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The Influence of Mix Design on Mechanical Properties of Oil Palm Shell Lightweight Concrete

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Abstract
This paper presents part of the experimental results of an in-progress research project to fabricate structural lightweight concrete using solid waste, Oil Palm Shell (OPS) as a coarse aggregate. The utilization OPS as lightweight aggregate in concrete especially in the structure application has been proven by previous researches. As an industrial waste product, Oil Palm Shell OPS may be the alternative material to be employed in the construction industry. This study will focus on the potential of OPS as lightweight aggregate with regard to the optimum content of OPS for strength development. A total of 15 mixes were prepared and tested with 3 different cement/sand ratios (1.7, 1.8, 1.9) and 5 different cement contents (300, 350, 400, 450, 500 kg/m³). The result of this study show that the compressive strength for all mix achieve the requirement for load bearing strength, the strength significantly improve with cement volume increased. Sand ratio showed, the highest sand used will produced good workability.

Keywords: oil-palm shell, concrete, compressive strength, load bearing, workability

Introduction
The use of concrete as building material is constantly in high demand. Good durability and workability of concrete makes it suitable for construction industry players. However, the high density of concrete will result in increase of dead load on building structures because of high usage of steel reinforced. The use of lightweight aggregate in concrete is an option to decrease the dead load on a building, particularly for high-rise buildings. Normally pumice and perlite are used as lightweight aggregate to produce lightweight aggregate concrete and both materials can be found at volcanic area [1]. However, it has not brought much advantage to countries which do not have volcanic environment. The alternative is to use industrial waste material as aggregates for construction. One of the solid waste products that have increasingly gained researchers' interest is oil palm shell produced from the processing of oil palm. Oil palm industry is a fast-growing industry and economically it is able to become the backbone of the economy.
This industry also produces other waste from palm oil processing but, such as fruits, trunks and leaves of palm tree that can be effectively utilized for producing valuable products. For instance approximately 19 million tonnes of crop residues (empty fruit bunch, fibre and shell) were produced per year [2].
It was estimated that over 4.56 million tonnes of oil palm shell are produced annually and that the amount of oil palm shell increases every year because there are more than 270 palm oil mills operating in this country to generate the waste [3]. The growing need for sustainable development has motivated researchers to focus their research on the use of waste or recycled materials in potential construction material. There are a number of studies related to OPS lightweight aggregate concrete especially for lightweight structure. The highest 28 day compressive strength produce by OPS is 53 MPa [4]. They used cement content in the range of 500-550 kg/m³ and 333 kg/m³ OPS. Some study added cementitious materials such as fly ash (5%) and silica fume (10%) to enhance the compressive strength [5]. In order to improve the strength of OPS, pre treatment using 20% poly (vinyl alcohol) which will increase the aggregate impact value increase 13.2% compared untreated OPS [6]. This paper will focus on experimental verification of mechanical properties of concrete using solid waste, oil palm shell (OPS) as a coarse aggregate.

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2. Material and Method

2.1 Materials

In this study, the materials used are ordinary Portland Cement SEM 1 with specific gravity of 3.10 Type I, local river sand with specific gravity, fineness modulus, water absorption and maximum grain size of 2.67, 2.28, 0.98% and 2.36 mm, respectively. OPS are used as course aggregate and the shells have been left outside the laboratory for 6 months to expose them to natural environment because there might be fibre and oil coating on the surface of fresh OPS. After the exposure, most of the fibres are removed from surface thus reducing the oil coating and other impurities present on the shells. Finally, OPS aggregate were rinsed with potable water to remove the detergent and then dried before being stored in containers. The OPS used has specific gravity, water absorption (24 hour), maximum grain, aggregate impact value and aggregate crushed value of 1.19, 22.1%, 14mm, 3.3% and 2.62% respectively. The OPS need be absorbed in water for 1 hour and left to saturated dry condition before it can be used and thermal conductivity of OPS are 0.137 W/mC.

