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Use of an agricultural by-product, nano sized Palm Oil Fuel Ash as a supplementary cementitious material

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HIGHLIGHTS

- Palm Oil Fuel Ash is one of the agricultural waste come from palm oil industry.
- Its material properties and its effects on cement matrix were examined.
- Through all experimental results, a schematic hydration mechanism could be drawn.
- Nano sized Palm Oil Fuel Ash could be used as an eco-friendly supplementary cementitious material.

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ABSTRACT

An experimental study was conducted with objectives to find out the properties of nano sized Palm Oil Fuel Ash (nPOFA), which is a by-product of palm oil industry, and its effects on the hydration kinetics. The replacement ratios of nPOFA was set at 0–90%. Mortar and paste specimens containing nPOFA were prepared to study the effects of nPOFA on compressive strength and the microstructure. The results of X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FT-IR), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) indicated that the nPOFA mainly consists of SiO_2 and its average size is 100–150 nm. There was an increase in compressive strength of mortar specimens by the incorporation of nPOFA. However, more than 40% of nPOFA caused the reduction in compressive strength. As curing age increases, the microstructure of the specimens with nPOFA became denser than the samples without nPOFA due to the refinement of microstructure. The reduction in $Ca(OH)_2$ from pozzolanic reaction and the further formation of C-S-H were confirmed by thermogravimetric analysis (TGA), XRD and FT-IR. On this basis, a schematic hydration mechanism of nPOFA in cement matrix was proposed, and it is anticipated that nPOFA could be used as eco-friendly cementitious materials.

1. Introduction

Cement is the most important ingredient in concrete manufacturing, but it requires a calcination process in high temperatures at about 1450 °C, which results in the emission of 0.85 ton of CO_2 per 1 ton of cement production [1]. The amount of CO_2 from this process takes approximately 7% of the global CO_2 generation and the cement industry releases the second biggest amount of CO_2 after the power generation industry [2]. In addition to this, 3.2–6.3 GJ of energy is consumed in the burning process [3,4]. Because of the drawbacks, such as the profuse CO_2 emission and energy consumption, there are active ongoing studies to develop new mineral admixtures and incorporate them into concrete to reduce cement usage in concrete manufacturing [5,6].

The by-products of power, steel, and agricultural product processing are widely used as supplementary cementitious materials (SCMs). They affect the strength and durability of concrete by forming additional hydration products with their high contents of SiO_2 or CaO. These materials can be generally classified into two categories of industrial and agricultural by-products [5,7]: slag, fly ash, and silica fume, etc. in industrial by-products [8–10]

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and Palm Oil Fuel Ash (POFA) [11,12], rice husk ash (RHA) [13,14], corn cob ash (CCA) [15,16], and bamboo leaf ash (BLA) [17], etc. in agricultural ones.

As seen in Fig. 1, Palm Oil Fuel Ash (POFA) is one of agricultural by-products obtained from the combustion of residues from a palm oil generation, such as palm fiber and palm kernel shell, for electricity production in a palm oil factory [18]. Then, approximately 5% of the whole residue capacity turns into POFA; as it is mainly composed of silica and alumina and has non-crystallinity, many researchers found out its potentials to be used as SCMs [19,20]. However, only some of the residues turn into POFA and the rest of them are left on the ground, thus causing environmental problems [21].

According to a statistical report from the United States Department of Agriculture, the global production of palm oil has been increasing every year, with 65 million tons currently in November 2016 [22]. Therefore, as the palm oil production increases, the necessity to handle the residues also does. Accordingly, there are many studies to enhance the usability of POFA, mainly in Southeast-Asian countries, Malaysia and Indonesia [23]. In order to solve the problems related to POFA, such as the huge amount of loss on ignition (LOI) and low specific surface area, POFA was treated with additional burning and grinding process [19], and the Universiti Teknologi Malaysia recently developed nanoscale POFA (nPOFA) with a high surface area and a low LOI [24]. However, there are still lack of studies about the effect and/or role of nPOFA on cement-based composite materials as SCMs.

