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Research Article

Structural Lightweight Concrete Production by Using Oil Palm Shell

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Conventional building materials are widely used in a developing country like Malaysia. This type of material is costly. Oil palm shell (OPS) is a type of farming solid waste in the tropical region. This paper aims to investigate strength characteristics and cost analysis of concrete produced using the gradation of OPS 0–50% on conventional coarse aggregate with the mix proportions 1 : 1.65 : 2.45, 1 : 2.5 : 3.3, and 1 : 3.3 : 4.2 by the weight of ordinary Portland cement, river sand, crushed stone, and OPS as a substitution for coarse aggregate. The corresponding w/c ratios were used: 0.45, 0.6, and 0.75, respectively, for the defined mix proportions. Test results indicate that compressive strength of concrete decreased as the percentage of the OPS increased in each mix ratio. Other properties of OPS concrete, namely, modulus of rupture, modulus of elasticity, splitting tensile strength, and density, were also determined and compared to the corresponding properties of conventional concrete. Economic analysis also indicates possible cost reduction of up to 15% due to the use of OPS as coarse aggregate. Finally, it is concluded that the use of OPS has great potential in the production of structural lightweight concrete.

1. Introduction

Malaysia is well known as one of the world's largest producers and exporters of palm oil. Palm kernel shells are a product of oil palm tree which are available in Malaysia in large quantity. Presently, 4.49 million hectares of land in Malaysia is under oil palm cultivation, producing over 17.73 million tonnes of palm oil and 2.13 tonnes of palm kernel oil annually, accounting for the biggest share of the global export market to date and yielding nearly about 18.9 tonnes/hectare of fresh fruit bunch (FFB) [1]. In the process of manufacturing oil palm, solid residues and liquid wastes are generated in the oil palm industry. These include empty fruit bunch (EFB), OPS, pericarp, and palm oil mill effluent (POME). Palm oil mills have different processing capacities of oil palm fresh fruit bunch (FFB) ranging from 20 to 90 tonnes per hour [2]. In Malaysia, there is an annual production of over 4 million tonnes of oil palm shell solid wastes [3, 4].

OPS are not commonly used in the construction industry but are often damped as agricultural wastes [5]. However, with the quest for affordable housing system for both the rural and urban populations of Malaysia and other developing countries, various proposals focusing on cutting down conventional building material costs have been considered. In countries where abundant agricultural wastes are discharged, these wastes can be used as potential material or replacement material in construction industry [6, 7]. One such alternative is OPS which, produced in abundance, has the potential to be used as substitute coarse aggregate in concrete [8]. The huge amount of oil palm solid waste produced in the factories is mainly incinerated by the conventional process and it adds air pollution [9]. Thus, these residues are becoming expensive to dispose by satisfying the requirements of environmental regulations. In such a situation, efforts are going on to improve the use of these by-products through the development of value-added products. One of the ways of disposing these

wastes would be the utilization of palm shell into constructive building materials.

Recently, some researches [3, 4, 7] have been carried out to utilize these disposed palm shell wastes in manufacturing lightweight concrete. OPS are the hard stony endocarp but are lightweight and naturally sized. Due to the stiff surfaces of organic origin, they will not contaminate or leach to produce toxic substances once they bound in the concrete matrix. In addition, OPS are lighter than the conventional coarse aggregate so the resulting concrete will be lightweight [10]. OPS replacement coarse aggregate is able to attain the strength of more than 17 MPa [3, 4], which is a requirement for structural lightweight concrete as per ASTM [11]. More recently, OPS concrete compressive strength has obtained more than 25 MPa [3, 4, 12]. The bulk density of OPS is in the range of 500–600 kg/m^3 [13, 14]. It was observed that partial replacement OPS concrete density varies in the range of 1700 to 2185 kg/m^3. Therefore, it can be used as a good replacement of coarse aggregate to produce structural lightweight concrete.

This paper represents the result of an investigation carried out on the comparative cost analysis and strength characteristics of concrete using the different proportions of palm shells as substitutes for conventional coarse aggregate. The properties of OPS are also compared with conventional concrete. The main objective is to encourage the use of these "seemingly" waste products as construction materials in low-cost housing and where crushed stones are costly for producing lightweight concrete.

