International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 4 (2016) pp 2379-2383

Use of Oil Palm Shell as Replacement of Coarse Aggregate for Investigating Properties of Concrete

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Abstract-
In Malaysia, oil palm shell (OPS) is an agricultural solid waste originating from the palm oil industry. In this short-term investigation, old OPS is used for production of lightweight concrete. The density, workability, cube compressive strength and water absorption are measured. Laboratory curing condition is also employed. The test results show that with the increasing amounts of normal aggregates replaced by OPS, the overall density and strength of the lightweight concrete has reduced gradually. The compressive strength of lightweight concrete by combination with 10 % OPS and 90 % coarse aggregate is found to be similar with the normal lightweight concrete from 100% coarse aggregate. And with the increasing amounts of aggregates replaced by OPS, water absorption of the lightweight concrete has increased gradually. It is concluded that OPS concrete has sufficient strength to be accepted as structural lightweight concrete and that the trend of behaviour of OPS concrete and control concrete is very similar.

Keywords: light-weight concrete, Oil palm shell, compressive strength, agricultural solid waste.

Introduction

The concrete industry today is the largest consumer of limited natural resources, such as water, sand, gravel and crushed rock [4]. Construction by its very nature is not necessarily an environmentally-friendly activity, therefore, the best alternative to achieve sustainable development of the concrete industry is the use of waste and by-product materials instead of raw materials in the concrete mixture [9]. Due to the large production of palm oil, a lot of wastes are produced from the oil palm mills such as OPS (Oil Palm Shell) and EFB (Empty Fruit Branch). Malaysia being the largest palm oil producer in the world produced more than 4 million tonnes of OPS annually [5]. The processing of palm oil has produced the biomass such as empty fruit bunches (EFB), oil palm shells (OPS) and the list goes on. The recycling process of the OPS can reduce the residues impacts and provide a cleaner environment.

Concrete is an artificial material similar to stone that is used for many different structural purposes. The density of normal concrete is 2400 kg/m^3. Concrete with the ranges of 500 kg/m^3 to 2000 kg/m^3 can be considered as lightweight concrete (LWC). On the other hand, Lightweight Aggregate Concrete (LWAC), was made using natural aggregates of volcanic origin such as pumice, scoria, etc. Sumerians used this in building Babylon in the 3rd millennium B.C. Lightweight aggregate concretes are of various types, depending upon the composition of the mortar matrix and the aggregates used. The properties of the aggregates also vary significantly depending upon the raw materials used for making them and the technique adopted to produce them. Now a days, lightweight aggregates are produced in a very wide range of densities varying from 50 kg/m3 for expanded perlite to 1000 kg/m3 for clinkers. With these aggregates and high range water reducers, it is possible to make LWAC of 80 MPa 15 cm cube compressive strength [10]. LWAC also possesses excellent heat insulation properties. It is usually can be used as lightweight roof, false ceiling, lightweight partition walls. In a Previous study, concrete using OPS as coarse aggregate has been found useful as structural concrete with the density of 1850 kg/m^3 and compressive strength between 20 and 24 MPa for 28 days [2]. The use of LWAC is increasing and research and development are going on worldwide to develop high performance structural lightweight aggregate concrete [10]. The objectives of the research are to study the effectiveness in utilizing oil palm shell into practical material such as lightweight concrete which later can be used in construction purposes. This research will concentrate on significant material properties related with the workability and strength as well as the performance of the material when introduced as a lightweight concrete.

Methodology

This study focuses on the workability and compressive strength of lightweight concrete. Mix designs of the concrete with the different percentage of oil palm shells were developed. Slump test and compaction factor test was conducted to measure the workability of the mix designs. Upon preparation of the lightweight concrete samples, they were cured in water for different ages of 3, 7, 14 and 28 days. Compressive strength test was conducted to measure the strength of the lightweight concrete.

Materials

The materials used usually need to be placed in dry environment and air dry naturally. The detailed description of each material that were required for this study is discussed below:

Oil Palm Shell (OPS)

OPS were used to replace the coarse aggregate. They were collected from Palm oil mill owned by Sime Darby plantation Sdn Bhd. Old OPS were used which mean the OPS were discarded for more than 6 months at the palm oil mill area. The OPS were cleaned and soaked in water for one day. Then the OPS were air dried in the laboratory.

Cement

The bag cement used was a Malaysian ordinary Portland cement (OPC) with of 28 days strength of 52.5 MPa.

Sand

Local mining sand with a specific gravity of 2.64 was used as the fine aggregate.

