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LONG TERM STUDIES ON COMPRESSIVE STRENGTH OF HIGH VOLUME NANO PALM OIL FUEL ASH MORTAR MIXES

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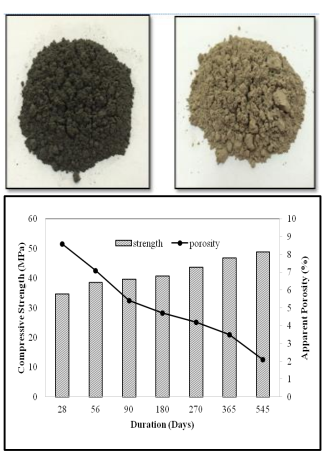
Graphical abstract



Abstract

Palm oil fuel ash is a waste material that can be used as partial cement replacement. However, its reactivity as pozzolanic material depends on the size of the particle. This paper presents the effects of nano size palm oil fuel ash on the long term characteristics of mortar. The study covers basic properties of mortar including the morphology, porosity, compressive strength and microstructural with regards to the variations in the mix design of the mortar. The palm oil fuel ash used has gone through heat treatment and was ground to a nano size with the percentage replacement of cement used was 60%, 80% and 100%. The different types of mortar samples were cast in a 70x70x70mm cube for compressive strength test. All casting and testing of the samples were conducted in the laboratory at ambient temperature. The results show that the use of 80% nano size palm oil fuel ash has produced higher compressive strength at the age of 28 days by 32% compared to the control mortar. Grinding the palm oil fuel ash to a nano size particle has improved the reactivity of the ash and because of it is a waste material it reduces the cost of the mortar. The experimental result also show that the compressive strength of the 80% nano size palm oil fuel ash mortar at 365 days was 25% higher than its strength at 28 days. In addition, the porosity of the 80% nano palm oil fuel ash mortar was reduced by 51% at the age of 1 year. The overall results have revealed that the use of high volume nano palm oil fuel ash can enhances the mortar properties and due to the high percentage of replacement it can contribute to a more sustainable construction.

Keywords: Palm oil fuel ash, nano size, high volume, porosity, strength development

1.0 INTRODUCTION

Huge amount of carbon dioxide is emitted into the atmosphere during cement manufacturing. Around 7% of the total carbon dioxide all over the world come from cement manufacturing according to the Intergovernmental Panel on Climate Change (IPCC) report in 2005 [1]. From 2005 to 2030 world cement manufacturing will increase yearly which could cause the level of carbon emission to reach 1.7 times more than what it was in 2005 [2, 3]. This carbon emission has negative effect on environment that causes global warming which concerns many researchers [4-6].

The need towards sustainability and sustainable environment has made the use of pozzolanic material in mortar popular. Therefore, reusing the abundant waste materials has become necessary especially wastes produced from palm oil manufacturing. One of the latest additions of pozzolanic material is palm oil fuel ash (POFA) [7-9]. POFA is a by-product from biomass thermal power plants where oil palm residues are burned to generate electricity [10] (Figure 1.)

(a) before

(b) after

Figure 1 POFA colour before and after heat treatment

Few studies have been done by other researchers on the replacement of partial weight of cement by POFA [11, 12], but there still remains high amount of ash abundantly available in the landfill which lead to environmental problems. It is reported that the maximum strength gain occurred at the cement replacement level of 30% POFA with the size of 45 µm. Further increment in the ash content would reduce the strength of mortar gradually [9].

Tangchirapat and Jaturapitakkul [13] reported that increasing the fineness of POFA has positive effect on the reduction of drying shrinkage and permeability of concrete. However none of researchers have studied the effect of POFA in nano size. The short term performances of nano palm oil fuel ash have been studied as cementitious materials in terms of chemical and physical properties [14, 16].

Therefore, in this paper, the long term effects of high volume of POFA with nano size used as cement replacement up to 80% were investigated. This could help prolong the age of mortar besides reducing the usage of expensive nano admixture for increasing compressive strength of mortar and carbon dioxide gas emission from cement production process.