2. Materials Investigations

2.1. Materials

2.1.1. Oil Palm Shells. OPS were collected from a local palm oil mill at RH Lundu Palm Oil Mill, Kuching. It was obtained after the oil extraction in the factory from the fresh fruit bunch. The shells were then washed and air-dried for some days under ambient temperature and later graded in accordance with the ASTM [11]. The OPS particle size generally ranges between 5 and 12.5 mm.

2.1.2. Aggregates. The coarse aggregate form crushed granite was collected from igneous origin. The particle size used ranges between 5 and 20 mm. River sand as fine aggregate was used to mix the concrete. All particles were passed through ASTM sieve number 4 aperture 4.75 mm but retained on sieve 5 number 230, aperture 63 μm.

2.1.3. Cement and Water. Malaysian ordinary Portland cement type whose properties conform with the requirement of ASTM type I was used with the content of 480 kg/m^3 and the water was collected from the laboratory stand post. The physical properties of OPS and crushed granite aggregate are illustrated in Table 1.

2.2. Mix Proportions. To achieve a 28-day design strength of concrete cube, three mix proportions of 1 : 1.65 : 2.45, 1 : 2.5 : 3.3, and 1 : 3.3 : 4.2 by the weight of ordinary Portland cement, river sand, crushed stone, and OPS as a substitution for coarse aggregate were used to cast the specimens. The corresponding water/cement ratio was 0.45, 0.6, and 0.75, respectively. For each mix, the water/cement ratio was maintained constant at all percentage replacements of crushed stone with OPS aggregate.

3. Experimental Procedure

3.1. Preparation of the Test Samples. Concrete cubes sizes of 150 × 150 × 150 mm, cylinders of 150 mm in diameter and 300 mm in height, and beams having dimension of 100 × 100 × 500 mm were casted for the determination of different properties of OPS concrete. Batching was by weight and mixing was performed manually in a flat plate. In each mix proportions as mentioned above, oil palm shell is substituted for gravel in the gradation of 0–50%. Hence, a total of 96 samples were casted in the laboratory for different testing. In preparing the specimens, at first, sand and cement were properly mixed with trowel and then oil palm shells and crushed stones were added. All the constituent materials were mixed together with the help of shovel. Water was added at interval after the cement and the aggregates had been mixed thoroughly.

Fresh concrete workability was investigated immediately after the final mixing of the concrete using slump test. The cubes and cylinders were cast by filling each mould in three layers; each layer had been compacted normally with 25 blows from a steel rod of 16 mm diameter before the next layer was poured. Each prism was applied a hundred and fifty strokes per layer distributed along the whole length of the prisms. Slump values achieved 62 mm at 0% replacement level (normal weight concrete) for mix proportion 1 : 1.65 : 2.45, 48 mm for mix proportion 1 : 2.5 : 3.3, and 42 mm for 1 : 3.3 : 4.2, representing high and medium workability. These values decreased gradually as the percentage of OPS substitution increased in the mix. All specimens were left in the moulds for 24 h to set under ambient temperature. They were removed from the mould and transferred into a curing tank that contained clean water. The curing temperature was 30±2°C. The concrete mixes and the specimens were prepared in accordance with the provisions of ASTM and BS standards [15–18].

3.2. Tests Applied to the Samples. The cubes and cylinders were tested on 2000 kN capacity Electronic Compression Machine using a loading rate of 6 kN/sec and 4.42 kN/sec, respectively, in 7 and 28 days. The average value of the load at which the group rate of three tested cubes for each mix failed was calculated and finally used to determine the compressive strength. A third point bending test was conducted for a simply supported beam over an effective span of 300 mm using a loading rate of 4.42 kN/sec. The maximum mean value of the load at which the beams failed was used to determine the flexural strength for each percentage of oil palm shells in the mix. Compressometer-extensometer (mechanical strain gauge) with the accuracy of $\pm 2 \times 10^{-3}$ was

Table 1: Properties of OPS and crushed stone aggregate.

