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Utilization of Oil Palm Shell as Lightweight Aggregate in Lightweight-Foamed Concrete

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ABSTRACT

The use of agricultural waste as lightweight coarse aggregate gives advantages in environment and economy aspects. This investigation presents the utilization of oil palm shell (OPS) in foamed concrete (OFC). Three mixtures were prepared with different target densities, namely 1100, 1300 and 1500 kg/m3. The test on the mechanical properties of OFC was investigated in this research work. Additionally, the fresh state properties were discussed. The experimental results showed that reducing the density of OFC, decreases the compressive strength as well. However, the OFC exhibited structural grade lightweight concrete with 28-day compressive strength and density of 17 MPa and 1544 kg/m3, respectively.

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INTRODUCTION

Lightweight concrete (LWC) has played an important role where its lower self-weight benefits in reduction of sizes of structural members and foundation, handling larger precast units and more economical. Since Malaysia is the second largest palm oil producer, the leftover agricultural wastes have been cumulative and caused land and air pollution in the vicinity of the palm oil factories. Hence, a resource-efficient material would be an additional advantage towards construction of green buildings. Moreover, the lower structure's weight contributes to the resistance towards the seismic force. Alengaram *et al* (2013b) reported that the utilization of OPS in foamed concrete can produce a structural LWC and exhibited a 39% of reduced thermal conductivity compared to the conventional brick. Panesar (2013) stated that the type of foaming agent used (synthetic- or protein-based) influenced the compressive strength of foamed concrete. In addition, Chen and Liu (2013) investigated that the expanded polystyrene foamed concrete (EPSFC) produces higher ductility and energy absorption capacity under compressive load, in comparison with the normal weight concrete (NWC). Also, there is no much difference in the deflection at service loads between the OPSC and NWC beams (Alengaram, 2008) As a further research, the fresh and mechanical properties of foamed concrete were studied with the incorporation of OPS as lightweight aggregate and mineral admixtures such as fly ash (FA) and silica fume (SF).

Experimental procedure:

The binder used in this experimental work is ordinary Portland cement (OPC) and class-F FA. Chemical compositions of class-F FA and SF are shown in Table 1, which conforming with the ASTM C618 (2012). The OPS of sizes between 2.36 and 14 mm with saturated surface dry condition was used as coarse LWA in this study. Mining sand with a specific gravity of 2.67 and sizes passing through 2.36 mm and retained on 300 μm was used as the fine aggregate. A naphthalene-based superplasticizer (SP) with a specific gravity of 1.2 and potable water were used for the concrete mixtures. The foaming agent used in this study was synthetic-based with a specific gravity of 1.02. It was diluted in water with the ratio of 1:20 and fed into the foam generator to produce stable foam, where the air pressure was maintained at 517 kN/m^2.

Table 1: Chemical composition (%) of OPC, class-F FA and SF.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	LOI
OPC	19.0	4.6	3.1	63.2	2.6	1.0	2.6	2.9
Class-F FA	57.6	28.9	5.8	0.2	0.9	0.9	0.2	3.6
SF	86.6	1.9	3.3	0.0	2.1	1.7	0.1	4.6

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The ratios of OPS/binder, sand/binder and water/binder were kept constant at 0.8, 1.6 and 0.35, respectively for all OFC mixtures. The dosage of the SP was at 1% of the binder; and the FA replaced 10% of the binder (by mass) while 5% of SF by mass of binder was added. The concrete specimens were cured inside the curing chamber at a temperature of 65˚C for 48 hours. Three mixtures of OFC were prepared with target densities of 1100, 1300 and 1500 kg/m^3. The mix proportions of the mixtures are presented in Table 2.

Table 2: Mix proportions of OFC

Mix	Mix proportions (kg/m^3)							
	OPC	FA	SF	OPS	Sand	Water	SP	Foam
OFC-11	468.3	26.7	49.3	394.3	788.7	189.8	5.0	12.2
OFC-13	468.3	26.7	49.3	394.3	788.7	189.8	5.0	10.9
OFC-15	468.3	26.7	49.3	394.3	788.7	189.8	5.0	8.5

The slump test (ASTM C143, 2012) was carried out soon after getting the required fresh density of the mixture. The concrete specimens were cast in 100-mm cubes for the compressive test, which was carried out at the ages of 3-, 7-, 14- and 28-days in accordance with BS EN 12390-3 (2002). The specimens of 100 mm ϕ x 200 mm height cylinders were prepared for the splitting tensile strength (ASTM C496, 2011) whereas the tests on the flexural strength (ASTM C78, 2010) and the modulus of elasticity (ASTM C469, 2010) were carried out on prisms of size 100 x 100 x 500 mm and on 150 ϕ x 300 mm cylinders, respectively.

RESULTS AND DISCUSSIONS

Slump, fresh and oven-dry densities:

As revealed in Table 3, the addition of foam increases the slump value, resulting in higher workability. This phenomenon is attributed to the reduction of the bulk density of slurry while increasing the available volume of the cement paste (Chen, 2013). Additionally, the inclusion of FA generally contribute to higher slump due to the ball bearing effect owing to its spherical shape. The smooth surface of the OPS does not have much cohesiveness with the cement paste, thus exhibited higher workability.

