Long Term Studies on Compressive Strength of High Volume Ultrafine Palm Oil Fuel Ash Mortar Mixes

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ABSTRACT

The long term characteristics of nano palm oil fuel ash in the mortar were investigated. This study covers basic properties like the morphology, porosity, compressive strength and microstructure properties with regards to the variations in the mix design process of mortar. To get a better performance in terms of strength development, the ash used has gone through heat treatment and was ground up to nano size. The mortar mixes were cast in 70x70x70mm cubes for compressive strength test. The incorporation of more than 80% nano size palm oil fuel ash as cement replacement has produced a mortar having a compressive strength more than OPC mortar at a later age. By treating the palm oil fuel ash to nano size, help reduce the cost of expensive admixture for improving the compressive strength of mortar. The results also revealed that the compressive strength of mortar using nano size palm oil fuel ash shows higher value as compared to initial strength at the later age of 1 year by 25%. The porosity of 80% nano palm oil fuel ash mortar reduced 51% as the age of curing increased. The overall results have revealed that the inclusion of high volume nano palm oil fuel ash can produce a mortar mix with high strength, low porosity, good quality and most importantly that is more sustainable.

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

1. INTRODUCTION

Huge amount of carbon dioxide 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) reported in 2005 [1]. From 2005 to 2030 world cement manufacturing will increase yearly which causes the level of carbon emission reach to 1.7 times more than 2005 [2]. This carbon emission has negative effect in environment that cause warming which concern of many researchers.

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 waste produced from palm oil manufacturing. One of the latest additions of pozzolanic material is palm oil fuel ash (POFA) [3-5]. Palm oil fuel ash (POFA) is a by-product from biomass thermal power plants where oil palm residues are burned to generate electricity [6].

Few studies have been done by other researchers on the replacement of partial weight of cement by POFA [7, 8], but there is still high amount of ash abundant in the landfill which lead to environmental problems. It is reported that the maximum strength gain occurred at the replacement level of 30% with the size of 45 μm but further increment in the ash content would reduce the strength of mortar gradually [5].

Tangchirapat and Jaturapitakkul reported that increasing the fineness of POFA has positive effect on the reduction of dry shrinkage and permeability of concrete [9]. However none of them have studied the effect of POFA in nano size. The short term performances of nano palm oil fuel ash have been studied as cementatious materials in term of chemical and physical properties [10]. 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 helps to prolong the age of mortar besides reducing the usage of expensive nano admixture for increasing compressive strength of mortar and carbon dioxide gasses emission from cement production process.

2. METHODOLOGY

2.1. Materials

The cement used in this study complies with Portland cement Type I as stated in the ASTM C 150-12 [11]. Palm Oil Fuel Ash (POFA) was obtained from the burning of palm oil shell and husk (in equal volume) at 450°C from a southern part of Malaysia. The collected ashes were dark in colour as shown in Figure 1 and the losses on ignitions (LOI) were 20.9% for ground POFA. POFA has low pozzolanic reactivity due to its large particle size and porous structure [12]. Therefore, the POFA have been treated and ground until nano size to increase the pozzolanic reactivity and removed the unburned materials [10].

(a) before treatment (GPOFA) (b) after treatment (UPOFA)

Figure 1: POFA colour before and after treatment.

In the preparation process for all specimens, the fine aggregates were used in the saturated surface dry condition. The fine aggregate was 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[13].

