15.86%. Similarly, 10% OPS replacement is the lowest percentage difference among others.

Table 11: Comparison on percentage of densities from previous study

| **w/c 0.45, 28 days (Sobuz *et al.*, 2014)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| OPS % | 0 | 10 | 15 | 20 | 30 | 40 | 50 |
| Previous Result (kg/m$^3$) | 2360 | 2180 | 2092 | 2000 | 1980 | 1785 | 1650 |
| The difference by percentage, % | 1.78 | 0.46 | - | 4.35 | 3.79 | 6.05 | - |
| **w/c 0.50, 28 days (Daneshmand and Saadatian, 2011)** | | | | | | | |
| OPS% | 0 | 10 | 15 | 20 | 30 | 40 | 50 |
| Previous Result (kg/m$^3$) | 2476 | 2292 | - | 2194 | 2129 | 2056 | 1925 |
| The difference by percentage, % | 4.40 | 0.04 | - | 4.38 | 12.50 | 15.86 | - |

***Compressive Strength*** Compressive strength test was conducted on concrete cubes of size 100mm x 100mm x 100mm accordance to ASTM C39. In Table 12 and Table 13 shows the results of the compressive strength for w/c ratio at 0.45 and 0.50 respectively. The tests were made on the concrete age of 7 days, 14 days and 28 days.

The control concrete on compressive strength at 28 days based on w/c ratio at 0.45 and 0.50 are 44.90 N/mm$^2$ and 33.27 N/mm$^2$ while the 40% of OPS replacement the compressive strength are 1.53 N/mm$^2$ (w/c ratio of 0.45) and 3.82 N/mm$^2$ (w/c ratio of 0.50). The difference value between the control and 40% OPS replacement are 96.6% and 88.5% respectively. The conventional concrete with 0% OPS replacement has the highest compressive strength values at both w/c ratios.

From the results obtained, it was found that the OPS replacement for OPS concrete and NWC greatly influences the compressive strength of concrete. The effects of replacement of coarse aggregate with OPS content on compressive strengths of the specimens are shown in Figure 15 and Figure 16 respectively.

Table 12: Compressive strength for 0.45 of w/c ratio

| Day | OPS % | Sample | Strength (N/mm$^2$) |
|---|---|---|---|
| 7 | 0 | 0 A1 | 36.62 |
| | 10 | 10 A2 | 15.28 |
| | 20 | 20 A3 | 13.26 |
| | 30 | 30 A4 | 6.34 |
| | 40 | 40 A5 | 10.78 |
| 14 | 0 | 0 B1 | 34.36 |
| | 10 | 10 B2 | 18.37 |
| | 20 | 20 B3 | 14.32 |
| | 30 | 30 B4 | 3.72 |
| | 40 | 40 B5 | 1.64 |
| 28 | 0 | 0 C1 | 44.90 |
| | 10 | 10 C2 | 16.32 |
| | 20 | 20 C3 | 10.96 |
| | 30 | 30 C4 | 5.27 |
| | 40 | 40 C5 | 1.53 |

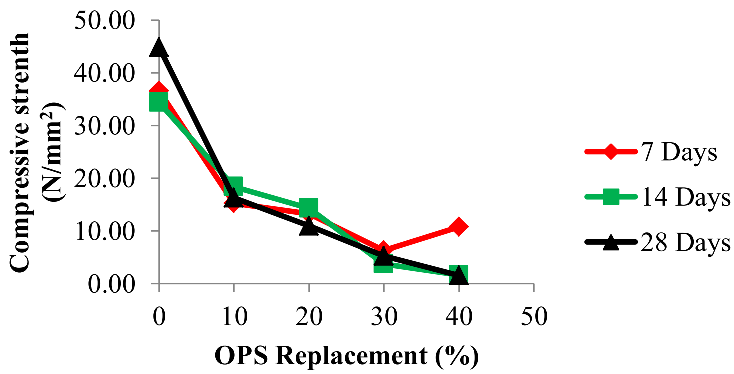



Figure 15: Variation of compressive strength with OPS replacement at0.45 of w/c ratio

The conventional concrete at w/c ratio at 0.45 shows the value of compressive strength were increases followed the age of concrete at 7 days, 14 days and 28 days. The compressive strength started to decrease when the percentage of the OPS replacement is added from 10% until 40% OPS content. The minimum required value of compressive strength based on recommendation by BS 8110 1997 is 15 N/mm$^2$ for structural lightweight concrete.

