



# Mechanical, thermal insulation, thermal resistance and acoustic absorption properties of geopolymer foam concrete



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## ABSTRACT

This study reports the synthesis and characterization of geopolymer foam concrete (GFC). A Class F fly ash with partial slag substitution was used for GFC synthesis by mechanical mixing of preformed foam. The GFCs exhibited 28 d compressive strengths ranging from 3 to 48 MPa with demolded densities from 720 to 1600 kg/m<sup>3</sup> (105 °C oven-dried densities from 585 to 1370 kg/m<sup>3</sup>), with the different densities achieved through alteration of the foam content. The thermal conductivity of GFCs was in the range 0.15–0.48 W/m K, showing better thermal insulation properties than normal Portland cement foam concrete at the same density and/or at the same strength. The GFC derived from alkali activation of fly ash as a sole precursor showed excellent strength retention after heating to temperatures from 100 to 800 °C, and the post-cooling compressive strength increased by as much as 100% after exposure at 800 °C due to densification and phase transformations. Partial substitution of slag for fly ash increased the strength of GFC at room temperature, but led to notable shrinkage and strength loss at high temperature. Thin GFC panels (20–25 mm) exhibited acoustic absorption coefficients of 0.7–1.0 at 40–150 Hz, and 0.1–0.3 at 800–1600 Hz.

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## 1. Introduction

The search for materials offering high thermal insulation has increasingly become a target of the modern construction and building industry, as energy-efficiency of buildings in service has become of ever increasing concern. Foam concrete is well known for its relatively low thermal conductivity, usually 10–50% of that of normal dense concrete, depending on the designed material density and composition [1–3]. This low thermal conductivity brings good thermal insulation, and usually energy efficiency in operation. Recent developments in alternative binders, and in engineering of products based on these binders, have led to the manufacture of foam concrete using geopolymer as the binder [4]. Geopolymers are a complex class of materials, principally manufactured through alkali hydroxide and/or silicate activation of a reactive aluminosilicate, in particular calcined clays (metakaolin) or fly ash [5]. One of the most attractive benefits of geopolymer

materials is the reduced energy consumption and CO<sub>2</sub> emissions which are achievable compared to ordinary Portland cement [6]. The innovation of geopolymer foam concrete (GFC) creates an approach of developing energy efficient materials from material manufacturing to building operation, which seems to offer the possibility to be eco-friendly across the whole life cycle.

GFC can be synthesized effectively by a chemical foaming technique [4]. Arellano Aguilar et al. [7] prepared GFCs based on alkali-activated metakaolin binders with Al powder as gas-releasing agent. The 28 d compressive strength of GFCs was in the range of 2–14 MPa for densities from 600 to 1200 kg/m<sup>3</sup>. This strength is relatively high when compared with Portland cement-based foam concrete in a similar density range [8]. However, the thermal conductivity of the GFCs was high, from 0.49 to 1.22 W/m K, and this was attributed to the high humidity in the GFCs and the quartz and cristobalite present in metakaolin [7]. Kamseu et al. [9] also prepared metakaolin-based geopolymer foams using Al powder as a foaming agent, and the resulting foams had low thermal conductivity (0.15–0.4 W/m K). The thermal conductivities of the solid geopolymer binders synthesized by those authors increased with increasing Si/Al ratio [10], in agreement with previous research [11], which is related to the increased

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connectivity, the reduced porosity and the finer pore size distribution as the Si/Al ratio increases. Silica fume can also be used as the foaming agent in GFC production via an *in situ* foaming technique [12]. During sealed curing, free (reduced) silicon present in the silica fume will be oxidized by water, releasing hydrogen gas, which introduces bubbles into the geopolymer paste. Such products usually exhibit low thermal conductivity (0.22–0.24 W/m K) but also low strength (around 1 MPa), due to the extremely heterogeneous pore structure and large pore size [13,14].

GFC can also be made using a mechanical pre-foaming technique. Zhang et al. [15] manufactured a series of GFCs using fly ash as the main aluminosilicate precursor by mechanical mixing with a preformed foam. The fly ash-based GFCs possessed dry densities from 850 to 950 kg/m<sup>3</sup> and compressive strengths of 4–9 MPa, depending on the type and dosage of alkali activator. Al Bakri Abdullah et al. [16] also manufactured GFC with fly ash by mixing pre-formed foam into geopolymer paste at a 2:1 volume ratio. The resulting GFCs reached 18 MPa under room temperature curing conditions at a density of 1660 kg/m<sup>3</sup>.

The development of GFC is currently in the relatively early stages of technological maturity. Only limited information has been reported regarding the relationship between composition, structure and properties of this new material. Some special challenges related to this material require particular attention, such as understanding the differences between dense and foamed geopolymers [4]. This study has been conducted to investigate the key properties of GFCs, including compressive strength, acoustic absorption, thermal insulation and fire resistance. Understanding of these properties is useful for the widespread uptake of this new material.