Properties	Palm shell aggregate	Crushed stone aggregate
Specific gravity	1.21	2.72
Bulk density (Kg/m^3)	572	1445
Los Angles abrasion value, %	5.1	24.5
Water absorption for 24 h (%)	25.64	0.7
Aggregate crushing value	6.78	17.92
Aggregate impact value	6.65	12.32
Fineness modulus	6.24	6.76
Shell thickness, mm	0.5–4.0	5–20
Maximum aggregate size, mm	12.5	20

Table 2: Modulus of elasticity of 0%, 10%, 15%, and 25% OPS replacement concrete.

	Modulus of elasticity (N/mm^2)			
Mix proportions	0% replacement	10% replacement	15% replacement	20% replacement
1 : 1.65 : 2.45	28350	20338	16350	12343
1 : 2.5 : 3.3	23850	18478	15800	11982
1 : 3.3 : 4.2	22100	17122	14620	11238

used to measure the modulus of elasticity of normal weight and OPS substitute concrete under the controlled laboratory conditions. In addition, the modulus of elasticity, splitting tensile strength, and flexural strength tests were done at 28 days.

4. Results and Discussion

4.1. Density of Concrete. 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 1. To begin with, at the replacement level of 0% of OPS substitution, the density of the concrete was 2360 kg/m^3, 2255 kg/m^3, and 2232 kg/m^3 for the mix proportions 1 : 1.65 : 2.45, 1 : 2.5 : 3.3, and 1 : 3.3 : 4.2, respectively. At 10%, 15%, and 40% levels of OPS substitution, the density has decreased, respectively, to 2180 kg/m^3, 2092 kg/m^3, and 1785 kg/m^3 for the mix ratio 1 : 1.65 : 2.45; in contrast at the same percentage replacement of OPS the density has substantially decreased to 2160 kg/m^3, 2078 kg/m^3, and 1760 kg/m^3 for the mix ratio 1 : 2.5 : 3.3 and 2116 kg/m^3, 2012 kg/m^3, and 1708 kg/m^3 for 1 : 3.3 : 4.2. Lightweight concrete has a density in the range of 300–1850 kg/m^3 [19]. This density was obtained in the range of lightweight concrete when 40% and 50% of the OPS were used to replace crushed stone as coarse aggregates for the above mentioned mix ratios. However, at 15% level of OPS substitution, the density is still slightly higher than what is normally considered for lightweight concrete. Nevertheless, it can be used to fulfill the requirement of lightweight concrete strength.

4.2. Modulus of Elasticity. According to the experimental results (refer to Table 2), it is observed that the modulus of elasticity of 15% OPS substituted concrete is approximately half of that of conventional concrete for the mix ratios 1 : 1.65 : 2.45, 1 : 2.5 : 3.3, and 1 : 3.3 : 4.2, respectively. This is mainly attributed to the less stiffness value of OPS aggregate compared to gravel. The development of E values of concrete is influenced by the type of coarse aggregate, type of cement, w/c ratio of the mix, aggregate size, and curing age [20]. Generally the modulus of elasticity of concrete depends on the stiffness of coarse aggregate. Also, the interfacial zone between the aggregates and paste and the elastic properties of component materials influence the modulus of elasticity of concrete. It is also observed from Table 2 that modulus of elasticity of concrete is gradually decreased with higher OPS mix proportions and substitution.

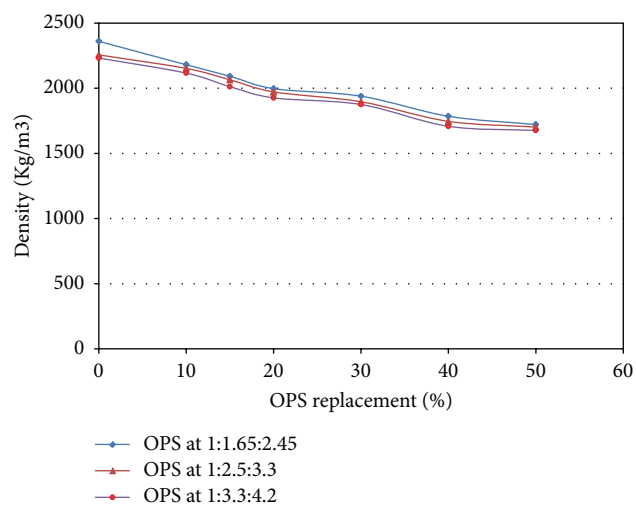

Figure 1: Density of OPS at three mix ratios.

