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PRELIMINARY STUDY ON THE EFFECT OF THE INCLUSION OF PALM OIL FUEL ASH (POFA) IN FOAMED CONCRETE ON COMPRESSIVE STRENGTH AND POROSITY

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ABSTRACT

Utilization of palm oil fuel ash (POFA) in concrete is increasing in recent years as an effort to mitigate the global warming and environmental damage caused by the high energy consumption due to the production of cement. Many researchers investigated the POFA as an alternative binder to mitigate the cement usage in producing concrete. A foamed concrete mixes have been prepared having a density of 900kg/m^3 with a filler to binder ratio of 1:1.5 and three levels of POFA replacement. A polycarboxylate based superplasticizer was added to the mixes at a dosage of 0.75% by weight of the binder. The compressive strength and porosity have been investigated for preliminary study. The results reveal that at 28 days, the LFC-PF30 concrete obtained higher compressive strength and porosity of 1.78MPa and 56% respectively, as compared with the normal foamed concrete (NFC).

Keywords: palm oil fuel ash, compressive strength and porosity.

INTRODUCTION

Palm oil fuel ash (POFA), an agrowaste ash, is a solid waste by-product of palm oil industry obtained from the combustion of palm oil biomass containing palm oil empty fruit bunch, fibers, and kernel shell; which is used as the alternative fuel in palm oil steam boiler [1]. Before the bio-diesel becoming popular, 90% of palm oil was used in the food commodity while the remaining 10% was used as raw material in soap production [2]. However, when the potential of palm oil in producing bio-diesel has been realized, Malaysian palm oil industry grew significantly from 400 hectares in 1920 [3] to 5.64 million hectares in 2015 [4].

Aside from the profitable potential of combustion biomass in producing bio-diesel, there are problems that arise from the ashes produced. The combustion of biomass produces 5% POFA by weight of biomass which equal to 0.1 million tons per year and increases annually, while the utilization of POFA is limited. Approximately 2,6million tons of POFA was produced in Malaysia annually [5] and the amount increases every year, causing numerous problems to the environment because of the disposal process. Due to the huge amount of POFA produced, it is practically disposed of with uncontrolled dumping ways because of the limited landfill. The uncontrolled disposal of such waste, especially ash, will lead to the deterioration of the environment due to the fact that they are rich in organic substance [6].

To overcome the disposal problems, recycling of palm oil fuel ash is expected to be a potential method for improving economic benefits and environmental awareness. A number of researchers studied the usage of agrowaste ashes as constituents in concrete, such as rice husk ash (RHA), sawdust and rice straw. Those agrowaste ashes contained a high amount of silica and can be classified as a pozzolanic material. The Silica oxide content in pozzolans can react with Calcium hydroxide (Ca(OH)) from hydration process and produce more Calcium silicate hydrate (C-S-H) gel. This contributes to the strength of concrete and produces a stronger and denser concrete as well as improves the durability of concrete.

CONSTITUENT MATERIAL AND PROCEDURES

Binders

A Portland Composite Cement (PCC) with particle size of 4.92µm was used in this study. POFA from a palm oil mill located in Nibong Tebal, Penang was used as a cement replacement. The POFA was a result of incinerated palm oil biomass at temperatures exceeding 1000^{o}C. The collected ash was dried in an oven for 24 hours at a temperature of 105±5 ^{0}C then sieved through a 300µm sieve to remove all the unwanted particles and unburned carbon. The POFA was ground using ball mill machine to achieve the fineness particle size, which is 4.03µm. The X-ray diffraction (XRD) pattern of POFA is shown in Figure-1. It was found that the major phase of POFA is α-quartz (SiO_2), and small phase is Gehlenite (Ca_2Al ($AlSiO_7$)). The chemical properties of POFA and cement are shown in Table-1. It was found that POFA contains 62.16% of Silicon dioxide (SiO_2) + Aluminium oxide (Al_2O_3) + Iron oxide (Fe_2O_3). It reveals that POFA satisfied the requirements to be pozzolanic and may be classified as in between Class C and Class F according to the standard in ASTM C618 [7].

