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Synergism between palm oil fuel ash and slag: Production of environmental-friendly alkali activated mortars with enhanced properties

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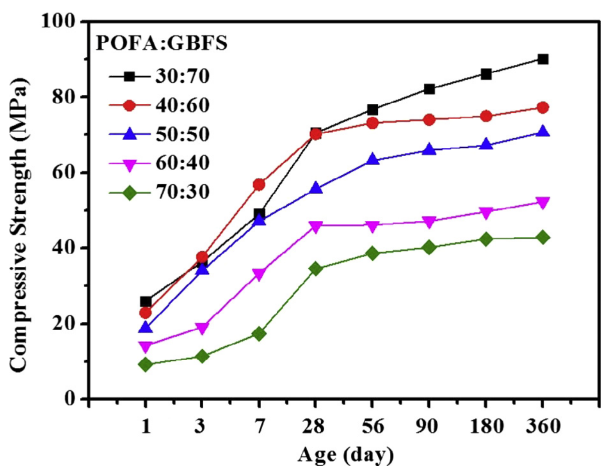
HIGHLIGHTS

- Developped sustainable and high performance environmental-friendly alkali activated mortars.
- The inclusion of high volume POFA enhanced the setting time of alkali activated mortars.
- The addition of POFA improved the resistance to acid attack of alkali activated mortars.

GRAPHICAL ABSTRACT



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ABSTRACT

Environmental concern raised by the production of ordinary Portland cement (OPC), is behind the search for greener construction materials and remediation. One such material is alkali activated mortars (AAMs). It is well known that the high molarity of sodium hydroxide (12–16 M) and high content of sodium silicate (sodium silicate to sodium hydroxide higher than 2.5) have negative impacts on the environment. Driven by this idea, we prepared some binary alkali activated mortars by combining palm oil fuel ash (POFA) and ground blast furnace slag (GBFS) at varying ratios. The effect of low concentration alkaline solution on the fresh, mechanical and durable properties of alkali activated was determined. The ratio of sodium hydroxide (molarity 4 M) (NH) to sodium silicate (NS) in the mixture was kept at 0.75. Microstructures of the prepared alkali activated mortars were analyzed using SEM, XRD and FTIR measurements. The achieved high strength (≈72 MPa at age of 28 days) of the alkali activated mortars was attributed to the synergy between GBFS and POFA. Partial replacement of GBFS with POFA was

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demonstrated to be beneficial for improving the compressive strength, durability and resistance against sulphuric acid attack. Meanwhile, calcium aluminium silicate hydrate (CASH) gel was discerned to be the main reaction product of POFA and GBFS in these binary systems. It was established that the proposed AAMs can contribute towards the development of sustainable materials.

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1. Introduction

Over the years, the celebrated ordinary Portland cement (OPC) has been widely exploited as concrete binder in the construction industries worldwide. Having known that large scale manufacturing of OPC has been causing serious pollution issues in terms of considerable amount of greenhouse gas emissions, yet alternative solutions are still lacking [1–4]. The ever increasing environmental pollution, massive depletion of finite natural resources, and low durability of conventional concrete in aggressive environments together with its rapid degradation compelled several researchers to create construction materials to use instead of the OPC [3,5]. Lately, alkalis activated are introduced as substitute binder material to OPC in the construction sector [6,7]. Commonly, Alkalis activated are prepared via the alkaline solution activation of GBFS, calcined clay, fly ash (FA) and other aluminosilicates (ASs). They are established to be prospective unconventional binding agent [8–10].

Diverse agriculture industries in Malaysia, Indonesia and Thailand produce huge quantities of palm oil by-product as wastes and called POFA. Increased plantation of palm oil trees in these countries is expected to raise the POFA production continually [11]. POFA is derived by burning empty fruit bunches, oil palm clinkers and shell for electricity generation. In 2007, a survey revealed that the annual production of POFA in Malaysia and Thailand was above few million tons and is continuously escalating [12]. Interestingly, POFA having no market value is simply dumped as land fillers into the ponds or lagoons [13], which creates a serious environmental concern. However, recent studies [14,15] have shown that POFA being rich in silica content can be beneficial for the construction purposes in terms of sustainable development. Such advancement added further research impetus towards intensive use of this cheap and abundantly available resource material (POFA). Yet, POFA being classified as pozzolanic substance [16] can be used as a partial substitute for OPC in the traditional concrete to enhance its strength and durability [17] or as AAMs binder [18–20].

