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Physical and mechanical properties of lightweight aerated geopolymer

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HIGHLIGHTS

- Aerated geopolymers were produced by the aim of aluminium powders.
- Strength, density and microstructure of specimens were studied.
- The analysed aerated geopolymers are suitable for lightweight applications.

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ABSTRACT

In this study, it is going to investigate properties of lightweight geopolymer specimens aerated by aluminium powder. It has been established well that aluminium powder can be appropriately used for foaming of traditional concrete. Reaction between aluminium powder and alkali activator in geopolymers of this study caused high porous structures based on the weight ratios of constituent materials. Different specimens were made by changing sodium silicate to sodium hydroxide, and alkali activator to fly ash weight ratios. Fly ash was partially substituted by aluminium powder with 1.5, 3.0 and 5.0 wt.% in different mixtures. Results indicated that substituting of 5.0 wt.% of fly ash by aluminium powder in the specimens with alkali activator to fly ash weight ratio of 0.35 and sodium silicate to sodium hydroxide weight ratio of 2.5 causes the best foamed specimen with the lowest density. Compressive strength of all aerated specimens were in the range of 0.9–4.35 MPa, which is suitable for using as bricks, fire-resistant panels, buried pipeline and so on. SEM analysis was conducted to evaluate the microstructure of successfully aerated geopolymers. It was seen that in highly aerated specimens, the foaming reaction is too fast that prevents complete alkali activation of geopolymers and therefore, many unreacted fly ash particles remains.

1. Introduction

Geopolymerization technology was proudly introduced in early 1980s by Joseph Davidovits because of its environmental friendly process [1]. Geopolymer is an adhesive aluminosilicate forming by alkaline activation of alumina and silica as starting materials at temperature slightly higher than room temperature [1,2]. These alkali-activated materials are arranged of tetrahedral silicate and aluminate units bonded in a three dimensional structure by covalent bonds [2]. The materials used for geopolymerization are divided into two parts: a reactive aluminosilicate material such as fly ash or calcined clays, and alkali activator solution (generally a mixture of alkali metal hydroxide such as sodium hydroxide and silicate solution such as sodium silicate) [2]. Geopolymers are usually used in building construction, bridge superstructure and deck pavements.

Geopolymers are fire-resistant materials and hence, fabricating lightweight geopolymers with enhanced thermal resistivity can be considered as an effective way of their usage. Although properties and the nature of geopolymers are now clearer, their lightweight structures have not been developed well. However, some attempts have been made to introduce lightweight geopolymers through different methods. Omar et al. [1] produced geopolymers containing lightweight aggregate and tested them at elevated temperatures. Results indicated that lightweight geopolymers have better fire resistance than normal geopolymer at temperatures above 100 °C. Successful utilizing of lightweight aggregates for production of geopolymers has been reported in some other works. Aggregates may be provided from recycle lightweight block [3], oil palm shell as coarse lightweight aggregate [4–6], Cold bonded lightweight aggregate [7], Cenospheres and expanded polystyrene (EPS) lightweight aggregates [8], palm oil clinker aggregates [9], mixture of expanded vermiculite and electrical porcelain [10,11], refractory shale haydite [12] and artificially expanded clay granules [13,14]. Pimraksa et al. [15] studied properties of geopolymers

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Table 1
Chemical composition of fly ash.

Chemical composition	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	P_2O_5	K_2O_5	MnO	SO_3	TiO_2	L.O.I.
Content (wt.%)	51.1	25.6	4.30	1.45	12.5	0.77	0.89	0.70	0.15	0.24	1.32	0.57

Table 2
Mineralogical phases of fly ash.

Material	Quartz	Mullite	Hematite	Magnetite	Amorphous (SiO_2 + Al_2O_3 + CaO + other oxides)
Content (wt.%)	13.0	14.6	4.17	1.83	66.0 (32.3 + 16.8 + 4.30 + 12.6)

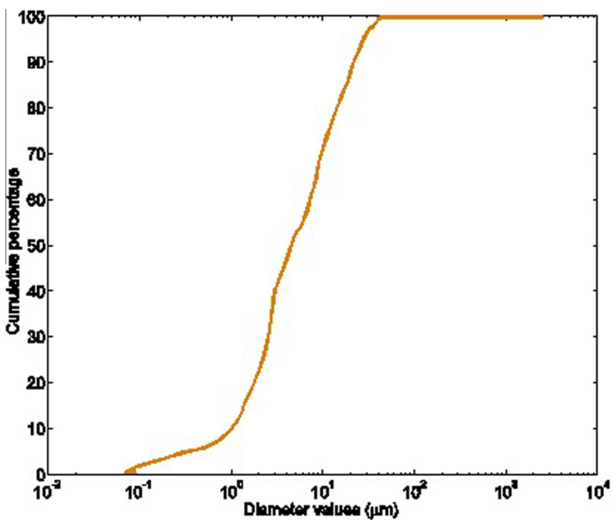

Fig. 1. Particle size distribution of fly ash sample.