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Table-1. Chemical compositions of cement and POFA

Oxide Compositions	Cement (%)	POFA (%)
Silicon dioxide (SiO_2)	14.84	54.93
Aluminium Oxide (Al_2O_3)	3.64	3.27
Ferric Oxide (Fe_2O_3)	2.44	3.96
Calcium Oxide (CaO)	56.09	10.77
Magnesium Oxide (MgO)	1.52	5.02
Sulphur Oxide (SO_3)	2.65	4.09
Sodium Oxide (Na_2O)	bdl*	0.40
Potassium Oxide (K_2O)	0.57	9.50
Phosphorus Oxide (P_2O_5)	0.06	5.64
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	62.16

* Below the limit of detection tools

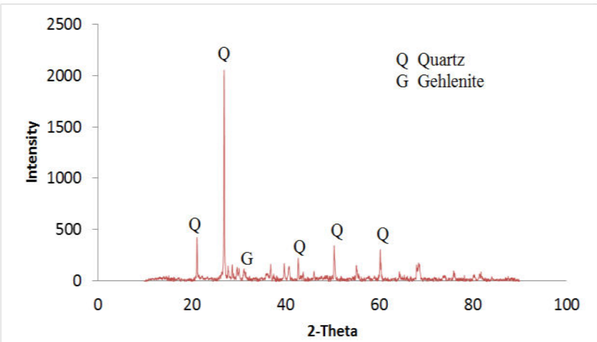

Figure-1. X-ray diffraction patterns of POFA.

Fine aggregate

River sand was used as a fine aggregate in the saturated dried surface condition which has a fineness modulus of 2.08. The fine sand was then being sieved until passing through a 600μm sieve before storing in the airtight container. The larger particles were removed because they settle in a lightweight mix and resulted the foam will collapse during mixing [8]. The sand sieve analysis is shown in Figure-2.

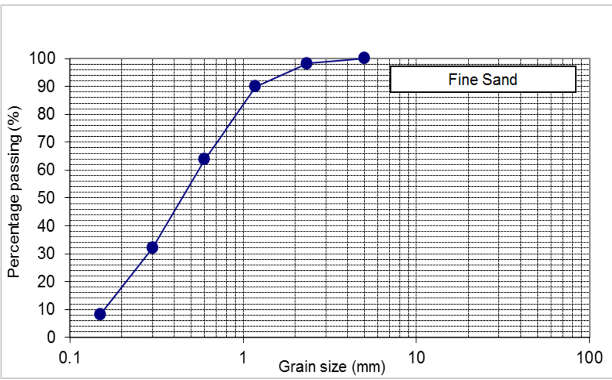

Figure-2. Sand sieve analysis.

Other concrete mix constituent

A polycarboxylate based water reducer superplasticizer (SP) was used as the chemical admixture in concrete with a fixed dosage of 0.75% by weight of binder for LFC-PF30 and LFC-PF50. Water used was ordinary tap water comply with BS EN 1008 [9]. The water used should not contain any substance that can be harmful to the process of hydration of cement and also the durability of concrete. A protein based foaming agent was used in thorough of the study. The foaming agent was diluted in water with a ratio of 1:30, and was then aerated to produce stable foam using a portafoam machine with the air pressure 70-75Psi.

MIX PROPORTION AND CASTING

In this study, POFA was used to partially replacing cement at the proportion of 30% (LFC-PF30) and 50% (LFC-PF50) by weight of cement. The targeted density of foamed concrete is 900kg/m^3. All mix proportion of foamed concrete had the same binder content (cement and POFA) of 338.5 kg/m^3, and the water/binder ratio was set to 0.45 (Table-2). Superplasticizer was used in the concrete mixtures to obtain high workability with the slump of fresh concrete between 160 and 210mm and do not exceed 240mm. Only in NFC, the mix proportion was similar to other mixtures except for the addition of superplasticizer and POFA.

Table-2. Mix constituent proportions of foamed concrete.

Materials	NFC	LFC-PF30	LFC-PF50
Cement (kg/m^3)	338.5	237	169.5
POFA (kg/m^3)	0	101.5	169.5
Sand (kg/m^3)	508	508	508
SP (kg/m^3)	0	2.35	2.35
Foam (kg/m^3)	0.011	0.013	0.011
Additional water (%)	24.6	16.4	49

After casting for 24hr, the specimens were removed from the moulds and air cured. The specimens were put into the oven at the temperature of 105±5°C for 24 hours prior to testing day. Three different mixes were prepared and tested; including NFC, LFC-PF30 and LFC-PF50. Concrete cubes of 100x100mm were cast and used to determine the compressive strength at 7, 14, and 28 days using compression machine named GOTECH GT-7001-BS300 with 3000kN compressive capacity comply with BS EN 12390-3.

To determine the porosity, the concrete cylinder of 45mm in diameter and 50mm in height were cast. After removed from the oven, concrete cylinder specimens then placed in a desiccator under a Vacuum Saturation Apparatus for at least 3 hours, after which the desiccator was filled with de-aired, distilled water. The porosity was calculated using the following equation:

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$$\boldsymbol{e} = \frac{(W_{sat} - W_{dry})}{(W_{sat} - W_{wet})} \, x\, 100 \qquad (1)$$

where $\boldsymbol{e}$ is the porosity (%), W_{sat} is the weight in air of saturated sample, W_{wet} is the weight in water of saturated sample and W_{dry} is the weight of oven-dried sample.

