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Characterization of Alkali-Activated Palm Oil Fuel Ash Pastes as a Function of Calcination Temperatures of Raw Precursor

Reference

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ABSTRACT

This research investigates the influence of calcination temperatures of palm oil fuel ash (POFA) on the properties of the raw precursor and its hardened binder after alkali activation. The raw POFA obtained from palm oil mill is treated at 500°C, 600°C, and 700°C for approximately 6 h. The treated POFA (TPOFA) is characterized for particle size distributions and chemical compositions by X-ray fluorescence (XRF); microstructural properties by observing through scanning electron microscopy (SEM); and Fourier-transform infrared spectroscopy (FTIR) for molecular functional groups. Pastes of alkali-activated POFA (AAPOFA) are synthesized with 12 M sodium hydroxide (NaOH) as alkali activator where the liquid to binder ratio is 0.4. Calcination temperatures are observed to have some influences on the physical properties (such as color, texture, particle size and fineness) and chemical properties (such as composition and reactivity) of the raw precursor. These properties control microstructural evolution of hardened pastes, compressive strength and capillary sorptivity properties of the hardened pastes. Overall results show 500°C is the optimum calcination temperature for POFA that contributes to comparable strength and lowest permeability of AAPOFA binders.

Keywords

palm oil fuel ash, calcination, alkali-activated materials, microstructure

Introduction

A total of 8 % of the world's total carbon dioxide (CO_2) emissions are mainly contributed by carbonation of calcium carbonate or fuel utilized for clinker formation in cement production.[1] The high demand of concrete as construction material in the construction industry has resulted in high volume of CO_2 emissions, which, consequently, yields adverse environmental impacts. Because of this matter, the need for new alternative binders utilizing industrial by-products such as fly ash, silica fume, and ground granulated blast-furnace slag as raw materials for cement making has increasingly become an interest in the concrete industry.

Southeast Asia countries (such as Malaysia, Indonesia, and Thailand) are among the largest producers of palm oil in the world. This is supported by a statistical analysis conducted in 2015, which indicated that Indonesia, Malaysia, and Thailand have significantly contributed to 48 %, 38 %, and 3 % of the world's palm oil production respectively, as compared with Nigeria (2 %), Columbia (1 %), Papua New Guinea (1 %), and others (7 %).[2] With this mass production, huge amount of wastes and by-products from palm oil mills and industries are also generated and discarded. These include empty fruit bunches, oil palm shells, palm oil clinker, and palm oil fuel ash (POFA).[3–5]

POFA as waste has been shown to have good pozzolanic properties when used as cement replacement.[6–9] POFA is rich in silica and alumina, which promote its potential to be used as a partial cement replacement.[10,11] This good pozzolanic properties are because of the richness of siliceous source in POFA, which leads to stronger and dense concrete.[12] The lime content in POFA is found to be distinctly lower than the ordinary portland cement (OPC), thus attributing to less cementing properties (such as cohesive and adhesive features). However, with the presence of calcium oxide (CaO) or calcium hydroxide ($CaOH_2$), the silica and alumina in POFA will react and form cementitious materials that potentially depict good pozzolanic properties.

The differences in the properties of POFA collected from various palm factories are normally due to the different industrial processes and technologies adapted by the mills. For instance, different incineration temperatures operated by different factories will cause varying physical properties of POFA, such as carbon content and colors. The color of POFA implies its carbon composition. Dark-colored POFA, which is produced when the palm oil industrial by-products are incinerated at low temperatures, indicates that there is still a high amount of unburned carbon present in the POFA after incineration. In comparison, light-colored POFA is produced when POFA is burned at higher temperatures, with greater extent of combustion. This, therefore, leads to different classification of POFA. For instance, based on ASTM C618-17a, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, Class F POFA contains a lower amount of carbon, as compared with Class C POFA, which has a high amount of carbon. Hence, chemical compositions of POFA taken from various sources can vary because of the different operational methods or conditions undertaken by the plants.

POFA is not suitable to be used as cement replacement material because of its low rate of pozzolanic reaction.[13] However, when sieved POFA with much smaller particles size is used in making concrete, it is observed that its rate of pozzolanic reaction increases.[14,15] Studies conducted by Chindaprasirt and Rukson[16] and Al-Mulali et al.[17] also revealed the same trend, in which particle size of POFA would affect its pozzolanic reactivity. It was deduced that the smaller the particles size of POFA, the higher its pozzolanic reaction. Therefore, POFA needs to be sieved or grinded prior to the experiment to ensure that only fine POFA is used in the analysis.[17]

The application of POFA in concretes is not limited to normal concretes but it also extends in producing special concretes such as high-performance concretes,[18] self-compacting concretes,[19] and lightweight concretes for nonstructural building materials.[20] Other research studies also show that POFA can be incorporated in bricks and interlocking blocks production for use in sustainable housing.[21]

Alkali-activated materials have shown their very promising potential as OPC replacement materials. They are produced from the reaction between pozzolanic materials that are rich in alumina and silica with alkaline solution. POFA has also been investigated as one of the potential alkali-activated materials.[18–21] Regardless, there have been very minimal studies conducted on the influence of calcination temperatures on the mechanical