4.3. Compressive Strength. It was observed from the test results (refer to Figures 2, 3, and 4) that the compressive

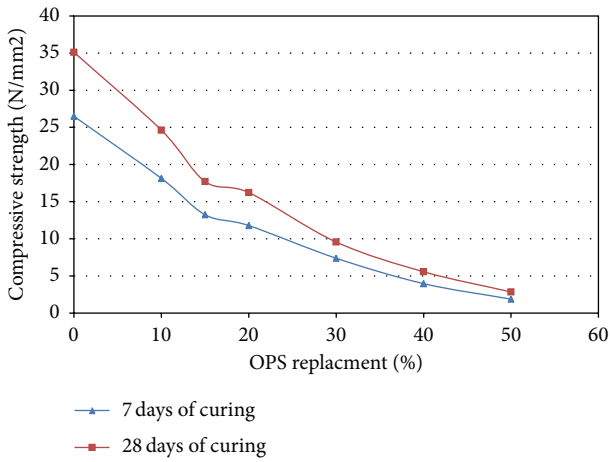

Figure 2: Compressive strength of OPS (1 : 1.65 : 2.45).

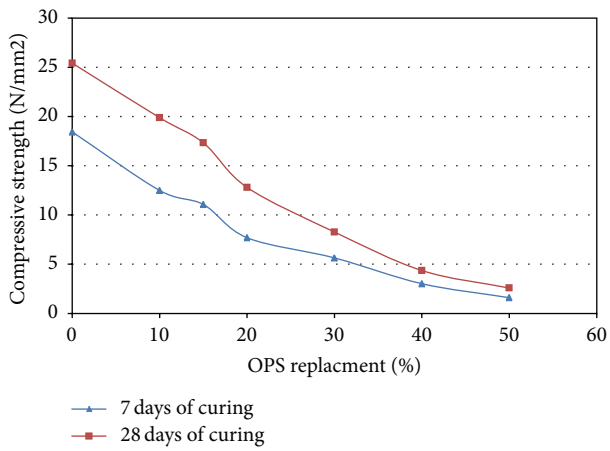

Figure 3: Compressive strength of OPS (1 : 2.5 : 3.3).

strength decreased gradually due to the increase of OPS percentage in conventional concrete. The three mix proportions considered in this paper showed the same pattern for this decrease in strength. The conventional concrete with 0% OPS has the highest compressive strength values for all the mix ratios. For the mix proportion 1 : 1.65 : 2.45, OPS replacement (0–50%) exhibited a higher compressive strength compared to the other two mix proportions as shown in Figures 5 and 6. From the results, it is identified that lightweight concrete design strength can be achieved if the percentage replacement levels of OPS do not exceed 15% for the mix proportions considered in this paper.

It is concluded that the concrete strength depends on the strength, stiffness, and density of coarse aggregates. Generally, lower density causes lower strength. Increased percentage of OPS lower the density of concrete, hence, giving less compressive strength.

4.4. Flexural Strength. The result has shown that the flexural strength of concrete decreased as the percentage of OPS increased in the mix proportions. Figures 7 and 8 show these strength variations for 7 days and 28 days, respectively.

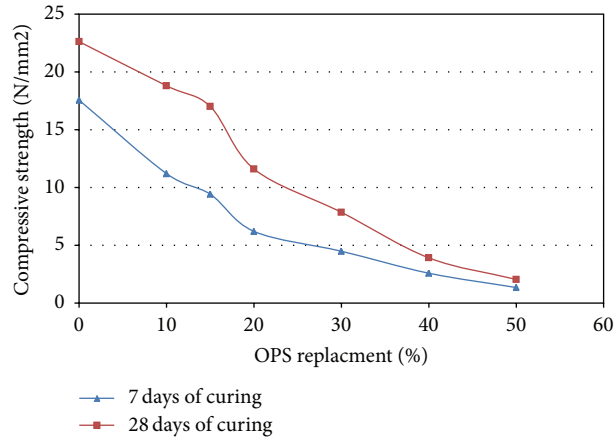

Figure 4: Compressive strength of OPS (1 : 3.3 : 4.2).