Likewise, GBFS is also a waste material that is obtained by quenching molten iron slag. It is a by-product of iron and steel-making produced from the blast furnace in water or steam. The product is a glassy and granular material. Such slag is further dried and ground into a fine powder. The chemical composition of slag alters greatly based on the raw material constituents in the iron production process. Additionally, GBFS shows cementing and pozzolanic properties due to the presence of high contents of CaO and SiO_2. Consequently, GBFS has been widely used in the construction industries to improve the durability and mechanical properties of conventional concrete [21]. GBFS incorporation in alkalis activated was found to modify the microstructure and durability of the concrete [22]. Yusuf et al. [23] reported the inclusion of GBFS in alkalis activated mortars as binder to enhance its strength. The strength enhancement was primarily attributed to the pore-filling effects, formation of weakly ordered homogenous microstructures, and dual products made of highly polymerized alkali activated unit and calcium-silicate-hydrate (C-S-H) gel. GBFS was shown to contribute gradually to the solubility of Ca, heterogeneity, and amorphosity of the product. Furthermore, the formation of C-S-H and C(N)AH products of Ca/Na-aluminosilicate-hydrate was responsible for the enhancement of the compressive strength of the concrete [22,24,25].

Despite excellent performances of the aforementioned alkali activated materials several existing shortcomings limits their practical applications. The high molarity of sodium hydroxide and excessive ratio of sodium silicate to sodium hydroxide restricts the broad usage of alkalis activated in the construction industries. On top, the cost, hazard, toxicity and environmental problems enhances with the increase of NH molarity and NS content required for alkalis activated preparation. Alkalis activated with low concentration of alkaline solution lead to the environmental remedy, energy saving and intensive applications in the construction fields. Thus, by activating low molarity alkaline solution to POFA and GBFS blends a robust alkali activated material with enhanced properties can be achieved, which requires thorough evaluation.

By considering the notable attributes of POFA and GBFS, we prepared environmental-friendly alkali activated mortars using various combinations of POFA and GBFS activated with low molar concentration of alkaline solution (4 M of NaOH with sodium silicate to sodium hydroxide ratio of 0.75). This new type of alkali activated (at low molar contents) mortar was prepared via the partial replacement of GBFS (in the range of 30%–70% by weight) with POFA. In this study, the solid wastes were recycled effectively to determine the feasibility of reducing their impact on environmental pollution. Furthermore, it established a probable working range for the use of waste materials and other physical conditions for alkali activated mortar preparation which could reduce the conventional use of excessive alkaline solution. The fresh properties, density, mechanical strength, microstructure evolution and water absorption of the achieved alkali activated mortars were evaluated. Consequently, an alternate sustainable construction material with excellent engineering properties was developed.

2. Experimental program

2.1. Constituent materials

2.1.1. Palm oil fuel ash (POFA)

As aforementioned, POFA is a waste material generated by the palm oil mills. In the present study, POFA was collected from an ash outlet in Kilang Sawit PPNJ Kahang (Johor, Malaysia). The large particles from POFA were removed using 600 μm sieve before being dried in an oven at 105 °C for 24 h. This was followed by sieving using 300 μm to eliminate the presence of large particles to improving the efficiency of the POFA. Next, the sieved POFA was ground for a period of 6 h using Loss Angeles Abrasion milling machine to achieve fine particles. The machine contained 15 stainless balls (each 50 mm in diameter) with a drum speed ranging between 32 and 35 revolutions per minutes (rpm). The grinding duration has affected the particles finesse, which was measured in every hour. The percentage of particles retained on 45 μm sieves is reduced with grinding duration. All the POFA samples were passed through the same sieve after grinding completed. It is well known that the engineering properties and microstructural density of mortar and concrete enhance with the increase in the fineness of binder materials. Table 1 provides the essential properties of POFA which is grouped to Class F pozzolana according to ASTM C618-15 specifications. The physical properties such as colour, particle size, specific surface area and specific gravity were evaluated. POFA was dark grey in colour, particle size 8.2 μm, specific surface area 23.1 g/m^2, and specific gravity 1.96.

2.1.2. Granulated blast furnace slag (GBFS)

The cement-free binder was made using pure GBFS which was collected from Ipoh (Malaysia). This resource material was utilized without any laboratory treatment. GBFS is considered differently than the other supplementary binding

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