Water

The water from pipeline in the laboratory was used for preparing concrete and curing purposes.

Water reducers (Super plasticisers)

Super plasticisers (Sikament-NN) was used in the concrete to improve the workability of the fresh OPS concrete. Sikament-NN is a high range water-reducing concrete admixture. It is a highly effective dual action liquid super plasticiser for the production of free flowing concrete or as a substantial water reducing agent for promoting high early and ultimate strength. Sikament-NN is chloride free and is compatible with all types of Portland Cement..

Sieve Analysis Test

Sieve analysis is a test which commonly used in civil engineering to classify soils. The standard sieve analysis test determines the relative propositions of different grains sizes and classified them into certain size ranges.

Concrete Mix Design

The mixture proportioning which is commonly called mix design. Mix design is a process to let engineer to select the suitable ingredients of the concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notably consistence, strength and durability.

In this study, old OPS were used in the concrete mix design because the old OPS which are without fibre will have higher workability and strength. The old OPS were washed and sieved. They were soaked in the water for 24 hours and air dried in the laboratory. Eight concretes were produced for each type of concrete mix proportions and were tested at ages of 3, 7, 14 and 28 days. Hence, total of 56 cubes were produced for the tests. Ordinary Portland (Type I) and the uncrushed aggregate (20 mm) were used in this study. The specific gravity of the aggregate is 2.64.

TABLE 1: Mix Proportions in kg/m^3

Mix No.	Content kg/m^3				
	OPS	OPC	Water	Fine Aggregate	Coarse Aggregate
1(0%)	0.00	400	180	582.4	1237.60
2(10%)	123.76	400	180	582.4	1113.84
3(15%)	185.64	400	180	582.4	1051.96
4(20%)	247.52	400	180	582.4	990.08
5(25%)	309.40	400	180	582.4	928.20
6(30%)	371.28	400	180	582.4	866.32
7(40%)	495.04	400	180	582.4	742.56

Slump Test

Slump is a measurement of consistency. The slump is the distance between a 12-inches (300mm) truncated cone of concrete and the slump down when the moulding cone is removed. Slump test is a test used extensively in site work all over the world. The slump test measure the workability of fresh concrete. It is also a laboratory test that used to determine the hard and consistent of a sample of concrete before curing. It is also a method of quality control. For particular mix, the slump should be consistent.

Compaction Factor Test

There is no generally accepted method of directly measuring the workability. The degree of compaction, called the compacting factor, is measured by the density ratio. The ratio of the density actually achieved in the test to the density of the same concrete fully compacted. These tests were developed in the UK by Glanville in 1947. And it is measuring the degree of compaction. For the standard amount of work and thus offer a direct and reasonably reliable assessment of the workability of concrete. The test requires measurement of the weight of the partially and fully compacted concrete and the ratio the partially compacted weight to the fully compacted weight which is always less than one which is known as compacted factor. For the normal range of concrete the compacting factor should between 0.8-0.92.

Rebound Hammer Test

Rebound hammer also named as Schmidt hammer which is normally used for testing the quality of hardened concrete in a structure. The rebound hammer can provide a fairly accurate estimate of concrete compressive strength. It is a non-destructive and hand held testing device. It can be used on the finished concrete structures but strict procedures must be followed. In this study, the tests were conducted at the age of 3, 7, 14 and 28 days under full water curing.

Compressive Strength Test

By far the most common method of determining the strength of concrete is to test in simple compression. The strength is the maximum stress sustained. With the results that obtained from the compression machine, the concrete can be classified after calculating the value of compressive strength. In this study, the compressive strength tests were conducted at the age of 3, 7, 14 and 28 days under full water curing.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 4 (2016) pp 2379-2383

Density Test

The density of concrete is involving for numerous reasons including its effect on durability, strength and resistance to permeability. After curing for the specified number of days, the concrete was removed from the curing tank and wiped dry with a cloth to get rid of the excess curing water on the surface of the concrete. After drying the concrete, it was weighed with weighing machine. The density (kg/m^3) was calculated by formula-

$$\text{Density} = \frac{\text{Weight of concrete}}{\text{Volume of concrete}}$$

Water Absorption Test

The volume of pore space in concrete which a fluid such as water, carbon dioxide and oxygen which can penetrate the concrete. Water absorption test was used to measure the quality of concrete. Water absorption test was done to determine the percentage of water absorption of the concrete by drying the concrete, immersing the concrete in the water and measuring the increase in mass of the concrete. The best concrete will has absorption of below 10 % by mass.