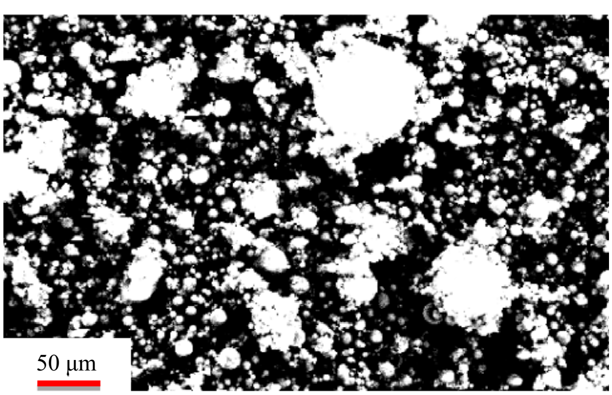

Fig. 2. SEM micrograph of fly ash powder.

produced by highly porous lightweight siliceous materials including rice husk ash and diatomaceous earth. They could obtain mean bulk density of 0.88 g/cm^3 and compressive strength of 15 kg/cm^2 in the best condition. Alkali-activated fly ash has also been used as lightweight aggregate in traditional concrete [16]. Some works have been performed on production of lightweight aerated geopolymers by means of aluminium powders [17,18].

Aerated concrete with significant reduction in density is basically a mortar with pulverized sand and industrial waste like fly ash as filler (individually or together). In these type of lightweight products, air is entrapped artificially by chemical (metallic powders like Al, Zn, H_2O_2) or mechanical (foaming agents) facilities [19]. A wide range of densities are obtained by suitable aeration of concrete and the products are used in specific applications in structural, partition and insulation grades [20]. Aerated concrete is an old concept and it is interesting that the first comprehensive review on it was made in 1954 [20–22]. Therefore, it is not convenient to review all published works in this area and just few of them are summarized here. Since the aim of this paper is to facilitate the development of aerated geopolymers by means of aluminium powder, a short survey has been conducted on traditional aerated concrete produced by this powder.

Huang et al. [23] produced aerated concrete by utilizing skarn-type copper tailings and blast furnace slag, and achieved compressive strength of 4 MPa and density of 610 kg/m^3. They proposed participation of most minerals available in the copper tailings in the hydration reaction during the procuring process. Kurama et al. [24] used coal bottom ash in ordinary Portland cement (OPC) concrete and achieved compressive strengths up to 3.0 MPa. Wongkeo et al. [25] have also reported production of aerated concrete by using bottom ash. Although their specimens have relatively high compressive strengths (even greater than 10 MPa), the density of all produced samples is above 1000 kg/m^3. By increasing the content of bottom ash in their examined concrete, they achieved a slight improvement in compressive strength, flexural strength and thermal conductivity. Not only aerated OPC concrete, but aerated geopolymer are also produced by using aluminium powder. Arellano Aguilar [17] produced aerated geopolymer paste and concrete by utilizing a mixture of metakaolin and fly ash. Densities were fixed at 600, 900 and 1200 kg/m^3 and maximum compressive strength of about 3.5, 8 and 16 was achieved by using these densities, respectively. Brooks et al. [18] produced aerated geopolymeric specimens from high strength geopolymer and while their minimum density was 1000 kg/cm^3, compressive strength values were less than 10 MPa. This short review indicates the relationship between compressive strength and density of OPC and geopolymer concrete specimens and where density of specimens is below 1000 kg/cm^3, compressive strength is normally less than 4 MPa. Liu et al. [26] studied physical and thermal properties of aerated geopolymers made from metakaolin, α-Al_2O_3, Al powder and phosphoric acid. Compressive strength of all specimens was more than 6 MPa while their porosities ranged between 40% and 83%. This relatively high strength was supposed to be due to formation of Al–O–P bonds. Thermal analysis of the specimens revealed that those are thermal-stable, in terms of compressive strength and shrinkage, at temperatures up to 1450 °C.

The aim of the present paper is to produce aerated fly ash-based geopolymer pastes by using different amount of aluminium powder. Density, compressive strength, macro- and micro-structure of the produced samples are studied. Different sodium silicate to sodium hydroxide (NaOH) and alkali activator to fly ash ratios are investigated, and the effect of percentage of aluminium powder on foam-ability is surveyed.