2.2 Mixtures

In the experiment, there are 15 mixes with different cement contents (300, 350, 400, 450 and 500 kg/m³) and different sand ratios (1.7, 1.8 and 1.9). For lightweight concrete, the amount of cement content specified is in the range of 285–510 kg/m³ [7]. The mixture proportion is shown in Table 1. Effective water-cement ratio used 0.4 as suggested by previous researchers [4] and it is constant in all mixture. The mix proportioning was based on the absolute volume. The unit weight of the concrete increased as a result of the increase of cement content used. The OPS was kept in water for 1 hour so that the OPS can absorb water and the effective water/cement ratio is not affected.

In order to enhance the workability of the mixture, 1.5% of cement weight was used in all mixture. All mixes were prepared in a laboratory mixer with vertical rotation axis by forced mixing. Precautions were taken to ensure it is homogeneous and fully compacted.

All specimens were kept in their moulds for 24 hours. After demould, they were stored in a water tank until the age of 28 days. At this age, the specimens were taken out of the curing tank and kept in laboratory condition (50% RH at 20°C) until testing day.

The specimens were tested based on the following testing standard:

i. Density: Test is carried out according to the BS EN 12390-7:2009, the specimens are weighted in air and suspended in water, as they removed from the curing or exposure conditions.

ii. Compressive Strength: Test is done in accordance to BS 12390-3:2009, and 3 cube was tested for each test.

iii. Ultrasonic pulse velocity was measured according to BS EN 12504-4:2004

3. Result and Discussion

The results obtained on mix design are shown in Table 1. They are also displayed to some extent in graphical form (figures) and further discussed.

Table 1. Mix Proportion

Mix Order	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Sand Ratio	1.7	1.8	1.9	1.7	1.8	1.9	1.7	1.8	1.9	1.7	1.8	1.9	1.7	1.8	1.9
Cement (kg/m³)	300	300	300	350	350	350	400	400	400	450	450	450	500	500	500
Sand (kg/m³)	516	539	570	595	630	666	679	721	760	764	811	854	850	899	951
OPS (kg/m³)	699	692	678	623	609	592	544	525	508	463	441	423	375	360	335
Water (kg/m³)	124	124	124	140	140	140	160	160	160	180	180	180	200	200	200
Sp (kg/m³)	4.5	4.5	4.5	5.25	5.25	5.25	6	6	6	6.75	6.75	6.75	7.5	7.5	7.5
Workability (mm)	collapse	5	10	10	15	15	15	20	20	25	25	30	35	40	50
OPS % (kg/m³)	42.59	41.92	40.65	36.48	35.22	33.87	30.49	29.05	27.79	24.76	23.44	22.17	19.69	18.37	16.88

3.1 Workability

As can be seen in Table 1, the mix design result showed the workability of fresh concrete. Bond between aggregate and mortar phase are significantly affected by physical properties and the volume of OPS. This study used the lowest sand ratio (1.7) because it is the minimum amount based on absolute volume design for cement content as low as 300 kg/m³. Mix T1, T2 and T3 with 1.7, 1.8 and 1.9 sand ratios with cement content of 300 kg/m³ show collapse and low workability. A lot of honeycomb is present on cube surface produced from this mix proportion. The bond between aggregate and mortar is very weak because the volume of OPS is high. Therefore mix proportion with cement content of 300 kg/m³ is not acceptable. The workability increased with increased cement content and high sand ratio.

All mixes, except for mix T15, showed low or poor workability. The mix T15 mixes had the highest slump value of greater than 40mm. Although mix T15 had same water/cement ratio with all mix, by using a higher amount of super plasticizer and coarser fine aggregate,.1.9 (for reduction of total surface area) than other mix, a only medium workability was achieved. Nevertheless, other mix slump values were significantly lower than T15 mix. Lower cement content and sand ratio is lower due to higher amount of OPS.

