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The effects of high volume nano palm oil fuel ash on microstructure properties and hydration temperature of mortar

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HIGHLIGHTS

- High volume of nano POFA as cement replacement improves strength.
- Nano POFA reduces hydration temperature of massive concreting in early age.
- Treatment of POFA increases pozzolanic properties and activity index.

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ABSTRACT

The effect of high volume nano palm oil fuel ash in the mortar was investigated. This study covers basic properties like the morphology of the composite, the hydration temperature, strength activity index, thermal conductivity and microstructure properties with regards to the variations in the mix design process of mortar. The effects of fineness of the ash on the strength properties of mortar were also investigated. To get a better performance in terms of strength development, the ash used has gone through heat treatment and was ground up to less than 1 μm. 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. The overall results have revealed that the inclusion of high volume nano palm oil fuel ash can produce a mortar mix with high strength, good quality and most importantly that is more sustainable.

1. Introduction

Affordable products with advanced properties are necessary towards the higher human development and sustainable economic growth. Therefore, reusing the abundant waste materials has become necessary especially waste coming from palm oil manufacturing. It is estimated that "the total potential palm biomass from 4.69 million hectares of palm oil planted area in Malaysia in 2009 is 77.24 million tonnes per year comprising of 13.0 million tonnes of Oil Palm Trunks (OPT), 47.7 million tonnes of Oil Palm Fronds (OPF), 6.7 million tonnes of Empty Fruit Bunches (EFB), 4.0 million tonnes of Palm Kernal Shell (PKS) and 7.1 million tonnes of Mesocarp Fibre (MF) (all dry weight)" [1,2]. These wastes are usually used as fuel in palm oil mill to generate electricity [3] and after the combustion in the boiler there are approximately 5% of ash generated [4] and another solid waste being produced. The need towards sustainability and sustainable environment has made the use of pozzolanic material in mortar popular. One of the latest additions of pozzolanic material is palm oil fuel ash (POFA) [5–7]. This POFA is the source of silicate that produced after the combustion of palm oil fibre, shell and mesocarp as fuel to generate electricity [8]. Few studies were done by other researchers on the replacement of partial weight of cement by POFA [9,10], 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]. Besides, POFA was also used as nano filler [11].

The hydration temperature of mortar describes the hardening behaviour of it. The mix properties and component of materials

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used in mortar have too much effect on hydration temperature. The heat released in hydration process of mortar containing blended ash is originating from two reactions firstly heat released from hydration of cement and secondly heat released from admixture reactions [12]. Therefore, exploring POFA as nano material would create an advanced waste material. In this paper, high volume of POFA with size less than 1 μm was used as cement replacement up to 80%. This helps to reduce the hydration temperature and carbon dioxide gasses emission from cement production process.

2. Materials and methods

2.1. Materials

The cement used in this study complies with Portland cement Type I as stated in the ASTM C 150-12 [13]. Palm oil fuel ash (POFA) was obtained from the burning of palm oil shell and husk (in equal volume) from a southern part of Malaysia. The collected ashes were dark in colour and the losses on ignitions (LOI) were 20.9% for ground POFA. The POFA was then dried in the oven for 24 h at 105 ± 5 °C and sieved through a 150 μm size sieve to remove coarser particles. Then the POFA was ground up until 90% passing 45 μm sieve according to ASTM C618-12 [14] and mention in this paper as GPOFA for ground POFA. Meanwhile, the POFA was then heated to 500 °C for 1 h in a furnace to remove the excessive unburned carbon [15,16]. The carbon content is an important factor to consider. These particles result in the increasing of water demand because it is absorbed by carbon particles [15,17]. Then it was subjected to further grinding using ball mill until it reaches the meridian size of less than 1 μm and in this paper refer to UPOFA for ultrafine POFA. To ensure the uniformity and fineness of POFA, all the treatment processes were controlled [16].

In the preparation process for all specimens, the fine aggregates were used in the saturated dried surface condition. The fine aggregate was sieved through 2.35 mm sieve and retained at 300 μm before storing in the airtight container. Fig. 1 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[18].

