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The Potential Use of Palm Oil Fuel Ash (POFA) As Properties of Lightweight Concrete

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Abstract
Malaysia is well known as the main crude palm oil producer and exporter in the world. Million tonnes of agro wastes such as Palm Oil Fuel Ash (POFA) is being produced every year with no commercial return on it. Due to pozzolanic behaviour possessed by POFA, it could be significance if the POFA is being recycled and used in production of lightweight concrete. Thus, this study investigated the effects of Palm Oil Fuel Ash (POFA) on engineering properties in terms of compressive strength, flexural strength and splitting tensile strength. Three types of concrete were prepared, lightweight concrete with 100 % sand as control mix (CM), lightweight concrete with 10 % POFA replacement as part of filler (POFA10), and lightweight concrete with 20 % POFA replacement as part of filler (POFA20). All the specimens were water cured prior mechanical tests. The laboratory results showed that the incorporation of POFA into lightweight concrete has increased its compressive strength about 10%, flexural strength about 28% and splitting tensile strength about 23%. This shows that Palm Oil Fuel Ash has a great potential to be applied as part of lightweight concrete materials.

Keywords: palm oil fuel ash (POFA), lightweight concrete, flexural strength, compressive strength, mechanical tests

Introduction

Palm oil is extracted from the fruit and copra of the palm oil tree. After the extraction operation, waste products such as palm oil, fibres, shells, and empty fruit bunches are mostly burnt as biomass fuel to boil water, which generates steam for electricity and for the extraction process in palm oil factories. The combustion of palm oil husk and palm kernel shell in the steam boiler produces palm oil fuel ash (POFA), which is approximately 5 % of solid waste by-product, equivalent to 3.1 million tonnes in Malaysia in 2010 (Tangchirapat et al., 2007; Sooraj VM, 2013).

POFA has been identified as a good pozzolanic material, it is because POFA contains siliceous compositions produces a stronger and compact concrete (Sooraj VM, 2013). Pozzolanic is a natural or artificial material containing silica and alumina in a reactive form and only have little cementitious properties. However, in a smooth and moist form, pozzolanic will react with alkali to form cement compounds (Setina et al., 2013). The silica oxide content in POFA can react with calcium hydroxide ($Ca(OH)_2$) from the hydration process which is deteriorated to concrete and the pozzolanic reactions produce more calcium silicate hydrate (C-S-H) which is a gel compound as well as reducing the amount of calcium hydroxide. Due to high silica oxide content in POFA which met the pozzolanic property criteria, it is potentially utilized as cement replacement or as filler to produce hard and durable concrete (Munir et al., 2015) for example as lightweight concrete. Lightweight concrete is a special concrete which weights lighter than conventional concrete. Density of this concrete is considerably low about 300 kg/m^3 to 1850 kg/m^3 when compare to normal concrete is 2200 kg/m^3 to 2600 kg/m^3 (Islam et al, 2015). Lightweight concrete means that the concrete has more the following properties such as less specific gravity, high water absorption and less bulk density, relatively less compressive strength, and less modulus of elasticity.

Materials and methods

Preparation of Raw Materials

The making of lightweight concrete incorporated with POFA consist of four types of raw material, namely Ordinary Portland Cement (OPC), POFA, fine aggregates of sand and water. The POFA was obtained from Kilang Sawit LCSB Lepar at Gambang, Pahang. The OPC, POFA and sand were dried in an oven at temperature of 105 °C ± 5 °C for two hours. The OPC, POFA and sand were sieved through 300µm sieve

Mix proportions

OPC, Sand and POFA were weighted and mixed in a concrete mixer until the dry mix was uniformly mixed. Next, water was weighted and added into the dry mix to obtain the ratio of 100 % sand as filler (CM), 10 % POFA replacement as part of filler (POFA10) and 20 % POFA replacement as part of filler (POFA20). The slump test was carried out before fresh lightweight concrete is poured into the mould. The specimens for each mix proportions were water cured for 7, 14 and 28 days before undergoing compression test.