2.0 EXPERIMENTAL

2.1 Materials

The cement used in this study complies with Portland cement Type I as stated in the ASTM C 150-12 [16]. POFA was obtained from the burning of palm oil shell and husk (in equal volume) at 450°C from a palm oil mill in Johor Malaysia. The collected ashes were dark in colour as shown in Figure 1 and the loss on ignition (LOI) was 20.9% for ground POFA. POFA has low pozzolanic reactivity due to its large particle size and porous structure [17]. Therefore, POFA has been treated and ground until nano size to increase the pozzolanic reactivity and to remove the unburned materials. Details of POFA treatment and its chemical compositions are presented in other published work [14, 15].

In the preparation process for all specimens, the fine aggregates (sand) were used in the saturated surface dry condition to reduce water absorption during mixing process [18, 19]. Fine aggregates were sieved through 2.35 mm sieve and retained at 300 µm before storing in the airtight container. Figure 2 shows the sieve analysis test on the fine aggregates. The grading curve for fine aggregates was within the limit line prescribed according to ASTM C33-03[20].

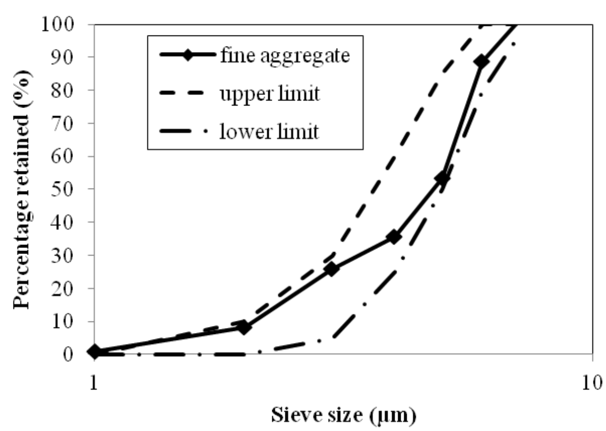


Figure 2 Sieve analysis for sand

2.2 Testing Procedures

All mortar specimens were prepared with sand to binder ratio of 3:1, whereby the sand was prepared into saturated surface dry condition. The mixing was carried out in a room temperature. The mix proportions are given in Table 1 based on weight of materials according to BS EN 998-1:2010 [21]. 60%, 80% and 100% of POFA were used as cement replacement. The test specimens of 70 x 70 x 70 mm cubes were prepared. The specimens were compacted in two-layers with rod tamping as described in ASTM C109-13 [22]. Additional vibration of about 10s was applied using the vibrating table. The test specimens were cured in water for 7, 14 and 28 days.

The particle size of POFA was measured using transmission electron microscopy (TEM). The morphology of POFA mortar was investigated by using field emission scanning electron microscopy (FESEM). The surface of the specimens obtained from the compressive strength test was coated with gold prior to their morphological observation.

Determination of apparent porosity of mortars was done according to ASTM C1403-13 [23]. Three cubes of mortars were oven-dried at 85°C for 24 hours and then immersed in water for 48 hours. The cubes were further suspended in water and weighted. The data were recorded and calculated for average.

Table 1 Mix proportion of mortar

Materials	Mortar mix			
	OPC	60% POFA	80% POFA	100% POFA
Cement (kg/m³)	525	210	105	-
POFA (kg/m³)	-	315	420	525
Sand (kg/m³)	1578	1578	1578	1578
w/c ratio	0.4	0.4	0.4	0.4

3.0 RESULTS AND DISCUSSION

3.1 Determination of Particle Size of POFA

The particle size of POFA was examined using transmission electron microscopy (TEM) technique. As shown in Figure 3, the particle size of POFA varied between 50-100 nm. The figure shows that POFA has spherical, crushed and irregular shape [14, 15].