RESULT AND DISCUSSIONS

Properties of fresh concrete

Table-3 presents the compressive strength, porosity and slump value of foamed concrete with POFA inclusion. Properties of fresh concrete; i.e., workability was measured using slump value test for all mixes. It is found that the LFC-PF30 and LFC-PF50 had slump reading of 180mm and 185mm, respectively. These values were lower than the control specimen which had 200mm. From table-2, it can be seen that even though the LFC-PF50 has 49% additional water; the slump value is still less than control mix. This indicates that the high amount of POFA in concrete will reduce the workability and significantly increase the water demand.

Compressive strength

Figure-3 shows the development of compressive strength of concrete with different percentage of POFA replacement level at different ages. The results of control specimens are concrete with 100% cement content. Found that at 28 days, the LFC-PF30 and LFC-PF50 concrete obtained the compressive strength of 1.78 and 0.85Mpa, respectively. However, the compressive strength of LFC-PF30 was higher than NFC concrete which only obtained 1.38MPa at the same age. The increasing compressive strength value of LFC-PF30 up to 130% of the normal concrete indicates that by replacing cement content with POFA might be able to improve the strength of concrete, moreover when superplasticizer introduced. Even though the inclusion of 50% POFA as cement replacement gained the low strength at the early age, the compressive strength was still increased at 28 days. The low initial strength of POFA mixes can be attributed to the high SiO_2/Al_2O_3 ratio in the POFA matrix, which is responsible for less $Al(OH)_4^{4-}$ availability for condensation in the early age of strength development [10].

The particle size of POFA also contributes to the strength of foamed concrete. The fineness of POFA had a greater filler effect on the void and the reaction of Silicon dioxide (SiO_2) content with Calcium hydroxide (Ca(OH)2) increasing the C-S-H content [11]. It refines the pore structure of POFA concrete and makes the concrete denser, hence increases the strength. In the previous study conducted by Krehong *et al.* [12], it was found that the inclusion 20-40% of POFA (d_{50}=15.6µm) replacing cement content had the compressive strength of 96-82% of control specimen at 28 days. This also agreed by Sata *et al.* [13] who stated that the compressive strength of concrete containing up to 30% POFA (d_{50}=10.1µm) at 28 days were about 101, 100 and 93% of control concrete at the same age.

Table-3. Compressive strength and porosity of foamed concrete with variation of POFA replacement.

Mix	POFA content (%)	Compressive strength (MPa)			Slump (mm)	Porosity (%)		
		7	14	28		7	14	28
NFC	0	1.27	1.34	1.38	200	54	54	56
LFC-PF30	30	1.67	1.76	1.78	180	53	55	56
LFC-PF50	50	0.59	0.79	0.85	185	55	56	59

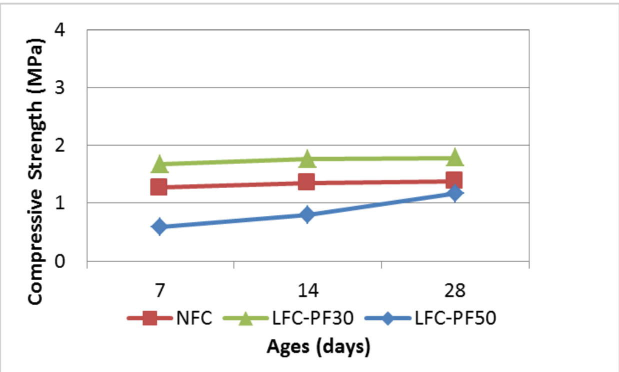

Figure-3. Compressive strength of foamed concrete for different replacement level of cement by POFA.

Porosity

The porosity of the foamed concrete is the sum of the air voids and the void inside the paste [14]. Figure-4 shows the porosity of mixtures with the different replacement level of cement by POFA which varied between 56% (for NFC and LFC-PF30) and 59% (for LFC-PF50). It can be seen that the porosity increases with the increasing the age of foamed concrete as well as with the increasing the POFA inclusion level.

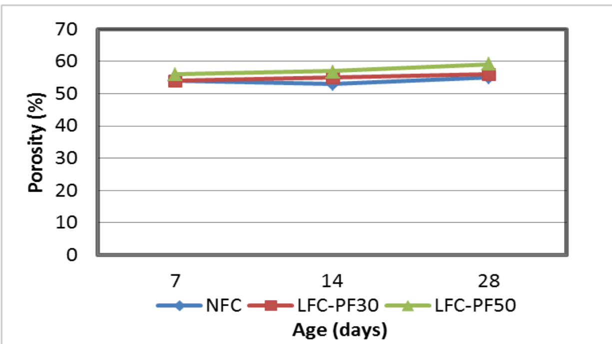

Figure-4. Porosity of foamed concrete for different replacement level of cement by POFA.