Slump test

The slump test was conducted by using a slump cone and flat base plate as complied with ASTM C995 (2001). Slump cone was placed at the centre of the base plate and filled with fresh lightweight foamed concrete until it was fully filled. Excessive fresh lightweight concrete was struck off and the slump cone was lifted to 1 ft. height. The four angle of dimension of spread was measured and recorded.

Compression test

The compression test was conducted by using compressive strength machine. The test was performed in accordance with BS EN 12390-3 (2002). The cubes were taken out from water tank and air-dried for two hours before the test is performed. Dimension of specimen was measured and loaded gradually with constant rate of loading of 0.02 mm/s until the specimen fails. The maximum load carried by the specimen was recorded and compressive strength was calculated based on the equation 1 (BS EN 12390-3, 2002).

$$\mathbf{Sc} = \frac{\mathbf{P}}{\mathbf{Width\ X\ Thickness}} \qquad (1)$$

Where

Sc = Compressive strength, MPa

P = Maximum load carried by specimen, N

Width = Width of specimen, mm

Thickness = Thickness of specimen, mm

Splitting tensile test

The test was performed in accordance with ASTM C496 (2004). The cylinders were taken out from water tank and air-dried for two hours before the test was performed. Using Concrete Compression Machine an axial load with a specified rate of loading was applied to cylinder with 100 mm of diameter and 200 mm of height until failure occurred. Test specimen was loaded gradually with constant rate of loading of 0.02 mm/s until the specimen fails. The maximum load carried by the specimen are recorded and splitting tensile strength was calculated based on equation 2 (ASTM C496, 2004).

$$\boldsymbol{T} = \frac{\boldsymbol{2P}}{\boldsymbol{\pi L D}} \qquad (2)$$

Where

T = Splitting tensile strength, MPa

P = Maximum load carried by specimen, N

L = Length of specimen, mm

D = Diameter of specimen, mm

Flexural stength test

Flexural test was performed in accordance with ASTM C293 (2002). The prisms will be taken out from water tank and air-dried for two hours before the test was performed. Using Concrete Flexural Machine a centre-point loading with a specified rate of loading was applied to prism with dimension of 25 mm x 25 mm x 250 mm until failure. An offset of 10 mm from both sides of prism was marked and the prism are placed on the support block. Test specimen was loaded gradually with constant rate of loading of 1.67 x 10^{-3} mm/s until the specimen fails. The maximum load carried by the specimen was recorded and flexural strength was calculated based on the equation 3 (ASTM C293, 2002).

$$\mathbf{R} = \frac{\mathbf{3PL}}{\mathbf{2bd^2}} \qquad (3)$$

Where

R = Flexural strength, MPa

P = Maximum load carried by specimen, N

L = Length of specimen, mm

d = Thickness of specimen, mm

b = Width of specimen, mm

Performance Index

The density of lightweight concrete was controlled to be within 1300 kg/m3 ± 50 kg/m3. The equation for performance index is shown in Equation 4 (Ramamurthy, 2009).

$$\mathbf{PI} = \frac{\mathbf{Sc}}{\left[\frac{\mathbf{hardened\ density}}{\mathbf{1000}}\right]} \qquad (4)$$

Where

PI = Performance Index, MPa per 1000 kg/m3

Sc = Compressive Strength, MPa

Results and discussion

Compression Test Profile

Figure 1 showed that the compressive strength is directly proportional to curing age for CM, POFA10 and POFA20, respectively. The highest compressive strength of CM required is 6.61 MPa which as obtained on the 90^{th} day of curing age. For POFA10, 7.82 MPa is the highest value of compressive strength with 0.54 of w/c mix proportion achieved in curing age 90 days.