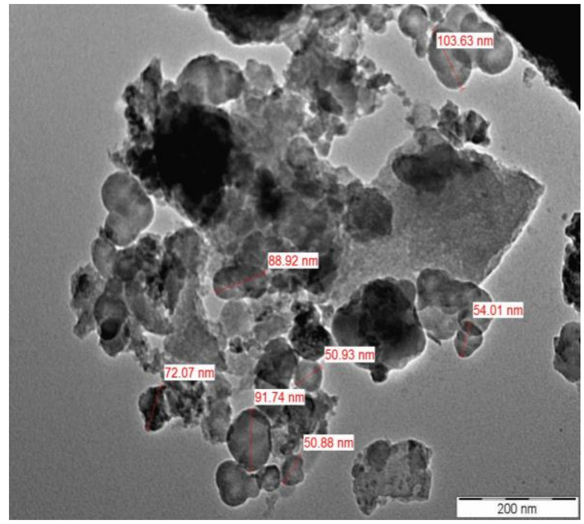


Figure 3 TEM test result for nano POFA

3.2 Compressive Strength

Figure 4 shows the strength development of OPC, 60%, 80% and 100% POFA mortar for more than one year. All the mortar mixes showed increment in compressive strength with the increasing duration of water curing. OPC mortar showed gradual increasing after 28 days meanwhile the specimens with 60% and 80% POFA mortar produced very high compressive strength at age of 28 days. This is due to the pozzolanic reaction between excessive $Ca(OH)_2$ formed from hydration process of cement with silica (SiO_2) of POFA. These, produce more C-S-H gel and make the mortar denser and more durable. Again, this showed that the packing effect of small particle size and pozzolanic reaction was fully involved [24]. However, the specimens with 100% POFA provided very low strength even at later age which was about 5 MPa. This is due to the lack of CaO content to produce $Ca(OH)_2$ for pozzolanic reaction to take place.

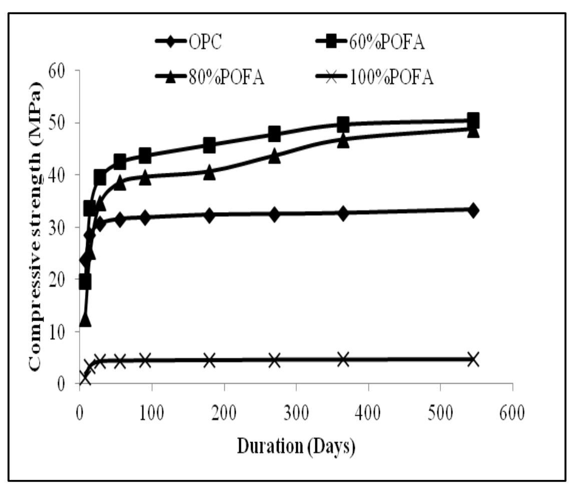


Figure 4 Strength development of POFA mortar up to 1.5 years

3.3 Porosity

Figure 5 shows the test results for apparent porosity of mortar mixes for more than one year. The results clearly indicated that the use of nano POFA reduced the porosity of mortar mixes at all ages. At early ages, the recorded porosity for high volume POFA mortar was higher compared with OPC mortar. This is due to the incomplete reaction between the binders. In addition, by increasing the POFA content from 60% to 100%, the porosity increases from 7.5% to 10%. However, the porosity for all POFA mortar reduces with the longer period of water curing. This is due to the hydration process and pozzolanic reaction during the period which was responsible for the reduction in porosity and the increase in strength of mortar.