Based on the results in Table 1, significantly shows that the mix that used sand ratio of 1.9 will produce better workability compared to those with ratio1.7 and 1.8. the addition of super plasticizer about 1.5 % from cement content has also increased workability, further increasing in sand content requires more water/cement ratio needed [5]. The workability of fresh OPS concrete decreased with an increase in the volume of the OPS. OPS have low specific gravity which is 1.19 will affect the workability and the flow of concrete. Nevertheless, the compatibility of this mix under vibration was satisfactory.

Figure 1: Distribution of OPS in concrete and cement content volume (left to right: 300,350,400,450 and 500 kg/m³ cement content)

3.2 Density

The 28-day density of OPS concrete shows that all mixes have density of below 2000 kg/m³. The changes in unit weight are shown in Figure 2. In average, density of oven dry OPS concrete produced in this study is approximately 8.7%-16% lighter than air dry OPS concrete. The highest gap of density (air dry to oven dry) can be seen in T1 mix. The result showed that higher OPS volume will reduce density. Mix T1, T2 and T3 which contained 40% of OPS display a reduction gap of 16% of weight (air dry to oven dry density). Compared to mix T13, T14 and T15, the reduction gap of the density are only 11%, 9.2%, 8.7% respectably with 16% to 20% volume of OPS. The tendency to impart the cohesiveness of the mixture is low. Therefore, the air void were easier to eliminate during vibrations, as compared to the mix T13, T14 and T15.

The density of concrete depends on the factors like compactions during the placing process and the specific gravity of incorporated OPS too. This is most probably due to the lower specific gravity of OPS aggregate as compared to the Portland Cement SEM 1. Hence, the volume of the OPS used would result in a reduction in the bulk density. Figure 1 show the OPS distribution in concrete follow by cement content volume in mix design. It can be clearly seen that the density of OPS is highest in the mix with 300 kg/m³ cement volume compared to other mix. The density of OPS will affect the bulk density concrete of mix. The mix with 300 kg/m³ concrete volume is lighter than the one with 500 kg/m³ cement content.

The substantial reduction of the unit weight due to oven dry is an indication of the presence of large and higher amounts of open pores on the specimens like mix T1, almost 16% reduced weight. The lowest density obtained for mix used 300kg/m³ cement content may due to more voids created as more volume OPS used will produce low compacted bulk density. OPS itself have high porosity aggregate, therefore the density within air and oven dry will show the significantly different. Other factor to consider regarding concrete density is sand ratio. Based on the result in Figure 2, the ratio of sand does not give much influence compared to the volume of OPS used. Sand ratio of 1.9 higher than 1.7 because of volume sand used in mix. For all mix the difference of density within sand ratio is around 0.3 to 0.6% only.