It has been observed that incorporation of POFA into lightweight concrete has increased its compressive strength. This mainly due to the pozzolanic process happened in lightweight concrete incorporated with POFA. The pozzolanic process ensures continuous development of strength due to addition reactive silica content by the incorporation of POFA, which more C-S-H was produced due to the reaction of reactive silica with calcium hydroxide. This additional C-S-H gel caused the lightweight concrete denser. The additional calcium silicate hydrate gel formed improves the interfacial bonding between the aggregates and pastes at later ages (Karim, 2011). Thus, the compressive strength increased. The compressive strength of POFA10 at 90 days of age was 10 % higher than that of CM. On the other hand, compressive strength of POFA20 at 90 days of age was 8 % higher than of CM.

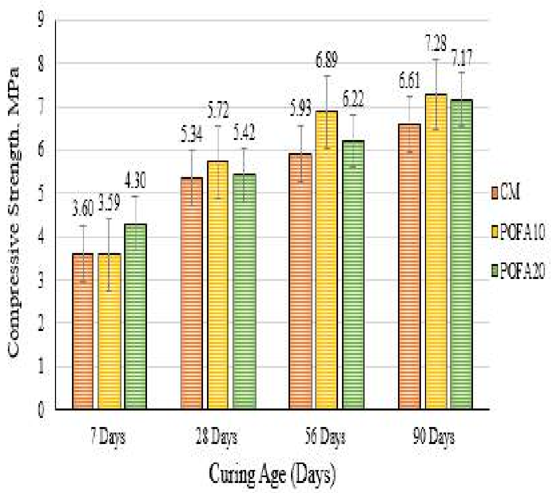

Figure 1: Compressive Strength from 7 to 90 Days Curing Age.

Slump Tests Profile

Table 1 presented the mix proportions used. The ration of water to cement (W/C) and the ratio of sand to POFA influenced the spread of the slump tests. An increase in the spread could be seen with a higher water to cement ratio, while the spread value decreased with high value of POFA in mix proportion.

Table 1: Mix Proportion

Mix Details	Sand : POFA[1]	W/C[2]	Slump Cone Spread Value (mm)
CM[3]	100:0	0.54	550-560
		0.56	580-590
		0.58	660-670
		0.60	690-695
POFA10[4]	90:10	0.54	460-500
		0.56	465-525
		0.58	480-530
		0.60	505-540
POFA20[5]	80:20	0.54	400-420
		0.56	410-450
		0.58	420-460
		0.60	470-510

Note:

[1] sand: POFA is in percent ratio
[2] W/C = water to cement ratio
[3] CM = lightweight concrete control mixture
[4] POFA10 = lightweight concrete with 10% of POFA
[5] POFA20 = lightweight concrete with 20% of POFA

Splitting Tensile Strength

Figure 2 shows the result of splitting tensile strength for CM, POFA10 and POFA20 for 7, 28, 56 and 90 days of curing ages. Both POFA10 and POFA20 have higher splitting tensile strength value compare to CM. POFA10 achieved the highest splitting tensile strength which is 1.002 MPa at 90 days curing age. Generally, the splitting tensile strength development shared the same trend with compressive strength development. Lightweight concrete incorporated with POFA shows higher splitting tensile strength than pure sand based lightweight concrete. Theoretically, splitting tensile strength is related to compressive strength, although this relationship depends on different factors namely aggregate type, particle size distribution, age of concrete, curing process and air content (Parra, 2011).

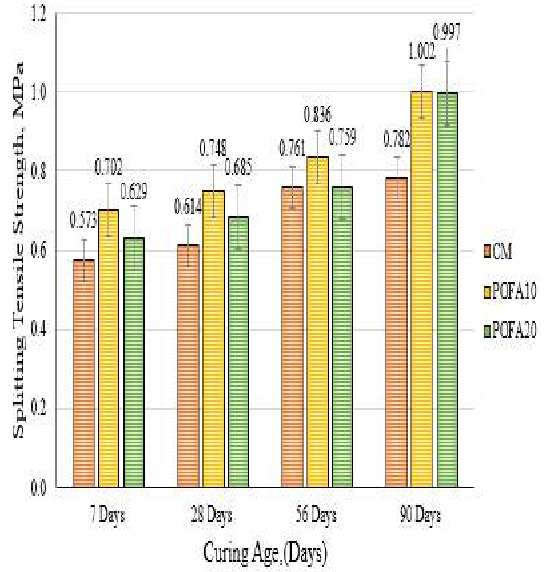

Figure 2: Splitting Tensile Strength Up To 90 Days Curing Age For CM, POFA10 and POFA20