Results & discussion

Sieve Analysis

Table 2 below shows the sieve analysis overall calculation sheet which comprises of percentage passing and percentage coarser.

TABLE 2: Calculation of OPS

Sieve No	Sieve Size	Weight Retained (g)	Weight Passing (g)	Percentage Passing (%)	Percentage Coarser (%)
1	10mm	148	352	70.4	29.6
2	5mm	329	23	4.6	95.4
3	2.36mm	19	4	0.8	99.2
4	1.18mm	2	2	0.4	99.6
5	0.6mm	1	1	0.2	99.8
6	0.3mm	0	1	0.2	99.8
7	0.15mm	1	0	0.0	100
8	0.075mm	0	0	0.0	100
9	PAN	0	0	0.0	100

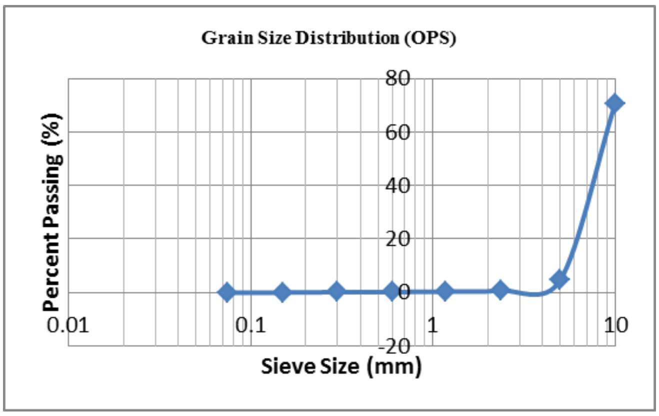

Fig.1: Grain Size Distribution for OPS

By comparing Fig. 1 and Fig. 2, both OPS aggregate were looked similar. Hence, it can be used to replace the coarse aggregate. It is difficult to find the exact size between 12.5 mm to 20 mm. The OPS were crushed by the supplier to make the process easier.

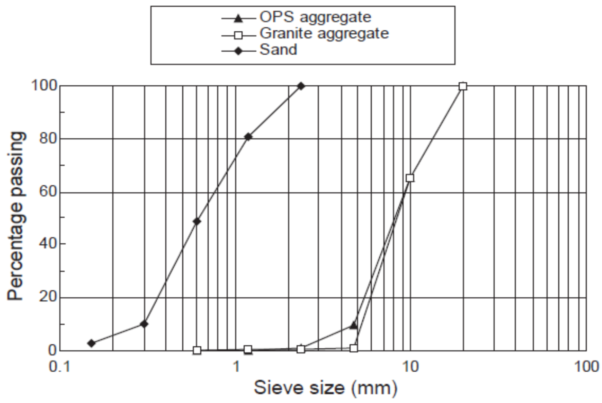

Fig.2: Gradation of OPS [3]

Slump Test

The slumps for the concretes ranged from 90.0 mm to 172.0 mm. The 10 % to 30 % slumps can be categorised as high workability because they are in between of 140.5 mm to 172.0mm. The mix with 40 % can be categorised as medium workability. From the results, the slumps decrease when the percentage of OPS replacement with the coarse aggregate is increased.

TABLE 3: Slump Test for different percentage of OPS

Oil Palm Shells (OPS)	Coarse Aggregate	SLUMP (mm)		
		1	2	Average
0 %	100%	165	170	167.5
10 %	90%	165	160	162.5
15 %	85 %	153	152	152.5
20 %	80 %	170	174	172.0
25 %	75 %	130	155	142.5
30 %	70 %	140	141	140.5
40 %	60 %	85	95	90.0

Compaction Factor

The compaction factor of the OPS concrete ranged from 0.874 to 0.862. For the normal range of concrete the compaction factor lies between 0.8 to 0.92. This test is particularly useful for dryer mixes for which the slump test is not satisfactory. The sensitivity of the compaction factor is reduced outside the normal range of workability and is generally unsatisfactory for compacting factor greater than 0.92.This is a site test to determine the consistency or self-compaction of the ready mixed concrete and is conducted by the supervisor on site. Nowadays, this test is commonly replaced by the slump test to determine the workability of the ready mixed concrete. The compaction factor test's result is ranged from 0.874 to 0.862 which can be considered as category of medium workability

