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Fabrication and characterization of thermally-insulating coconut ash-based geopolymer foam

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ABSTRACT

This study aims at synthesizing porous coconut ash (CA)-based geopolymer foam with high thermal insulation property. Sodium hydroxide (NaOH), alumina slag (AS) and water contents as the main parameters, which affect the performance hardened CA, have been studied. The porosity was developed by hydrogen gas resulted from the interaction of Al metal, in AS, with NaOH. The compressive strength, bulk density, porosity and thermal conductivity were evaluated. The results proved that the AS has a potential impact on the reduction of thermal conductivity of CA-based geopolymer foam by creation of high porous system. Open celled hardened CA-based geopolymer with high porosity (~87%), low thermal conductivity (~0.045 W/m·K), compressive strength (1.3 MPa) and bulk density (~0.60 g/cm^3) was obtained when 7% AS (by weight of CA powder) and water to CA powder ratio of 0.4 were used.

1. Introduction

Alkali activated cementitious materials can be defined as inorganic aluminosilicate polymer which prepared by mixing of alkaline solutions with amorphous aluminosilicate materials such as metakaolin, granulated slag, fly ash (Kouamoa et al., 2013; Pelisser et al., 2013; Saidi et al., 2013; Temuujin et al., 2010; Yusuf et al., 2014; Zhang and Chai, 2014). These binders regarded as environmentally friendly with higher mechanical properties and resistivity against acid as well as firing comparing with ordinary Portland cement (Bakharev et al., 2002; Berndt, 2009; El-Didamony et al., 2012). Also, alkali activated materials are categorized as good alternatives to ordinary Portland cement (OPC) due to decrease the CO_2 emission and the beneficial utilization of different types of wastes (Luukkonen et al., 2018).

The main shortcoming which retards the commercial viability of geopolymer is the corrosive nature of alkaline solution used in the activation of aluminosilicates. This issue has been resolved by synthesizing one-part geopolymers which react with water like Portland cement (Abdel-Gawwad et al., 2018a; Abdel-Gawwad et al., 2018b; Abdel-Gawwad et al., 2018c; Abdel-Gawwad and Khalil, 2018; Adesanya et al., 2018; Feng et al., 2012; Hajimohammadi et al., 2008; Kuloušek et al., 2007; Nematollahi et al., 2015; Peng et al., 2015; Yang and Song, 2009). Abdel Gawwad et al. (2016) have compared the mechanical properties of one-part alkali activated cement and conventional one. They found that the compressive strength of one-part alkali activated slag was lower than that of two-part mixture by 10%.

Recently alkali activated aluminosilicates or geopolymers have been foamed to create high porous and lightweight materials, which can be beneficially used for thermal insulation purposes (Ducman and Korat, 2016; Masi et al., 2014). There are two main experimental methods to make geopolymer foam, i.e. pre-foaming and mixed-foaming methods. The geopolymer foam synthesized using mixed-foaming method showed higher porosity, lower thermal conductivity and density comparing with that produced by pre-mixed one (Li, 2011; Neville and Brooks, 2010). Some approaches to make metakaolin and fly ash based-geopolymer foams have been published (Abdollahnejada et al., 2015; Baia et al., 2016; Bell and Kriven, 2009; Novais et al., 2016). Geopolymer foams are formed by the addition of foaming agent to slurry containing alkaline solution. The reaction of foaming agents, such as metals (alumina, silica and zinc powders) and H_2O_2, with alkaline solution led to release gasses, yielding high porous system (Ducman and Korat, 2016; Masi et al., 2014; Yang et al., 2012).

Coconut shell regarded as an important agricultural waste, generated from oil industry, which can be beneficially used as a

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new source of energy-biofuel (Bamgboye and Jekayinfa, 2006). Coconut shell is grown in more than 90 countries worldwide with production up to around 59 million tons annually. Coconut ashes are an amorphous aluminosilicate material produced as a result of coconut shell burning. According to report of the Food and Agriculture Organization of the United Nations, Mexico is the world's seventh largest producer of coconuts, producing 1,158,761,48 tons annually (FAO, 2018).

This paper deal with the fabrication of thermally insulatining materials using alkali activation of coconut ash in the presence of alumina slag as innovative foaming agent. Thermal conductivity, bulk density, porosity and compressive strength as the main parameters have been measured to elucidate the optimum mix which possesses high insulting property.