2.2. Testing procedures

All mortar specimens were prepared with sand to binder with the ratio of 3:1, whereby the sand was prepared into saturated surface dried condition. The mixing was carried out in a room temperature of approximately 28 ± 2 °C [19]. The mix proportions are given in Table 1 based on weight of materials according to BS EN 998-1:2010 [20]. The test specimens of 70 × 70 × 70 mm cubes were prepared. The specimens were compacted in two-layer with rod tamping as described in ASTM C109-13 [21]. Additional vibration of about 10 s was applied using the vibrating table. The test specimens were cured in water for 7, 14 and 28 days.

The morphology of UPOFA 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. A thermo gravimetric analysis (TGA) was carried out to investigate the thermal stability of the composites. The powder (about 25 ± 5 mg) was heated at a heating rate of 20 °C/min from 30 to 800 °C under nitrogen. Fourier transforms infrared spectroscopy (FTIR) which is a tool for qualitative and quantitative materials and identification of the composite group and chemical bonding in mortar specimens.

The activity index for UPOFA and GPOFA were checked for pozzolanic materials. As prescribed by ASTM C 311-13 [22], activity index is defined as:

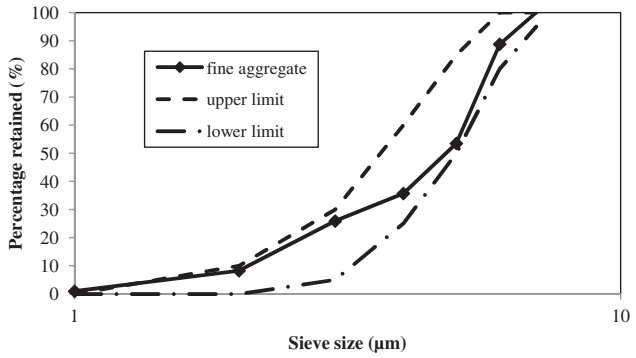

Fig. 1. Sieve analysis of fine aggregate.

Table 1
Mix proportions of mortar.

Materials (kg/m^3)		Mortar mix		
		OPC mortar	GPOFA mortar	UPOFA mortar
Binder	OPC	525	105	105
	GPOFA	–	420	–
	UPOFA	–	–	420
Fine aggregate		1578	1578	1578
w/b ratio		0.4	0.4	0.4

$$\text{Activity index (AI)} = (A/B) \times 100 \quad (1)$$

where A = average compressive strength of POFA mortar cube and B = average compressive strength of control mortar cube.

The compressive strength of the mortar cubes was determined using a 3000 kN compression machine according to ASTM C109-13 standards [21]. The test was performed on mortar cubes at the ages of 7, 14 and 28 days. For hydration temperature measurement, plywood with the size of 300 × 300 × 450 mm cube was used as the exterior mould. It was packed with 76 mm thick polystyrene acting as the insulator. Each mortar mix was cast into PVC pipe with the size of 150 mm diameter and 300 mm heights. The same method was used by other researchers [10,23] to determine the hydration temperature. A thermocouple (Type K) was inserted into the centre of each box and was connected to a data logger system. Recording the temperature was continued up to 7 days for the whole mortar types. Fig. 2 shows the equipment used in the test.

3. Results and discussions

3.1. Chemical and physical properties

The chemical and physical properties of OPC, GPOFA and UPOFA are shown in Tables 2 and 3, respectively. It reveals that the OPC and POFA have similar characteristics base on the chemical composition. UPOFA sample contains higher percentage of silica content than GPOFA and OPC. Obviously, the presence of higher silica content influences the pozzolanic reaction to produce extra calcium silicate hydroxide gels thus makes the mortar more durable and denser. The findings show that the GPOFA used is classified as Class C pozzolan meanwhile UPOFA as Class F pozzolan [14] which conform to the observations made by a previous research [23].

Results show that the heat treatment reduced the LOI of POFA from 20.9% to 1.3% hence removed the unburned elements in the POFA. The fineness of UPOFA is 146% more than OPC used in this study. The percentage of particle retain on sieve size 45 micron are 4.5, 4.9 and 0.13 for OPC, GPOFA and UPOFA, respectively. Thus, the UPOFA have large surface area and significantly smaller particle size in comparing with OPC and GPOFA.

Fig. 2. Test equipment for measuring hydration temperature.