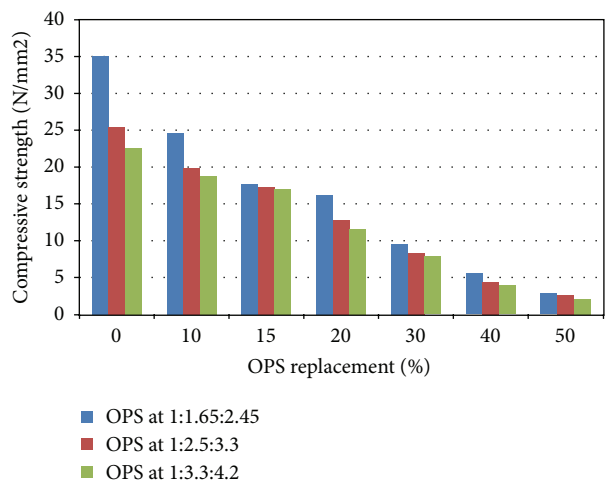

Figure 5: Comparison of compressive strength of OPS at 28 days of curing (1 : 2.5 : 3.3).

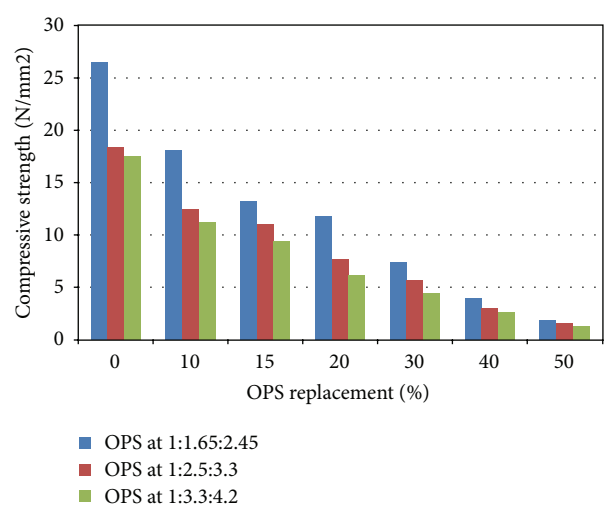

Figure 6: Comparison of compressive strength of OPS at 7 days of curing.

Table 3: Splitting tensile strength of 0%, 10%, 15%, and 20% OPS replacement concrete.

	Splitting tensile strength (N/mm^2)			
Mix proportions	0% replacement	10% replacement	15% replacement	20% replacement
1 : 1.65 : 2.45	2.96	2.50	2.30	2.07
1 : 2.5 : 3.3	2.82	2.36	2.18	1.94
1 : 3.3 : 4.2	2.58	2.14	1.96	1.73

Table 4: Crushed stone and OPS substitute per cubic meter concrete cost (Malaysian ringgit: RM)*.

Concrete category	Mix proportions		
	1 : 1.65 : 2.45	1 : 2.5 : 3.3	1 : 3.3 : 4.2
Crushed stone concrete	272	256	238
OPS concrete (15% replacement)	236	228	216

*1$ (US) = RM 3.00 (approximatelyin February, 2014).

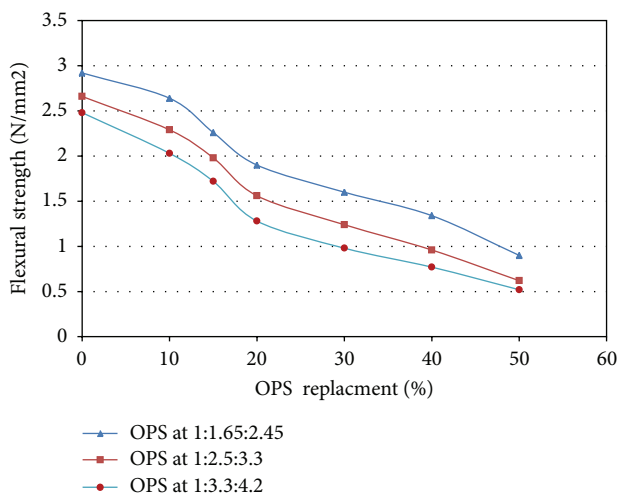

Figure 7: Comparison of flexural strength of OPS at 7 days of curing.