## 2. Materials and methods

### 2.1. Materials

The geopolymer binder was prepared using a Class F fly ash (Tarong, Australia) with partial substitution of a granulated blast furnace slag (Cement Australia Pty Ltd) as secondary calcium source. The chemical compositions of the fly ash and the slag were determined by X-ray fluorescence (Table 1). Fig. 1 shows their particle morphology, as observed using a JEOL JCM-600 Benchtop scanning electron microscope, for samples coated with gold. The majority of fly ash particles are in the range of 2–100 μm in diameter, and the slag seems to have more fine particles than the fly ash. The particle size distributions of the two solid materials were also determined using a Malvern Mastersizer 2000 (Fig. 2). The surface areas of the fly ash and the slag used are estimated by this method to be 0.64 and 0.69 m<sup>2</sup>/g respectively. The activators used included an NaOH solution and a sodium silicate solution. The NaOH solution was prepared by dissolving NaOH pellets (99% purity, Taiwan Alum Chemical Industrial Co., Ltd.) in water to a concentration of 12 mol/L, and cooling to room temperature. The sodium silicate solution was D-Grade™ liquid sodium silicate (PQ Australia) with Ms. (molar ratio SiO<sub>2</sub>/Na<sub>2</sub>O) = 2.0 (Na<sub>2</sub>O = 14.7 wt.%, SiO<sub>2</sub> = 29.4 wt.%). Distilled water was used throughout the experimental section. The foaming agent was a diluted aqueous surface active concentrate.

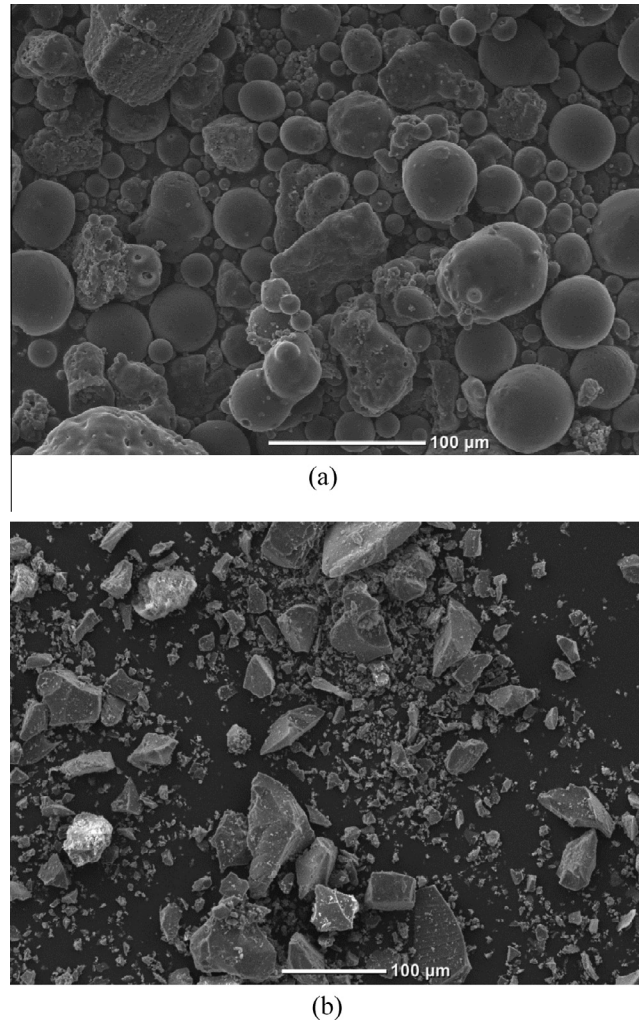


Fig. 1. SEM images of (a) fly ash and (b) slag.

### 2.2. Methods

#### 2.2.1. GFC manufacture

Two batches of GFCs (Table 2) were manufactured to examine the effects of slag substitution and foam dosage on the mechanical and thermal properties of the material. Due to the lack of standards available for GFC preparation, some Portland cement (PC) foam concrete specifications have been used as a reference baseline [17]. The fly ash and slag were dry-mixed for 5 min, then mixed with the NaOH solution, followed by the sodium silicate solution and additional water. At the end of paste mixing, foam was generated using an air pressure foam generator, weighed, and immediately transferred into the homogeneous geopolymer paste for final mixing for 1–2 min. Low speed mixing was used to avoid bubble breakage due to the high viscosity of the geopolymer paste. The fresh foamed mixtures were cast in Ø53 × 105 mm and Ø100 × 200 mm plastic molds, sealed with plastic film wrap,

Table 1

Compositions of fly ash and slag as determined by XRF, wt.%. LOI is loss on ignition at 1000 °C.

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	TiO <sub>2</sub>	LOI
Fly ash	72.1	24.7	0.1	0.2	0.5	≤0.1	1.2	≤0.1	≤0.1	1.4	0.4
Slag	33.3	14.6	41.7	6.1	0.3	0.2	0.8	0.2	0.6	0.6	0.5

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