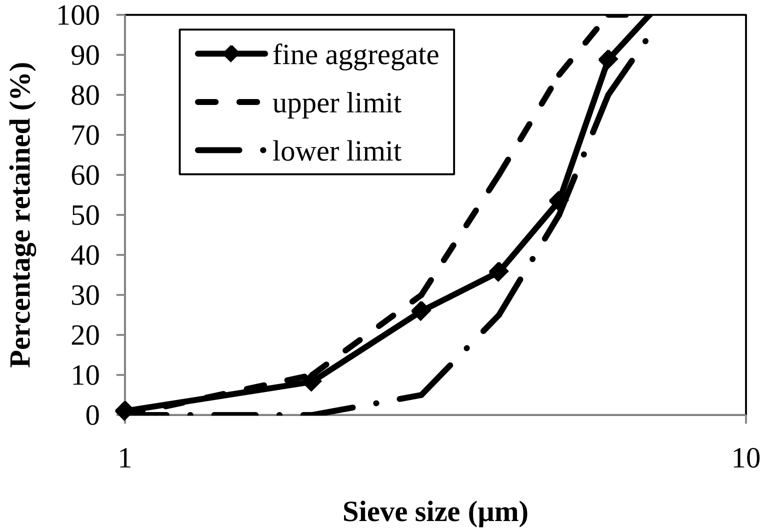


Figure 2: Sieve analysis of fine aggregate.

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 [14]. The test specimens of 70 x 70 x 70 mm cubes were prepared. The specimens were compacted in two-layer with rod tamping as described in ASTM C109-13 [15]. Additional vibration of about 10s was applied using the vibrating table. The test specimens were cured in water for 7, 14 and 28 days.

Table 1 Mix proportions of mortar.

Materials (kg/m^3)	**Mortar mix**			
	OPC	**60% POFA**	**80% POFA**	**100% POFA**
OPC	525	210	105	-
POFA	-	315	420	525
Sand	1578	1578	1578	1578
w/c ratio	0.4	0.4	0.4	0.4

The particle size of POFA was measured using transmission electron microscopy (TEM) and 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 [16]. 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.

3. TEST RESULTS AND DISCUSSIONS

3.1. Determination 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 were varied between 50-100nm.

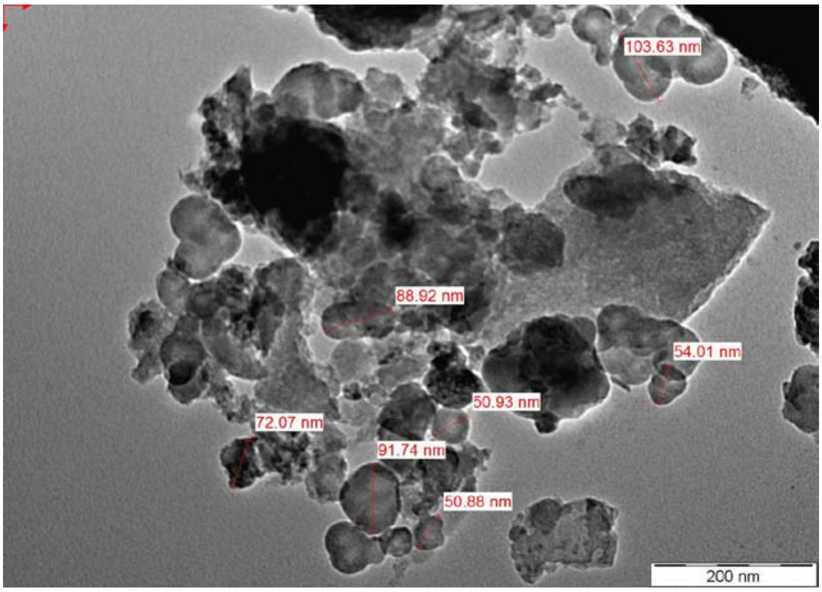


Figure 3: TEM test result for nano POFA

3.2. Compressive strength

Figure 4 shows the strength development of OPC, 60%, 80% and 100% POFA mortar until more than one year. All the mortar mixes shows increment in the compressive strength with the increasing duration of water curing. OPC mortar shows gradual increasing after 28 days meanwhile the specimens with 60% and 80% POFA mortar shows very high compressive strength at later age. This is due to the pozzolanic reaction between excessive $Ca(OH)_2$ from hydration process of cement with silica (SiO_2) from POFA. Therefore, 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 [17]. However, the specimens with 100% POFA shows very low strength even at later age which is about 5MPa. This is due to the lack of CaO content to produce $Ca(OH)_2$ for pozzolanic reaction to take place.