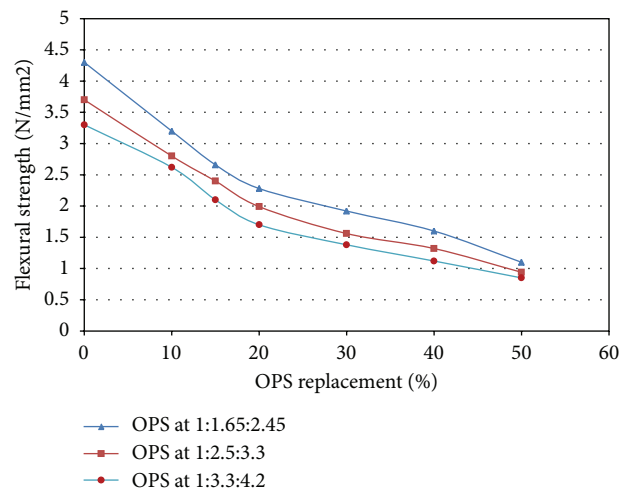

Figure 8: Comparison of flexural strength of OPS at 28 days of curing.

For the mix proportion 1 : 1.65 : 2.45, the strengths obtained at 7 days and 28 days were 2.92 N/mm^2 and 4.3 N/mm^2, respectively. The corresponding values at 50% replacement of OPS are 0.9 N/mm^2 and 1.1 N/mm^2. The other two mix proportions show the same trend for the strength decrease due to the increase of OPS percentage in concrete. In all cases, the 15% replacement of OPS gave a satisfactory strength for the flexural strength of concrete.

4.5. Splitting Tensile Strength. Table 3 shows the splitting tensile strength test result for 0%, 10%, 15%, and 20% OPS substituted concrete. Splitting tensile strength of 15% OPS substituted concrete is approximately 12% of its compressive strength at 28 days, whereas for conventional concrete the splitting tensile strength is nearly about 10%. It is observed from Table 3 that the splitting tensile strength of OPS replacement concrete decreased due to the higher OPS substitution and mix proportions of concrete.

4.6. Cost Investigation. Cost analysis result of OPS substitution per cubic meter concrete cost production is shown in Table 4. The result indicates that 15%, 12%, and 10% cost reduction could be achieved with the 15% OPS substitution for coarse aggregate in the mix ratios 1 : 1.65 : 2.45, 1 : 2.5 : 3.3, and 1 : 3.3 : 4.2, respectively. Thus, concrete that partially replaces aggregate with OPS is considered suitable for low-cost housing construction.

5. Conclusions and Recommendation

The following observations and conclusions can be made on the basis of the current experimental results.

(i) In all cases, the compressive strength of the concrete decreased as the percentage of OPS substitution increased in the mix.

(ii) Concrete compressive strengths with the 15% OPS substitution are between 17.01 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.

(iii) Splitting tensile strength of 15% OPS substitute concrete is an average 2.15 N/mm^2 at 28 days which is approximately 12% of its compressive strength. This strength is considered satisfactory for the lightweight concrete.

(iv) The 28-day modulus of elasticity of 15% OPS substituting concrete varies from 14620 to 16350 N/mm^2 for the mix proportions considered in this paper. These values are on average less than 50% of the corresponding value of conventional concrete.

(v) Flexural strength of 15% OPS substitute concrete is on average 2.4 N/mm^2 at 28 days which is approximately 14% of its compressive strength. On the other hand, the flexural strength of conventional concrete is nearly about 13% of its compressive strength.

(vi) The cost reduction was 15%, 12%, and 10% with the substitution of 15% OPS as coarse aggregates in concrete for the mix ratios 1 : 1.65 : 2.45, 1 : 2.5 : 3.3, and 1 : 3.3 : 4.2, respectively. OPS concrete appears to be cheaper compared to the conventional aggregate concrete. It is concluded that OPS has the potential to be used as substitute coarse aggregate in the production of low-cost lightweight concrete.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

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