The difference between the fresh and oven-dry densities is about 102-109 kg/m^3, which might be due to the water absorption of OPS (Alengaram, 2013). The stability of OFC, at which the density ratio (fresh density/target density) for all mixtures are close to one, showing consistency of the mixture. Nevertheless, the measured ODDs of the OFC were within the acceptable limit of ±50 kg/m^3 of the target densities.

Table 3: Development of compressive strength, slump and densities.

Mix	Slump	Fresh density	28-day ODD	Compressive strength (MPa)			
	(mm)	(kg/m^3)		3-day	7-day	14-day	28-day
OFC-11	146	1250	1148	2.7	2.9	3.5	3.8
OFC-13	98	1458	1349	6.6	7.3	8.4	8.6
OFC-15	77	1647	1544	10.3	14.1	15.7	17.2

Compressive and tensile strength:

The compressive strength development of all OFC mixtures present similar trend, where it showed a strength increase over time and ODD. The OFC-11 obtained lowest 28-day compressive strength of 3.8 MPa compared to OFC-13 and OFC-15 with 28-day strength of 8.6 and 17.2 MPa, respectively. Higher foam volume is added in OFC-11, resulting large amount of cells or pores that reduced its density. The compressive strength of OFC was said to be a function of porosity and age, where the porosity is largely dependent on the density instead of the ash type or content (Kearsley, 2002). At higher foam volume, the merging of bubbles seemed to produce larger voids that result in wide distribution of void size and lower strength (Nambiar, 2007). According to RILEM (1983), OFC-15 can be categorized as structural grade concrete, exhibiting 28-day compressive strength of more than 15 MPa.

It is clearly seen from Figure 1 that the tensile (splitting tensile and flexural) strength of OFC is directly proportional with its 28-day compressive strength. Similarly, the addition of foam formed a lower density of OFC by creating more pores within the cement matrix. A significant strength drop in strength is attributed to the formation of macropores in foamed concrete (Pospisil, 1992). Alengaram *et al* (2013a) reported that the splitting failure tend to occur at the convex surface of OPS with particle size of 10 mm due to bond failure. Having flexural strength of 2.35 MPa, OFC-15 showed a superior strength with a lower density compared to the previous study by Jumaat *et al*. (2009), which had flexural strength and density of 2.15 MPa and 1675 kg/m^3, respectively.

Modulus of elasticity:

The MOE (1.28-2.69 GPa) of OFC are presented in Figure 1, which varies linearly with the 28-day compressive strength. The MOE of foamed concrete is significantly low, where the MOE varies from 1-8 GPa for densities between 500 and 1500 kg/m^3 (Jones, 2005). Other than the influence of the density that induced by the addition of foam, the MOE is inversely proportional with the moisture content. Alengaram *et al* (2013a) reported that the MOE of OPSC can be enhanced with the usage of 5% of FA and 10% of SF. Generally, a lower MOE means a higher deflection in structural members. Alengaram *et al* (2008) reported that OPSC beam showed higher final deflections compared to NWC of similar compressive strength.

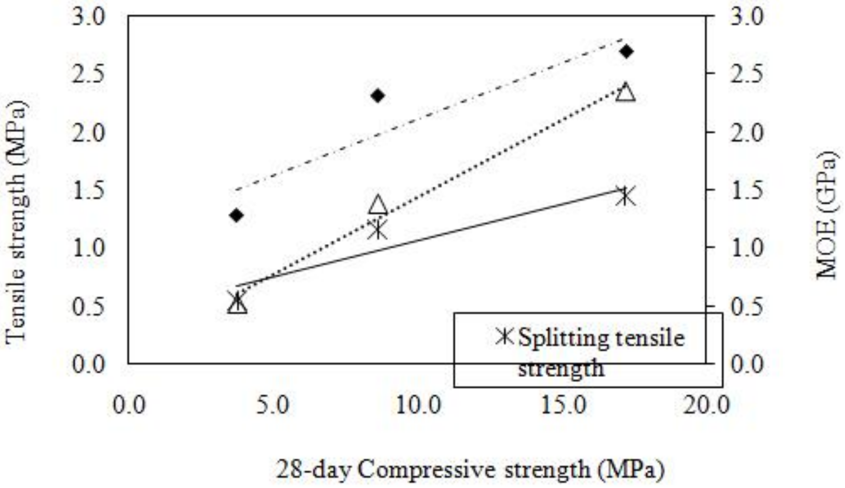

Fig. 1: Relationship between MOE, tensile and 28-day compressive strength.

Conclusion:

The OFC-15 with strength and ODD of 17 MPa and 1544 kg/m^3 can be regarded as structural grade concrete. It is found that the addition of foam in OPS concrete is consistent with its target density, which is within ±50 kg/m^3. The increase of the foam volume, creates more pores that reduced its density and hence, reduces the mechanical properties of OFC. In addition, the OFC could achieved about 1.28 to 2.69 GPa of MOE.

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