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Mechanical and durability performance of novel self-activating geopolymer mortars

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Abstract

The research project aimed to explore the feasibility of activating fly-ash based geopolymer by the hybridization of fly-ash (FA) with high calcium wood ash (HCWA), a by-product from timber manufacturing industry, without the addition of conventional alkaline activators and post heat treatment curing regime. The raw materials namely FA and HCWA were characterized in term of their chemical and mineralogical phases by X-ray diffraction (XRD) and X-ray fluorescence (XRF). FA was substituted by HCWA at high replacement level of 50% to 100% at 10% incremental, by binder weight. Hardened geopolymer mortars samples were subjected to water curing and tested on the age of 7, 28 and 7 days + 24 hours hydrothermal treatment. Mechanical performance of the geopolymer mortars were assessed in term of compressive, flexural strength, ultrasonic pulse velocity (UPV) and dynamic modulus. Durability properties namely water absorption, vacuum porosity and capillary absorption were also investigated. Results were positive on the viability of hybridizing FA with HCWA to produce novel self-activating geopolymer mortars as mixtures with PFA replacement level of 50% and 60% showed enhanced mechanical and durability performance at all curing ages in comparison with other HCWA-PFA geopolymer mortar mixtures. Early strength development of HCWA-PFA geopolymer mortars was mainly contributed by the combination of hydraulic reaction of HCWA and geopolymerization of FA. On prolonged curing, strength development was due to the aforementioned reactions, plus pozzolanic reaction between the reactive silica from FA and portlandite formed from HCWA, producing additional secondary C-S-H gels. This experimental program showed positive findings in incorporating highly alkaline materials i.e. HCWA (12% K_2O) towards activating FA based geopolymer, thus eliminating the needs of external alkaline activator in conventional geopolymer mix design.

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Keywords: geopolymer concrete; fly ash; self-activating; waste management; low embodied energy; high-calcium wood ash; low alkalinity.

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1. Introduction

Research in the field of geopolymer technology has gathered pace in the past decades owing to the environmental impact of Ordinary Portland Cement (OPC) production which raised concern amongst the practitioners regarding the sustainability of construction industry [1]. Various source materials have been employed with success such as pulverized fuel ash (PFA) or more commonly known as fly ash, ground granulated blast furnace slag (GGBS) , rice husk as (RHA), palm oil fuel ash (POFA) etc in which the resultant geopolymer mixes exhibited similar or enhanced mechanical and durability performance if compared with OPC concrete [2-5]. However, the transition of geopolymer technology into mass production has not been successful. One of the major drawback of geopolymer system is the over reliance of alkaline activator in order to achieves the desired mechanical and durability performance [6]. The most common alkaline activator used is the synergy mixes of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The dosage of alkaline activators (NaOH + Na_2SiO_3) in conventional geopolymer mix design ranged from 0.30-0.50 [7, 8] and moreover conventional geopolymeric system most often requires elevated temperature curing ranging from 60-90 ^oC [9, 10]. The two aforementioned factors have raised doubt on the practicability of geopolymer technology for industrial implementation as it significantly increased the effective cost and also the embodied energy of production of the resultant geopolymer mixes. Current laboratory investigation aims to tackle the aforementioned challenges by incorporating timber manufacturing waste material i.e. high calcium wood ash (HCWA) into fly ash based geopolymer mortar at high PFA replacement level i.e. ≥ 50% of total binder mass without the need of alkaline activators and elevated curing temperature.

2. Materials and methods

2.1. Materials

ASTM Class F PFA was sourced from local coal-fired power plant in Manjung, Perak, Malaysia. The specific gravity and specific surface area of PFA were determined to be 2.8 and 3244 cm^2/g, respectively.

High Calcium Wood Ash (HCWA) is a by-product from local timber manufacturing industry which utilized wood-waste such as saw dust, woodchips etc in the boiler unit to generate energy for wood drying purposes. Freshly extracted HCWA was sieved through laboratory sieve of 600µm to remove carbonaceous and large agglomerated particles before being used as constituent materials in the geopolymer mortars fabrication. HCWA was found to have specific gravity of 2.43 and specific surface area of 5671 cm^2/g. The detailed chemical composition characterization of PFA and HCWA can be found in author's previous publication [11, 12].

Locally available natural siliceous river sand with specific gravity of 2.65 and maximum aggregate size of 5mm was used as fine aggregate throughout the laboratory investigation. Potable water from local water supply network was used as mixing water.

2.2. Methods

2.2.1. Mixture proportioning, mixing and curing

In the experimental program, PFA was replaced by HCWA at 50-100% by binder weight, at 10% step incremental. The sand to binder ratio was held constant at 2.25 throughout the program. The workability of the fresh geopolymer mortars was controlled at between 120-150mm for adequate compaction using the flow table apparatus, thus the water to binder ratio for each mixes varied. The mixture proportioning of HCWA-PFA geopolymer mortars were shown in Table 1.

HCWA-PFA geopolymer mortar mixes were homogenized using epicyclic mixer. The freshly casted mortar samples were left to cure in ambient temperature curing condition i.e. 26^oC and 85% RH for 24 h before being subjected to water curing until the designated testing ages. All the hardened HCWA-PFA geopolymer mortar samples were tested at the age of 7, 28 and 7 + 24 h hydrothermal treatment.