In comparison between the porosity and compressive strength of foamed concrete with different level of POFA inclusion, it is seen that 30% POFA used as cement replacement was not significantly influencing the percentage of porosity. Although has higher porosity, concrete containing 30% POFA was still has higher compressive strength than control mix. However, by increasing the amount of POFA replacement level in foamed concrete, the porosity was also increased. Figure-5 shows the compressive strength and porosity of foamed concrete with the different replacement level of cement by POFA at 7, 14 and 28 days.

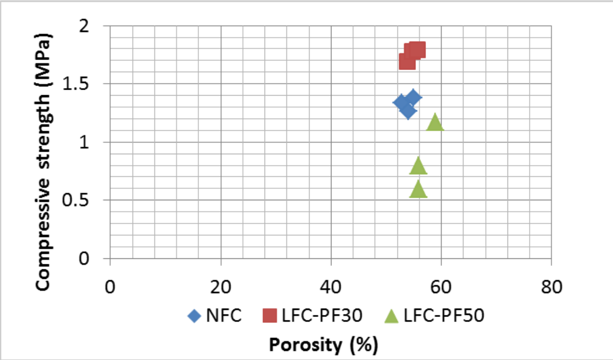

Figure-5. Effect of porosity on compressive strength for different replacement level of cement by POFA.

CONCLUSIONS

The conclusions are drawn from this study and summarized as below:

a) The high POFA content as cement replacement reduces the workability; hence need to increase the dosage of superplasticizer to achieve the sufficient workability,
b) Replacing 30% cement content with POFA gained a higher compressive strength compared to the normal foamed concrete (without POFA and superplasticizer),
c) Foamed concrete with 50% POFA content had the lowest compressive strength in this study, moreover at the early strength,
d) The higher POFA content, the higher percentage of porosity,
e) Percent of porosity is affected by the amount of POFA as cement replacement and density of foamed concrete,
f) POFA with only grinding treatment has potential to be used as cement replacement in foamed concrete.

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REFERENCES

[1] Munir, A., Abdullah, Huzaim, Sofyan, Irfandi, Safwan. 2015. Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. Procedia Engineering. 125: 739-746.

[2] Mahlia, T.M.I, Abdulmuin, M.Z., Alamsyah, T.M.I., Mukhlishien, D. 2001. An alternative energy source from palm waste industry for Malaysia and Indonesia. Energy Conversion and Management. 42: 2109-2118.

[3] Abdullah, A.Z., Salamatinia, B., Mootabadi, H. and Bhatia, S. 2009. Current status and policies on biodiesel industry in Malaysia as the world's leading producer of palm oil. Energy Policy. 37: 5440-5448.

[4] Malaysian Palm Oil Board (MPOB). 2015. http://bepi.mpob.gov.my/images/area/2015/Area_summary.pdf.

[5] Hassan, J.U., Noh, M.Z., Ahmad, Z.A. 2014. Effect of palm oil fuel ash composition on the properties and morphology of porcelain-palm oil fuel ash composition. Jurnal Teknologi. UTM Press.

[6] Singh, S., Kushwaha, B. P., Nag, S. K., Mishra, A. K., Bhattacharya, S., Gupta, P. K., and Singh, A. 2011. In vitro methane emission from Indian dry roughages in relation to chemical composition. Current Science. 101 (1): 57-65.

[7] ASTM Standard C618: 2003. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. Annual book of ASTM Standar.

[8] Brady, K.C., Watts, G.R.A., and Jones, M.R. 2001. Specification for foamed concrete. Iranian Cellular Lightweight Concrete Syndicate.

[9] BSI. 2002. Mixing water for concrete. Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete.

[10] Salami, B.A., Johari, M.A.M., Ahmad, Z.A. and Maslehuddin, M. 2016. Impact of added water and superplasticizer on early compressive strength of selected mixtures of palm oil fuel ash-based engineered geopolymer composited. Construction and Building Materials 109: 198-206.

[11] Zeyad, A.M., Johari, M.A.M., Tayeh, B.A. and Yusuf, M.O. 2017. Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete. Journal of Cleaner Production 144: 511-522.

[12] Kroehong, W., Sinsiri, T., Jaturapitakkul, C. and Chindaprasirt, P. 2011. Effect of palm oil fuel ash fineness on the microstructure of blended cement paste. Construction and Building Meterials 25: 4095-4104.

[13] Sata, V., Jaturapitakkul, C. and Rattanashotinunt, C. 2010. Compressive strength and heat evolution of concretes containing palm oil fuel ash. DOI: 10.1061/ (ASCE) MT.1943-5533.0000104.

[14] Kearsley, E.P and Wainwright, P.J. 2002. The effect of porosity on the strength of foamed concrete. Cement and concrete research 32: 233-239, 2011.