Some of the compressive strength obtained from the others percentage of the OPS content can be classified by following the standard criteria design of concrete class recommended by BS 8110

1997. The differences of compressive strength value of the OPS replacement compared with the conventional concrete are 63.7%, 75.6% and 88.3% at 10%, 20% and 30% of OPS replacement.

Table 13: Compressive strength for 0.50 of w/c ratio

| Day | OPS % | Sample | Strength (N/mm$^2$) |
|---|---|---|---|
| | 0 | 0 D1 | 21.10 |
| | 10 | 10 D2 | 26.52 |
| 7 | 20 | 20 D3 | 10.18 |
| | 30 | 30 D4 | 5.56 |
| | 40 | 40 D5 | 2.24 |
| | 0 | 0 F1 | 26.33 |
| | 10 | 10 F2 | 20.76 |
| 14 | 20 | 20 F3 | 11.03 |
| | 30 | 30 F4 | 3.82 |
| | 40 | 40 F5 | 2.09 |
| | 0 | 0 G1 | 33.27 |
| | 10 | 10 G2 | 19.87 |
| 28 | 20 | 20 G3 | 13.02 |
| | 30 | 30 G4 | 5.85 |
| | 40 | 40 G5 | 3.82 |

For the w/c ratio at 0.50 for 0% OPS replacement, from the table above the value of compressive strength based on age of concrete at 7 days, 14 days and 28 days are increased from 21.10 N/mm$^2$ to 33.27 N/mm$^2$. The same hypothesis can be obtained where when the content of the OPS was added increasingly by percentage, then the compressive strength result will be decrease respectively.

The range compressive strength obtained from the OPS replacement is 2.09 N/mm$^2$ to 26.52 N/mm$^2$. Figure 16 show the variation of compressive strength with the OPS replacement. The percentage difference of the OPS replacement with the conventional concrete on compressive strength were 40.3%, 60.9% and 82.4% concrete age 28 days followed by 10% up to 30% of OPS replacement.

Next, Figure 17 shows the development of compressive strength of concrete with age of concrete. It indicates the different amount of OPS that were added, as it affects the compressive strength of the concrete. The compressive strength of the concrete decreases as the percentage of OPS increases. Furthermore, the reduction in the compressive strength of concrete as a result of increment in the added percentage of the OPS aggregate could be attributed as a result of the highly irregular shapes of the OPS, which prevent full compaction with usual coarse aggregate, there by affecting the strength of the concrete. More also, the bonds between the OPS and mortar paste were not as strong as that of control concrete because of the smoothness of the sample.

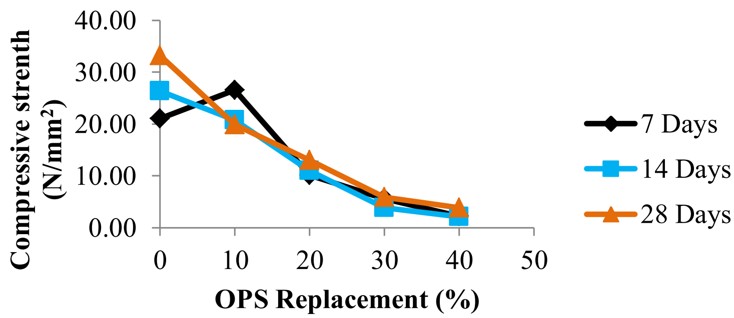



Figure 16: Variation of compressive strength with OPS replacement at 0.50 of w/c ratio

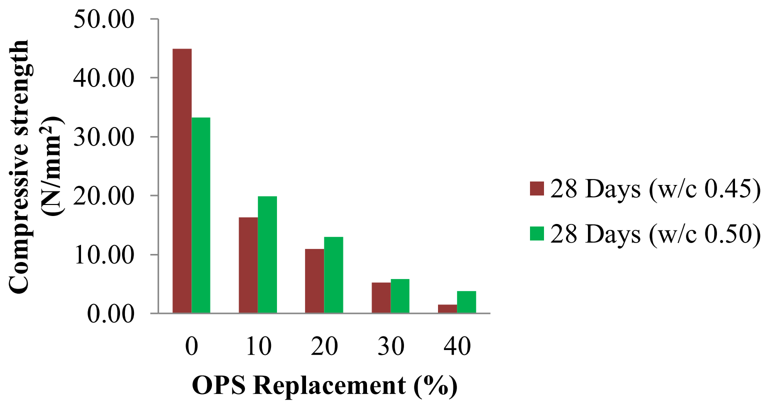



Figure 17: The development of compressive strength of concrete with age of 28 days

The comparison between w/c ratios that has been used in this study were 0.45 and 0.50. The conventional concrete at age 28 days obtained the compressive strength for w/c ratio at 0.45 is higher than the compressive strength for w/c ratio of 0.50. The difference percentage is 25.90%.