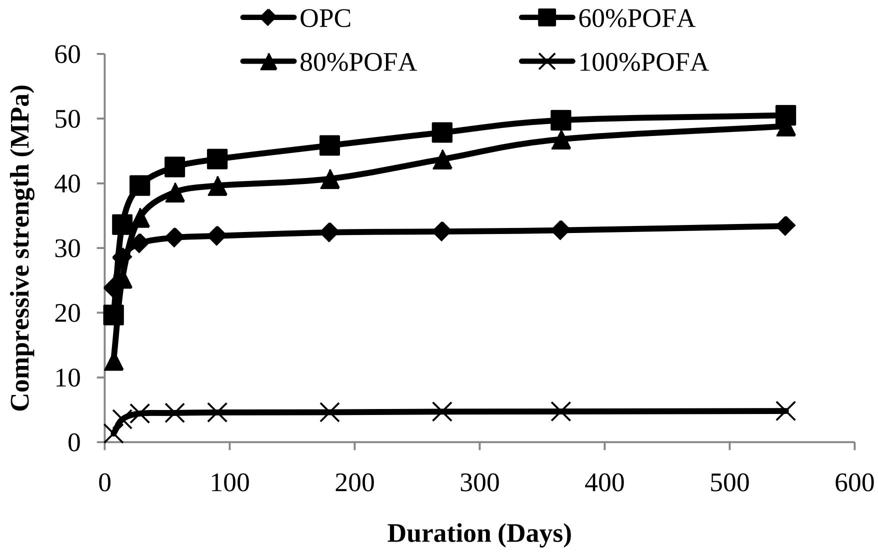


Figure 4: Strength development of POFA mortar until 1 year.

3.3 Porosity

Figure 5 shows the test results for porosity of mortar mixes up to more than one year. It is clearly indicates 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 compare to OPC mortar. This is due to the incomplete reaction between the binders. In addition, by increasing the POFA content from 60% to 100% increased the porosity 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 occurs during the period which responsible for the reduction in the porosity and increase in the strength of mortar.

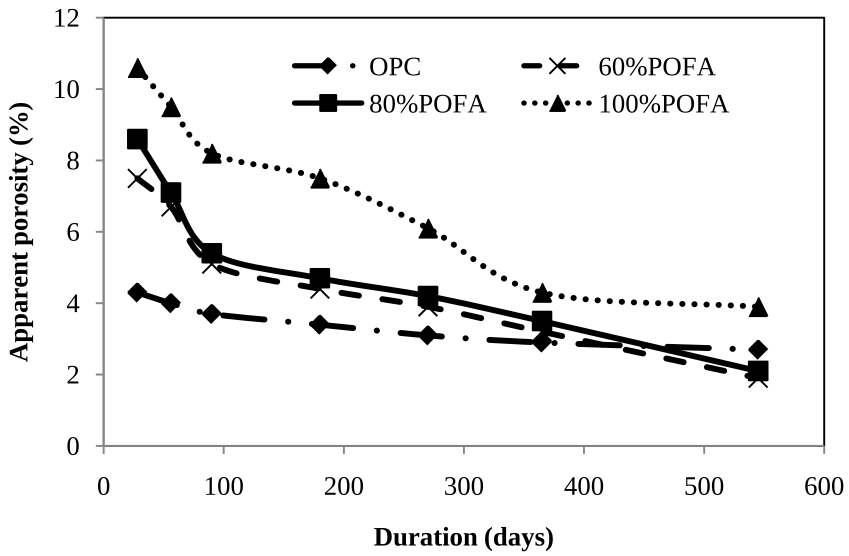


Figure 5: Apparent porosity of mortar mixes

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 denser. Figure 6 shows the result of strength development and apparent porosity of 80% POFA replacement with water curing for more than one year. As shown in Figure 6, the 28 days apparent porosity was recorded at 8.6 % while the strength was 35 MPa. Prolonged curing period has shown to lower the porosity and increases the strength of mortar. After 365 days of curing, the porosity was 3.5 % and the compressive strength was 47 MPa. The decreasing value of porosity at 365 days was recorded almost 51 % of 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 produce more C-S-H gel. Besides, the extra POFA also react as filler thus help reduce the porosity of mortar.