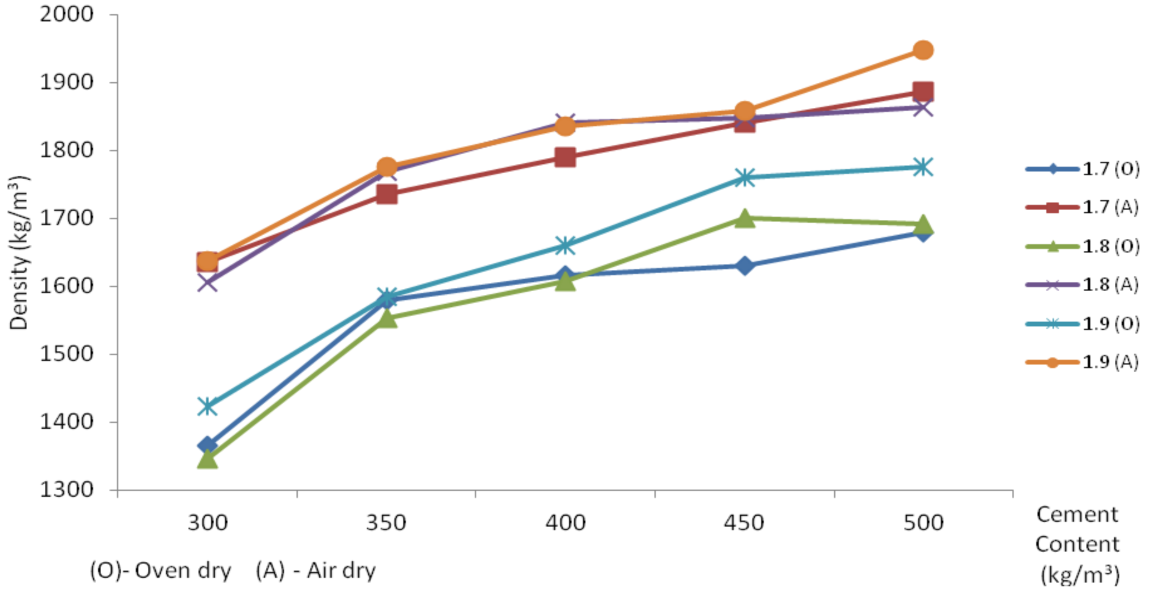

Figure 2. The relationship between unit weight density and cement content with different sand ratio of oven dry and air dry

3.3 Compressive Strength

Figure 3 shows the effect of cement content and sand ratio on the compressive strength of OPS lightweight concrete. As seen in the figure, compressive strength increased substantially with the increase of concrete cement content. The lowest strength is produced by T1 mix which is 11.56 N/mm and is still in the range of load bearing strength meanwhile the highest strength is produced by T15 which is 28 N/mm² which is in the range of lightweight aggregate structural concrete strength. When the relationship is shown in figure, it may be concluded that higher OPS aggregate and low cement content will produce low strength. In other words, compressive strength values changed significantly depending on cement content amount.

It can be seen that compressive strength values increase directly proportional to the increase in density values and inversely proportional to the increase in porosity values. In other words, with high density and low porosity produce high compressive strength values. Properties of these constituents affect the properties of concrete. Thus, OPS aggregate will cause high porosity in cement paste and reduced the strength. The air entrainment and bonding of the aggregate/ cement paste in the interfacial zone [8] contributed to the low strength of the concrete. The effect of cement content on the strength loss of OPS concrete is clearer when it can be observed that the strength loss of the T1, T2 & T3 mix is lower than the other mixtures. The mix T1,T2 and T3 mix has 40% lower cement content and 46% to 50% higher OPS content than mix T13, T14 and T15. The strength loss of this mix is significantly lower than the mix T13, T14 and T15.

In all mix, the strength gained was due to higher fine aggregate and lower OPS content. It was evident that good bond between OPS and cement matrix enabled concrete to sustain higher load. The presence of high volume of pores in OPS which was evident because of high water abortion of about 22.1% may weaken the particle strength and stiffness.

The comparison of 28 days compressive strength shows that the strength of T15 mix has increase to about 10% compared to T13. Similarly, T9 mix also has an inference of about 20% compared to T8. Thus the influence of sand content on compressive strength is evident. It can also be shown that the increase in compressive strength between T15 and T13 is not as high as compared to T8 and T9 and it can be concluded that sand/cement ratio of 1.8 could be the ideal mix as far as density in concerned.