For the 10% up to 40% OPS replacement, the result of compressive strength at w/c ratio of 0.50 were increases compared to the result of compressive strength at w/c ratio of 0.45. The differences percentage with varies of OPS replacement with both w/c ratios at 10%, 20%, 30% and 40% OPS replacement were 21.8%, 18.8%, 11.0% and 59.9%.

The pattern from the figure above shows that the compressive strength at both w/c ratios were decreases dramatically as the OPS replacement were increases. The comparison at both w/c ratios from the previous results are shown in Table 14. The largest difference by percentage obtained at w/c ratio of 0.45 was 99.56% for 0% OPS replacement. The results of compressive strength from [17] also decreases dramatically when the OPS replacement were increases. However, the compressive strength occurred at w/c ratio of 0.50 from [16] were also decreases as the OPS replacement increases but not too dramatically. The differences by percentage compared with this study at w/c ratio of 0.45 and 0.50 were obtained in range of 10.33% to 99.56% and 44.36% to 88.53%.

Table 14: Comparison on percentage of compressive strength from previous study

| **w/c 0.45, 28 days (Sobuz *et al.*, 2014)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| OPS % | 0 | 10 | 15 | 20 | 30 | 40 | 50 |
| Previous Result ($N/mm^2$) | 22.5 | 18.2 | 13.2 | 12.5 | 7.8 | 4.2 | 2.8 |
| The difference by percentage, % | 99.56 | 10.33 | - | 12.32 | 32.44 | 63.57 | - |
| **w/c 0.50, 28 days (Daneshmand and Saadatian, 2011)** | | | | | | | |
| OPS% | 0 | 10 | 15 | 20 | 30 | 40 | 50 |
| Previous Result ($N/mm^2$) | 59.8 | 52.2 | - | 43.63 | 39.24 | 33.3 | 29.51 |
| The difference by percentage, % | 44.36 | 61.93 | - | 70.16 | 85.09 | 88.53 | - |

Due to the higher moisture content of concrete, drying times are typically longer than regular concrete. The w/c ratio varies according to specific project requirements. For overall, the classification by class of concrete will be recommended by BS 8110 1997 as shown in Table 15. The characteristic strength of the concrete will be used as a guideline to establish the suitable classification of the concrete.

Table 15: Recommended grades of concrete BS 8110 1997

| **Characteristic Strength ($N/mm^2$)** | **Concrete Class** |
|---|---|
| 7.0<br>10.0 | Plain concrete |
| 15.0 | Reinforced concrete with lightweight aggregate |
| 20.0<br>25.0 | Reinforced concrete with dense aggregate |
| 30.0 | Concrete with post tensioned tendons |
| 40.0<br>50.0<br>60.0 | Concrete with pre tensioned tendons |

For 20% OPS replacement at age 28 days of concrete there can be potentially used in plain concrete works because the compressive strength produced from w/c ratio of 0.45 and 0.50 are 10.96 $N/mm^2$ and 13.02 $N/mm^2$. Although it is excluded from the standard range requirement, however, it can be considered nearly as the difference with the range is too slightly. The conventional concrete was classified as concrete class on concrete pre tensioned tendons. This is because the compressive strength value obtained from both w/c ratios without any OPS replacement were 44.90 $N/mm^2$ and 33.27 $N/mm^2$.

It is concluded that the compressive strength of concrete depends on the wet properties and mechanics properties condition. Generally, lower density causes lower strength. Increased percentage of the OPS can lower the density of concrete. Hence, it will give less compressive strength to the concrete.

## Conclusion

By substituting the OPS as coarse aggregate replacement on the concrete, it will effect to the wet properties condition on workability test and density criteria. The OPS replacement influences the workability of concrete and the performance of the concrete within cement and water to bond each other. The higher the percentage of OPS as coarse aggregate replacement, the lower the densities of concrete were obtained.

Based on the result obtained and analyzed from the Chapter 4, it was shown that the OPS replacement that were added into the concrete by percentage as coarse aggregate replacement, it can be summarized that the OPS content can affect the compressive strength of concrete. The higher the percentages of OPS replacement were added, the lower the strength of concrete will be produced. In conclusion, the strength of NWC with the final percentage of OPS replacement at age concrete, 28 days showed the highest difference. It was 96.6% and 88.5% differences of compressive strength for both w/c ratio at 0.45 and 0.50 as compared with 40% of OPS replacement.

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