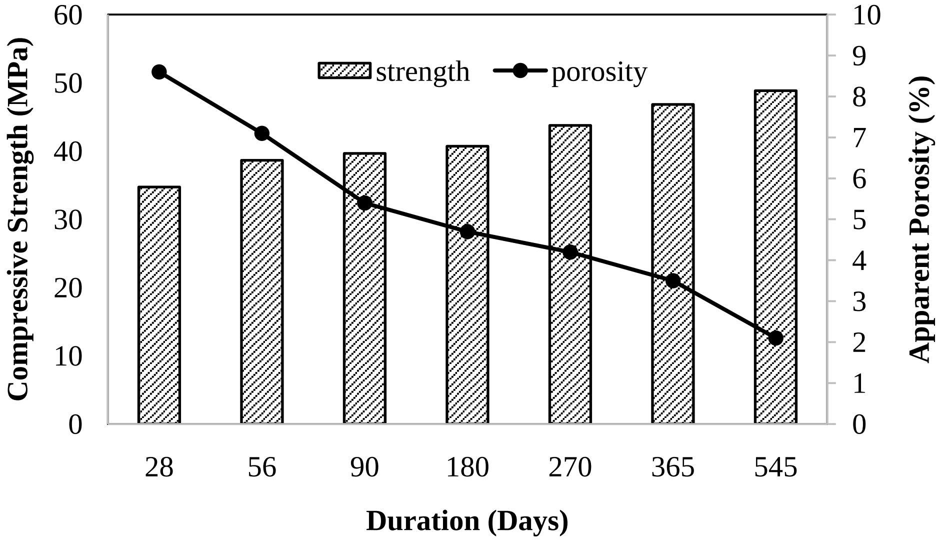
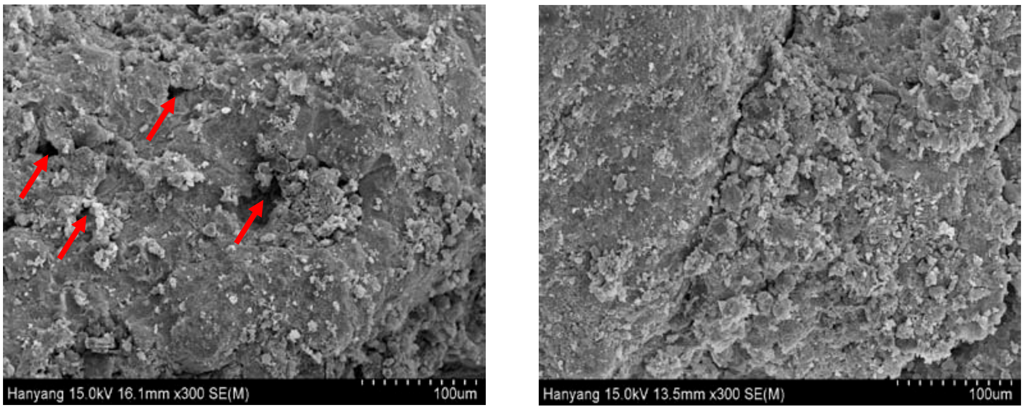


Figure 6: Relationship between compressive strength and porosity of 80% POFA replacement.

3.5 Morphology of POFA mortar

The microstructure of mortar was studied using Field Emission Scanning Electron Micrograph (FESEM) techniques. By increasing the age of curing the sample which containing 80% POFA as cement replacement the total amount of calcium silicate hydrated (C-S-H) crystals increase and consequently reduce the porosity. As shown in Figure 7, the specimen at 365 days has less void compare with specimen at 28 days. The ability of pozzolanic material to reduce the amount of calcium hydroxide ($Ca(OH)_2$) in the paste has also been proved by previous researchers [18].



a) at 28 days b) at 365 days

Figure 7: FESEM image of 80% POFA mortar at 28 and 365 days.

4. CONCLUSION

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. It was found that the compressive strength of mortar with 80% POFA shows better strength at later age due to the pozzolanic reaction. The porosity recorded for POFA specimens was decreasing for almost 51% while the compressive strength increased by 25% from initial strength.

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