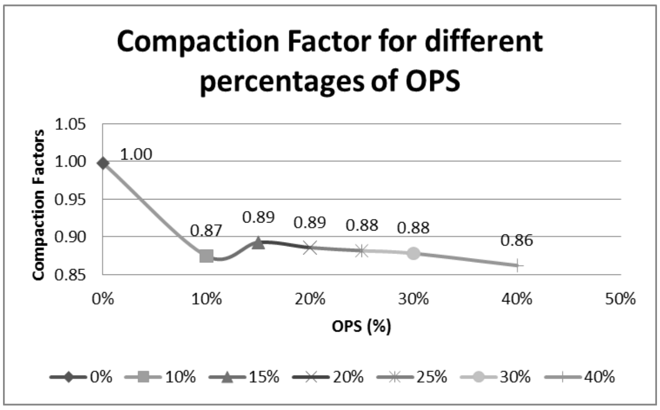

Fig. 3: Compaction factor for different OPS(%)

The rebound number of the OPS concrete ranged from 23.400 unit to 29.133 unit shown in Fig. 4. The rebound number is not that accurate due to the different point to test the strength. The rebound hammer may hit the aggregate which is strong enough and show higher rebound number.

Rebound Hammer Test Result

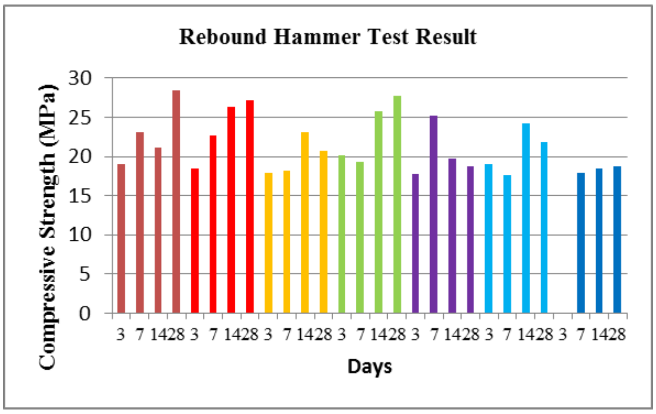

Fig. 4: Compressive Strength (Rebound Number)

The rebound hammer is good to test the concrete without destroying it like compressive strength machine. The quality of the OPS concrete produced is of fair quality according to Table 4.

TABLE 4: Quality of concrete from rebound values [11]

Average Rebound (Unit)	Quality of Concrete
> 40	Very good
30-40	Good
20-30	Fair
< 20	Poor and /or delaminated
0	Very poor and/ or delaminated

Compressive Strength

In Fig. 5 and Fig. 6, it can be observed that all the concretes were still gaining strength until 28 days. The concrete with 10% OPS replacement exhibited the best strength which is over 30 MPa and only 4.45 MPa lesser than the control.