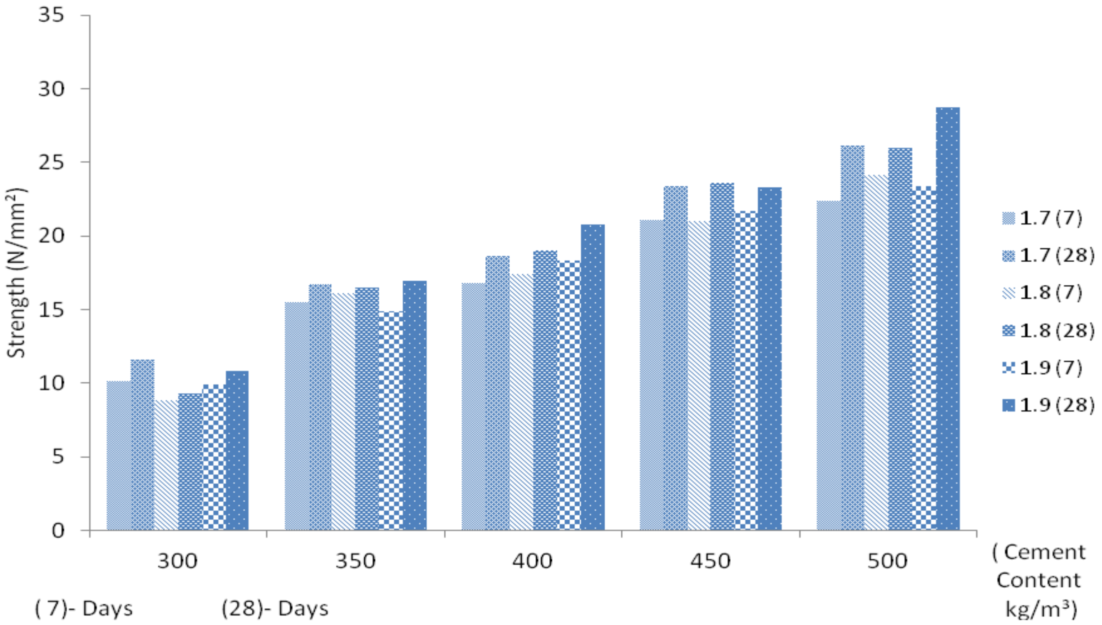

Figure 3: The relationship between compressive strength and cement content with different sand ratio at 7 and 28 days

3.4 Ultra Pulse Velocity

Different density in each mix lightweight concrete produces different result in pundit test. The pundit test also determines the process of hardening the concrete in laboratories. The pulse velocity is based on characteristics and elasticity in the concrete material. Based on Table 2, quality for air dry OPS concrete in mix T1, T2 and T3 is weak, mix T4 until T12 have moderate quality concrete and mix T13, T14 and T15 have good quality concrete. It may be concluded that when cement content of 300 kg/m is used, it will produce weak quality of concrete. Moderate quality of concrete is produced by cement content of 350, 400 and 450 kg/m and good quality of concrete is only produced by cement content of 500 kg/m. It was observed that there was an increase in pulse velocity values in parallel to the increase in cement content in concrete mixtures.

Table 2. Pulse Velocity Result (km/s)

Sand Ratio	Cement Content (kg/m³)				
	300	350	400	450	500
1.7	2.92	3	3.21	3.38	3.63
1.8	2.83	3.02	3.2	3.45	3.69
1.9	2.79	2.91	3.16	3.38	3.64
Quality of Concrete*	Weak	Moderate			Good

In additions, the UPV value of concrete may also greatly affected by the perfection of compaction. Since the specimens attained lower slump value, the compactness of the microstructures would definitely be affected. At the same time, the porous cellular structure and OPS itself are also partially contributed to the low UPV value.

Conclusion

The following conclusions can be withdrawn from the study:

1. The workability of mix design is categorized as being low especially for mix design using high proportion of OPS that have poor workability.
2. Cement/sand ratio of 1.8 is optimum ratio for load bearing strength purpose.
3. Unit weight of concrete can be reduced significantly by increasing OPS volume. In this study the substantial reduction of the air dry density due to oven dry density is 16% by mix T1. It shows higher amounts of open pores on the specimens.

4. The range of compressive strength for load bearing starts at 350 kg/m³ onwards, which is more than 11Mpa for structural strength requirement.
5. Pulse velocity value is of moderate quality except for mix design using 500 kg/m³ cement content that produced good quality concrete.

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