Mechanical Properties and Thermal Conductivity of Lightweight Foamed Geopolymer Concretes

Siti Fatimah Azzahran Abdullah, Liew Yun-Ming, Mohd Mustafa Al Bakri Abdullah, Heah Cheng-Yong, Khairunnisa Zulkifly

Center of Excellence Geopolymer & Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.

E-mail: ymliew@unimap.edu.my

Abstract. Foamed geopolymer concretes have a better performance in the thermal insulation properties compared to normal geopolymer concretes. In this research, lightweight aggregate geopolymer concretes was incorporated with different percentage of foaming agents (hydrogen peroxide). Compressive strength and thermal conductivity were measured. From results obtained, increased H₂O₂ contents will decrease the strength of lightweight foamed geopolymer concretes. Lightweight aggregate foamed geopolymer concretes (LWAFGC) with foaming agent content of 0.2wt.% obtained the highest strength of 19.601 MPa. Furthermore, Increased of H₂O₂ contents also will decrease the thermal conductivity of lightweight foamed geopolymer concretes. Lightweight foamed geopolymer concretes with 2wt.% H₂O₂ gave the good thermal insulating behavior when the thermal conductivity value recorded the lowest value compare to other wt.% of H₂O₂ content. The thermal conductivity value of lightweight foamed geopolymer concretes with 2wt.% of H₂O₂ was 0.072 W/m K while, the thermal conductivity of other mixtures ranged between 0.077 W/m K to 0.087 W/m K., respectively.

1. Introduction

In fact, geopolymers have potential in thermal application. There may be several ways to reach this goal and one of the major methods is to improve their thermal insulation properties. Insulation against environmental conditions and improving the energy efficiency of buildings is becoming increasingly important. The insulation properties of the buildings are one of the most important factors affecting both the operating cost and thermal comfort. Reduction of the heat loss in buildings decreases the consumption of energy, thus, reduces the cost of both heating and cooling. As a result of the lower use of energy, improvements in thermal insulation also affect sustainability [3].

Geopolymers are environmentally friendly concrete due to the low CO₂ emission during their production process [4,5,6]. Geopolymers, which have high strength, fire resistance, and chemical stability [7, 8], are formed by the condensation reaction between Si(OH)₄ and Al(OH)₃ after thermal curing. The curing temperature determines the strength development of geopolymers because temperature affects the condensation rate in the geopolymerization reaction [9, 10]. The sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃) have high alkalinity and are mostly used as activator solution to dissolve silica and alumina to Si(OH)₄ and Al(OH)₃, respectively.

Foaming agents generate a large volume of artificial pores in hardened pastes, leading to reduced specific gravities of the pastes. However, the foamed binder pastes are not suitable for structural purposes,
due to their significantly low strength; thus, they are limited in their use for improvements in non-structural properties such as thermal insulation or sound-proofing capacity [11].

Abdollahnejad et al. [12] studied on the several mix parameters on the properties of foam geopolymers. In their study, the foaming agent used was hydrogen peroxide (H2O2) and sodium perborate (NaBO2) with various mass ratio content of 1 %, 2 % and 3 %. They observed that low compressive strength below 3 MPa in geopolymer mixtures with 2 % and 3 % of H2O2. Masi et al. [13] studied a comparison between different foaming methods to produce lightweight geopolymers. Foaming agents reduced the density and compressive strength; however, it is effective in improving their insulating property. Increasing the concentration of the foaming agent (0.3 wt.%) reducing the density (1.12 g/cm3 to 0.91 g/cm3).

Furthermore, Liu et al. [14] studied on the thermal conductivity of oil palm shell foamed geopolymer concrete (OPSFGC) using aluminosilicate source class F fly ash and palm oil fuel ash (POFA) as a raw material, and oil palm shell (OPS) as lightweight coarse aggregate (LWA). From their study, they observed that the foamed and non-foamed OPSGC obtained lower thermal conductivity compared to the conventional materials, which is less than 0.75 W/m.K. This is due to the increase of void ratio thus decrease in thermal conductivity.

In this study, the effect of combination of lightweight aggregate and foam on geopolymer concrete samples was studied. The addition of foaming agent into lightweight geopolymer concretes would further reduce the thermal conductivity. It is important to properly tailoring the content of foaming agent and lightweight aggregate to achieve thermal insulation properties without seriously degrading the strength. Therefore, lightweight aggregate foamed geopolymer concretes are expected to have good properties such as lightness in weight, good thermal insulation and suitable as construction materials. In this study, physical, mechanical properties and thermal conductivity analysis of lightweight aggregate foamed geopolymer concretes are investigated.

2. Experimental

2.1. Material
Fly ash was used as the aluminosilicates for preparation of geopolymers. The alkaline activator used in this work was sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solution. Lightweight expanded clay aggregate (LECA) was used for the preparation of lightweight aggregate foamed geopolymer concretes (LWAFGC) as coarse aggregate. River sand was used as the fine aggregate in the preparation of LWAGC and LWAFGC. Hydrogen peroxide (H2O2) was used as the foaming agent in LWAFGC.