2. Experimental program

The materials used in this investigation are coconut ash (CA), aluminum slag (AS) and sodium hydroxide (NaOH). CA is derived from huge waste reserves in Charo, village 10Km west of Morelia city, Michoacán, México. It produced from the burning of coconut shells which used as alternative fuel in fabrication of brick stones. AS was supplied from Almexa, Toluca state, Mexico, and NaOH with 99.99% purity was purchased from Sigma-Aldrich, UK. The chemical compositions of CA and AS are listed in Table 1, using X-ray fluorescence (Philips X'Pert PRO MPD spectrometer). The X-ray diffractograms (Philips PW 1050/70 Diffractometer) with a Cu Kα source. The X-ray diffractograms proved the amorphous structure of CA having crystalline peaks related to quartz, lime, calcite and periclase (Fig. 1a). The AS is mainly composed of different crystalline peaks affiliated to spinel, crystoballite, corundum, bixobite and alumina metal (Fig. 1b). The Rietveld X-ray diffraction proved that the AS contains 7% of Al metal. Before alkali activation of CA, it milled to pass from 45 μm sieve to remove any contaminants. Also, AS has been crushed and passed from the same sieve size.

Unfoamed geopolymeric materials was synthesized by alkali activation of CA. It activated by 4, 5 and 6% NaOH (with respect to CA-powder). After mixing of CA with alkaline solution, the slurry was transferred to one-inch cubic steel mold and cured for 24 h in 99 ± 1% relative humidity (RH).

For foamed geopolymeric materials, different AS contents (3, 5 and 7%) were carefully dry-mixed with CA-powder; followed by mixing with alkaline solution. Three W/CA ratios were applied in the preparation of CA-based geopolymer foams i.e. 0.30, 0.35 and 0.40. The details of mix proportions are given in Table 2. After complete mixing, the workable paste was transferred to one-inch cubic mold and cured in 99 ± 1% RH for 24 h. The hardened foamed and unfoamed CA-based geopolymeric materials were demolded and cured under the same condition for 28-days.

The compressive strength test was carried out on three samples according to ASTM C109M-16 specification **(C109M)** using five tons German-Bruf-Pressing Machine with a loading rate of 100 kg/min. Thermal conductivity was measured with a thermal conductivity analyzer (Applied Precision ISOMET 2104). The bulk density and total porosity of the geopolymer foam were measured using the Archimedes method in deionized water.

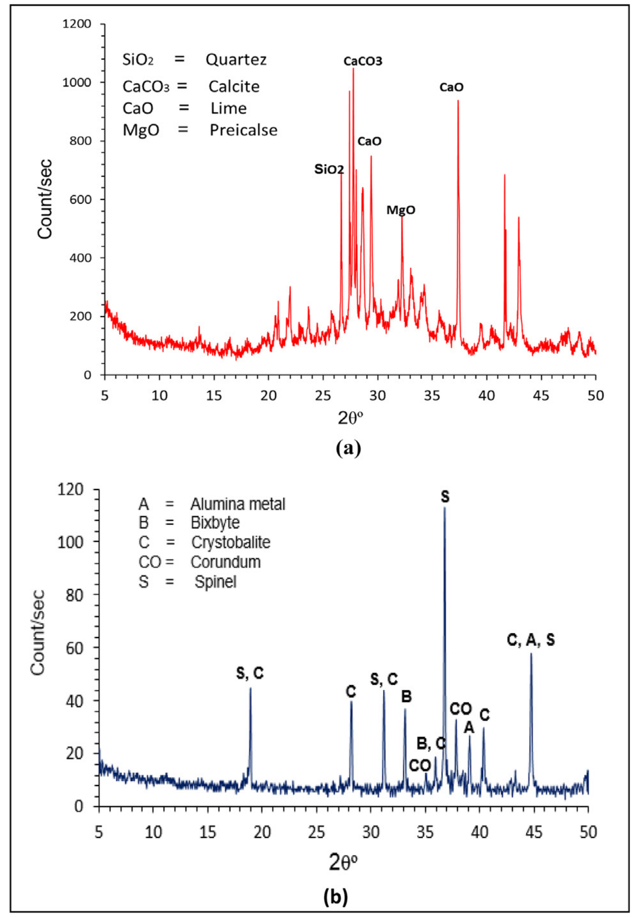

Fig. 1. XRD-patterns of (a) coconut ash and (b) alumina slag.

Table 2
Mix proportions (mass, %) of foamed and unfoamed geopolymeric materials.

Mix notations	CA	NaOH	AS	W/CP
CA-4	100	4	–	0.30
CA-5	100	5	–	0.30
CA-6	100	6	–	0.30
CA-5/AS3	100	5	3	0.30
CA-5/AS5	100	5	5	0.30
CA-5/AS7	100	5	7	0.30
CA-5/AS7-1	100	5	7	0.35
CA-5/AS7-2	100	5	7	0.40

3. Results and discussion

3.1. Optimization of alkali concentration

In order to optimize the concentration of alkali activator required to produce geopolymer with high mechanical properties, coconut ash (CA) was activated by 4, 5 and 6 wt%, NaOH. The compressive strength values of CA-based geopolymer activated by different NaOH concentrations are shown in Fig. 2. Evidently, the

Table 1
Chemical compositions of CA and AS.

Oxide, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl^-
CA	24.6	10.3	8.84	30.8	6.53	0.62	17	0.526	0.7
AS	21.42	72.37	1.03	4.30	0.95	0.32	0.15	0.06	0.04