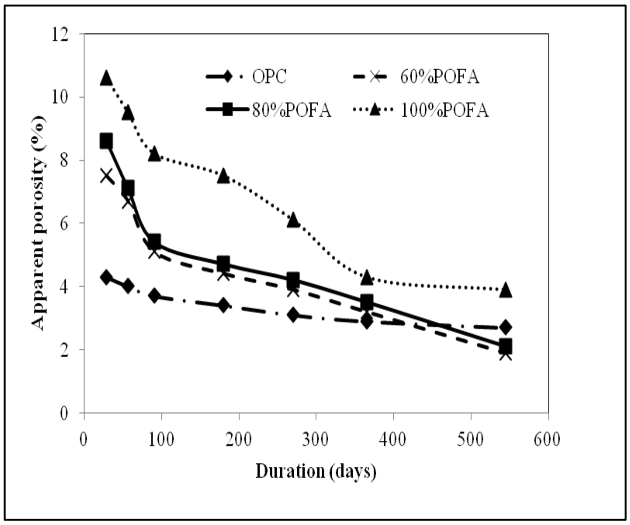


Figure 5 Apparent porosity of mortar mixes

3.4 Strength Development vs Porosity

Porosity of the mortars highly influences the strength of mortar. The reduction of porosity in mortar will increase its strength and makes it dense. Figure 6 shows the result of strength development and apparent porosity of 80% POFA replacement in water curing for more than one year. As shown in Figure 6, the 28 days apparent porosity was recorded as 8.6 % while the strength was 35 MPa. Prolonged curing period has shown to lower the porosity and increase the strength of the mortar. After 365 days of curing, the porosity was 3.5 % and the compressive strength was 47 MPa. The porosity decreased at 365 days which was recorded almost 51 % lower than its initial porosity. In the meantime, the compressive strength increased by 25 % from initial strength. This is due to the complete reaction between $Ca(OH)_2$ and SiO_2 from POFA that produced more C-S-H gel. Besides, the extra POFA also reacted as filler thus help reduce the porosity of mortar. Porosity has a significant effect on compressive strength of mortar [25].

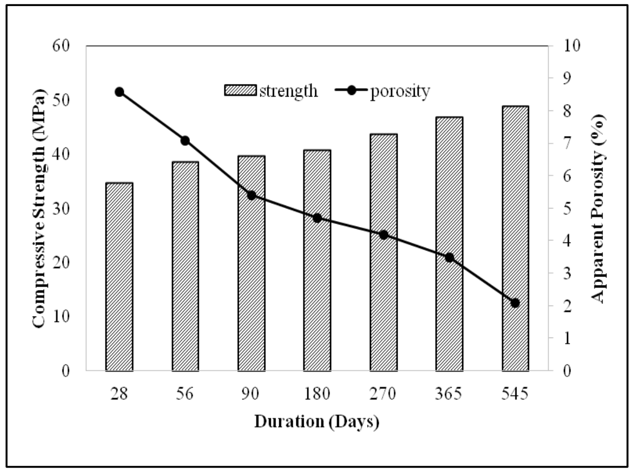


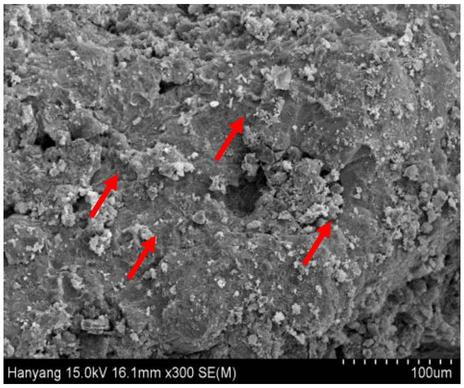
Figure 6 Relationship between compressive strength and porosity of 80% POFA replacement

3.5 Morphology of POFA Mortar

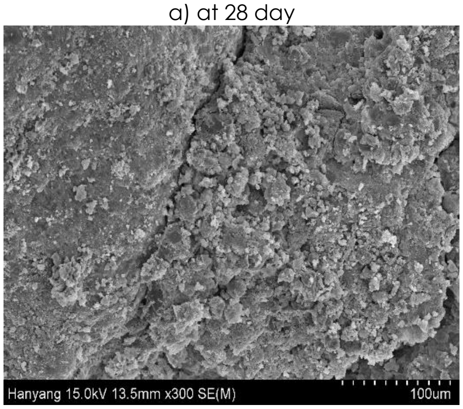
The microstructure of mortar was studied using Field Emission Scanning Electron Micrograph (FESEM) techniques. The porosity of mortar can be observed by using the FESEM techniques [26]. By increasing the age of curing the sample contains 80% POFA as cement replacement, the total amount of calcium silicate hydrated (C-S-H) crystals increased which consequently reduced the porosity. As shown in Figure 7, the specimens at 365 days carry fewer voids compared with specimens at 28 days. The ability of pozzolanic material to reduce the amount of $Ca(OH)_2$ in the paste has also been proved by previous researchers [27].

4.0 CONCLUSIONS

Based on the test results obtained it can be concluded that nano size POFA enhanced the properties of mortar and can be used up to 80% replacement of cement. The compressive strength of mortar with 80% POFA showed better strength at later age due to the pozzolanic reaction. The porosity recorded for POFA specimens decreased to almost 51% while the compressive strength increased by 25% from initial strength.



a) at 28 day



b) at 365 days

Figure 7 FESEM image of 80% POFA mortar at different ages

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