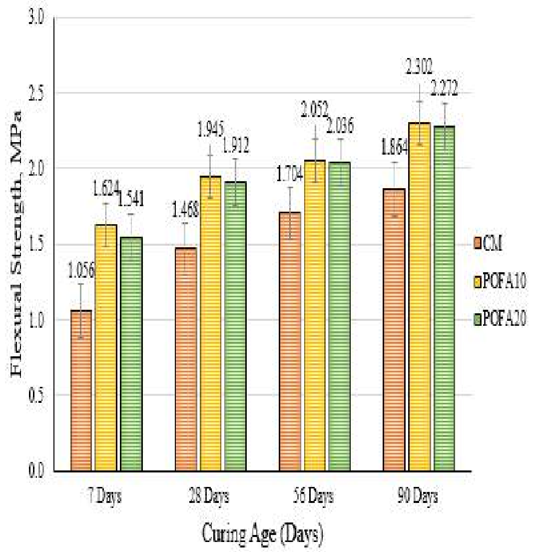

Figure 3: Flexural Strength Up To 90 Days Curing Age For CM, POFA10 and POFA20

The splitting tensile strength of POFA10 and POFA20 at 90 days of age were 28 % higher than that of CM. Generally, splitting tensile strength is much lower than compressive strength. This is because in this test, the cylinder specimen is placed with its axis horizontal between the plates of a testing machine. The load is increased until failure by indirect tension in the form of splitting along the vertical diameter takes places. It can be seen that a high horizontal compressive stress exists in the vicinity of the loads but, as this is accompanied by a vertical compressive stress of comparable magnitude, thus producing a state of biaxial stress. Hence, the cylinder fail at tension rather than failure in compression (Neville, 2010).

Flexural Strength

Figure 3 shows the flexural strength of each mix proportion increased with the curing age. Both POFA10 and POFA20 has higher flexural strength than CM at 90-day of age. The flexural strength of POFA10 at 90 days of age was 23 % higher than that of CM. On the other hand, flexural strength of POFA10 at 90 days of age was 22 % higher than that of CM. POFA10 achieved the highest flexural strength at 90 days of age which was 2.302 MPa.

In general, the flexural strength has same patterns with compressive strength. Lightweight concrete incorporated with POFA shows higher flexural strength than that of pure sand (CM) based lightweight concrete.

Performance Index

Table 2 presents the performance index of the lightweight concrete. The trend of performance index of lightweight concrete is similar as compressive strength, in which the performance index is directly proportional to curing age. The highest performance index was achieved by POFAF10 and followed by POFA20 at 90 days of age.

Generally, specimens with POFA as part of filler have higher compressive strength than that of 100 % sand as filler specimen. This is due to the pozzolanic behaviour possessed by POFA. A common trend can be obtained for flexural and splitting tensile strengths, where the flexural and splitting tensile strengths are directly proportional to its curing ages. Besides that, specimen incorporated with POFA has higher flexural and splitting tensile strengths than that of pure sand based specimens.

Table 2: Performance Index of Lightweight Concrete

Age (days)	CM: POFA Ratio	Performance Index
7	CM	2.80
	POFA10	2.77
	POFA20	3.26
28	CM	4.13
	POFA10	4.42
	POFA20	4.20
56	CM	4.51
	POFA10	5.40
	POFA20	4.72
90	CM	5.05
	POFA10	5.66
	POFA20	5.53

Conclusion

It can be concluded that the incorporation of POFA into lightweight concrete as sand replacement plays important role in improving the engineering properties of lightweight concrete in terms of compressive strength, splitting tensile strength, and flexural strength. The research work on lightweight concrete incorporated with POFA is still limited but it promises greater potential for industrial application.

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