Thus, we performed an empirical study to evaluate the material properties of the newly developed nPOFA and its hydration kinetics within cement paste. Based on the results obtained through the experiments, this study suggests a hydration mechanism of nPOFA in cement paste, and a possibility of nPOFA to be used as a cementitious material.

2. Experimental program

2.1. Outline of experiment

Experiment plan was prepared to analyze the material properties of nPOFA and its effects on mechanical properties and the microstructure of cement paste as shown in Table 1. First, in order to understand the composition and morphology of the nPOFA,

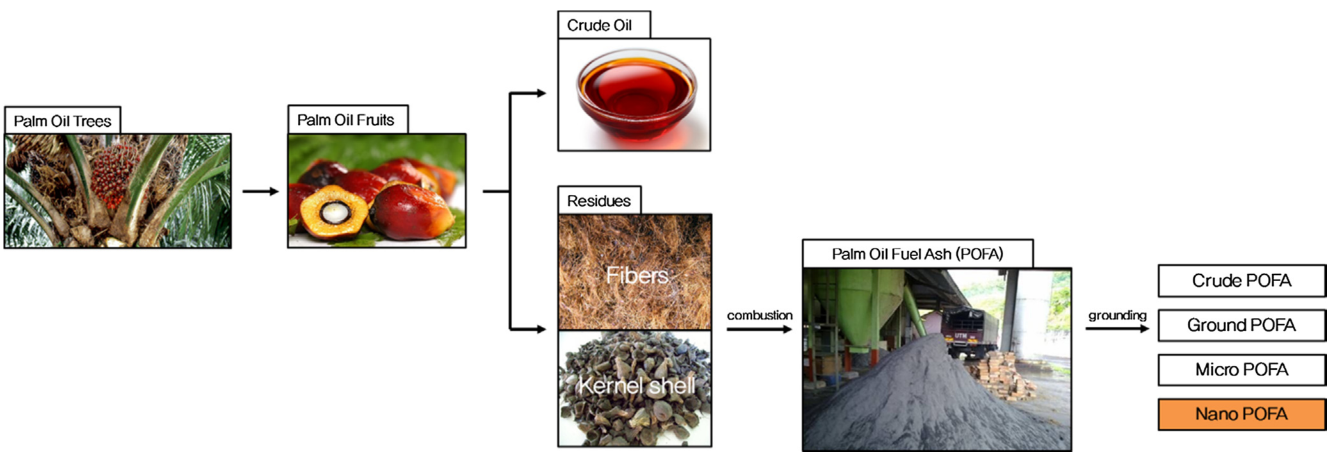

Fig. 1. Production of Palm Oil Fuel Ash (POFA).

Table 1
Experimental plans.

Category	Experiments	Experimental Factors
Characterization of the nPOFA	XRF, BET, XRD, FTIR, SEM, TEM	nPOFA particle
Effects of nPOFA on cement-based composite materials	Compressive strength	- Replacement ratio of nPOFA (0, 10, 20, 30, 40, 70, 80, 90%) - Curing ages (3, 7, 28, 56 days)
	MIP	- Replacement ratio of nPOFA (0, 10, 20, 30, 40, 70%) - Curing ages (7, 28, 56 days)
	TG/DTA	- Replacement ratio of nPOFA (0, 10, 20, 30, 40, 70, 80, 90%) - Curing ages (7, 28, 56 days)
	XRD	- Replacement ratio of nPOFA (0, 10, 20, 30, 40, 70%) - Curing ages (7, 28, 56 days)
	FTIR	- Replacement ratio of nPOFA (0, 10, 30, 70%) - Curing ages (7, 28, 56 days)
	SEM	- Replacement ratio of nPOFA (0, 30, 70%) - Curing ages (7, 28, 56 days)