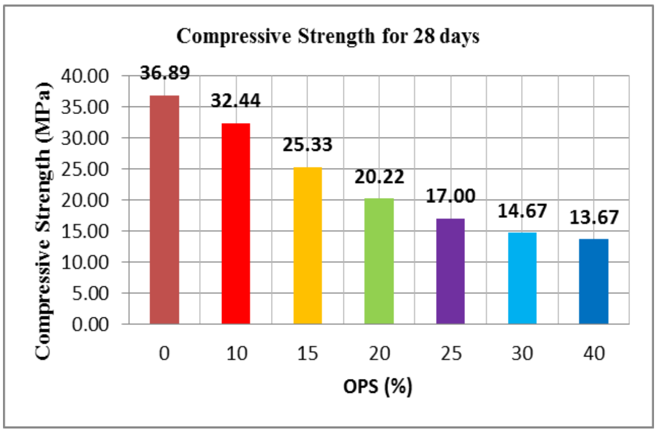

Fig. 5: Compressive Strength for 28 days

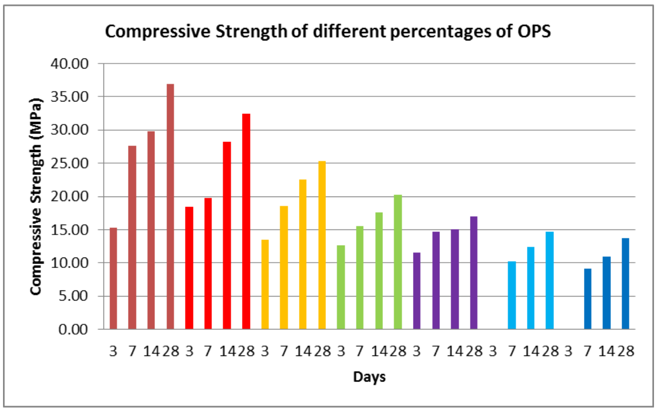

Fig. 6: Compressive Strengths for all OPS replacement

In Fig. 6, Compressive strengths shown for different ages of 3, 7, 14 and 28 days. Each four bars show one category i.e 0% OPS, 10% OPS etc. The highest found in the 0 % OPS coarse aggregate (Control), the average compressive strength is 36.89 MPa and the highest achievement is 39.56 MPa. For the replacement of coarse aggregate with OPS, the highest compressive strength is 28 days with 10 % OPS which is 32.44 MPa. The highest achievement is 35.11 MPa. That is quite above the requirement for structural lightweight concrete. According to the specification [1], the minimum compressive strength in structural lightweight concrete for 28 days is 17.0 MPa. Using Oil Palm Shell (OPS) as Lightweight Aggregate, the compressive strength of OPS concrete was 28.1 MPa at an age of 28 days [12].

Density Test

Fig. 7 shows the densities of the different percentages of OPS were ranged from 1908.15 kg/m^3 to 2229.63 kg/m^3. The densities are not more than 2400 kg/m^3. It means that they can be considered as lightweight aggregate concretes.

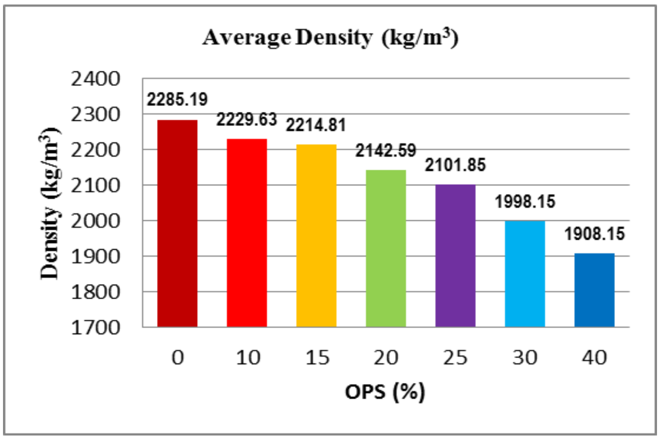

Fig. 7: Average Density of the different percentage of OPS

Fresh concrete densities of OPS concrete revealed in [6] investigation were within 1753-1763 kg/m^3 depending upon the mix proportions and w/c ratios In another study [7], it was found that the saturated densities of OPS concrete obtained were in the range of 1845-1915 kg/m^3 depending upon the dosage of superplasticizer and w/c ratios.

Water Absorption Test

In Fig. 8, the water absorption of the concretes ranged from 1.49 % to 4.57 %. The water absorption is increased when the percentage of OPS replacement was increased. According to study conducted [8], in OPS as a lightweight aggregate, for production high strength lightweight concrete, water absorption of OPS high-strength concrete varies from 3.1 % to 6.2 % which is in the range of good concrete. The results presented in Fig. 8 within the range of a good concrete.

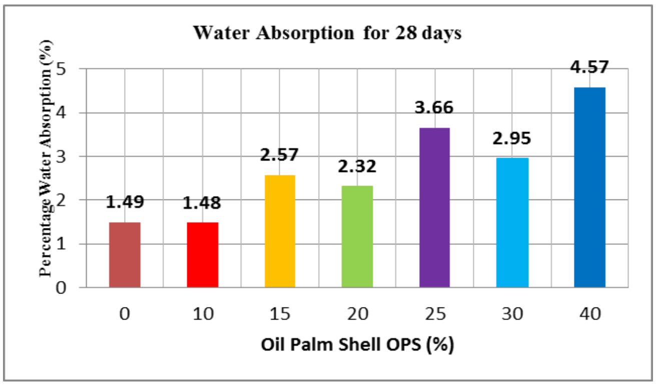

Fig. 8: Water absorption for 28 days with different percentage of OPS

Conclusion

With the analysis in previous sections, some conclusions can be made on the basis of the current experimental results. First of all, with the increasing amounts of normal aggregates replaced by OPS, the overall density and strength of the lightweight concrete reduces gradually. Secondly, the compressive strength of lightweight concrete with 10 % OPS and 90 % coarse aggregate shows the compressive strength that not much different from control concrete. Third, with the increasing amounts of aggregates replaced by OPS, water absorption of the lightweight concrete increases gradually. Overall, it can be concluded that, the use of OPS is a suitable alternative to the conventional building materials. The use of OPS in concrete can help to overcome the over dependence on the natural resources such as coarse aggregates.

Acknowledgements

The authors express sincere thanks to the authorities of INTI International University and Linton University College, Malaysia for their encouragement and supports.

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