2.2. Preparation of Lightweight Aggregate Foamed Geopolymer Concretes (LWAFGC)
Fly ash and alkaline activator were first mixed together in mechanical mixer for 3 minutes. Before the alkaline activator was mixed with the fly ash, the foaming agent were firstly added into the alkaline solution. Then, the LWA and sand river were added and mixed for another 5 minutes. The fresh concrete was then poured into 100 mm × 100 mm × 100 mm cubic molds to produce LWAFGC. Hydrogen peroxide (H2O2) content used was set at 0.2%, 0.4%, 0.6%, 1.0%, 1.5% and 2.0%. The ratio of both S/L and Na2SiO3/NaOH were maintained at 2.0 and 2.5 with a NaOH concentration of 12 M for Mixture 1-6. The total aggregate was selected at 70%. The lightweight aggregate (LWA) to river sand was fixed at 2:3. Then, the samples of LWAFGC were cured at room temperature (29°C) for 1 day and 60°C for another 1 day. Thus, the samples were demoulded and kept at room temperature (29°C) until the day of testing.

2.3. Testing and Analysis

Bulk Density Measurement
Bulk densities of LWAFGC was measured as according to BS EN12390-7. The bulk density measurement were taken after 7 and 28 days. Bulk density of samples were calculated using Equation (1) by measuring dimension and mass of the geopolymers.
Bulk density, \( \rho = \frac{m}{V} \)  

Where \( m \) is the mass of specimen and \( V \) is the volume of specimen.

**Compressive Strength Test**

Lightweight aggregate foam geopolymer concretes (LWAFGC) with dimension of 100 mm × 100 mm × 100 mm was prepared for compressive test. The compressive strength was tested using Mechanical Tester Shimadzu UH-1000 KNI as according to ASTM C 109/C 109M-08. Three samples were tested to obtain an average value of strength. The samples were loaded at a constant rate of 5 mm/min. The compressive test was performed after 7 and 28 days.

**Thermal Conductivity Measurement**

Lightweight aggregate foam geopolymer concrete (LWAFGC) was measured at room temperature according to the ASTM D5334-14, using the transient heat method using the KD2 Pro. The samples of the LWAFGC were drilled with diameter 3.9 mm drill, to form a hole with length of 60 mm. In order to ensure good contact between the pilot pin and samples’ hole, all samples were coated with the thermal grease on the pilot pin. After drilling the holes, all samples were cleaned from the dust and drill cuttings from the rotary hammer hole using a compressed air before inserting the pilot pin. Three measurement were taken to obtain the average values of thermal conductivity, thermal diffusivity and specific heat. The following Equation (2) was used to calculate the thermal conductivity, thermal diffusivity and specific heat of the samples, respectively in unit of W/ m. K, m²/s and J/ kg. K:

\[
\kappa = \frac{a}{\rho c_p}
\]

Where, \( k \) is the thermal conductivity (W/ m. K), \( \rho \) is the density (kg/m³) of the specimen, \( c_p \) is the specific heat capacity (J/ kg. K) and \( a \) is the thermal diffusivity (m²/s).

3. Results and Discussion

3.1 Bulk Density Measurement

Figure 1 shows the bulk density of the lightweight aggregate foam geopolymer concretes (LWAFGC) for Mixture 1 – 6 with different addition of foaming agent. In general, the bulk density of the lightweight aggregate foam geopolymer concretes decreased with the increase in addition of the foaming agent from Mixture 1 (0.2%) to Mixture 6 (2.0%). The bulk density values of the lightweight aggregate foam geopolymer concretes ranged between 1.523 g/cm³ and 1.425 g/cm³. Mixture 1 (0.2%) showed the higher bulk density meanwhile, Mixture 6 (2.0%) have the lowest bulk density. This is due to the increasing of foaming agent added reducing the bulk density.

According to the Feng et al. [14], the reduction of density has been identified due to the numbers of voids in the samples with air contained is generated. This is supported by the Demirboga and Gul [15].
Figure 1. Bulk density of lightweight aggregate foamed geopolymer concretes (LWAFGC) for Mixture 1 – 6 after 7 and 28 days.

3.2 Compressive strength

Figure 2 shows the compressive strength of lightweight aggregate foamed geopolymer concretes (LWAFGC) with various hydrogen peroxide (H₂O₂) after 7 and 28 days. After 7 days compressive strength of lightweight aggregate foamed geopolymer concretes fluctuated with the increasing of foaming agent added. However, after 28 days, strength of LWAFGC recorded that these samples had strength values of 19.601 MPa (Mixture 1) with the lowest foaming agent percentage (0.2%) compared than other mixtures due to its less porous structure meanwhile Mixture 6 obtained 14.257 MPa, which is the lowest compressive strength values with the addition of foaming agent of 2.0% by weight. This might be due to the addition of the foaming agent depleted the compressive strength due to the foaming agent generally created air voids and resulted in a lower density [16,17]. The compressive strength result complied with the bulk density value as shown in Figure 1.
Figure 2. Compressive strength of lightweight aggregate foamed geopolymer concretes (LWAFGC) for Mixture 1 – 6 after 7 and 28 days.

3.3 Thermal Conductivity Measurement
Figure 3 presents the thermal conductivity values of lightweight aggregate foamed geopolymer concretes with varying of foaming agent addition for Mixture 1 (0.2wt.%) to Mixture 6 (2.0wt.%). There was positive correlation between thermal conductivity and foaming agent content. Mixture 6 (foaming agent of 2.0%) has lower thermal conductivity compared to other mixtures because of high foaming agent content and low of density value. Thermal conductivity value of Mixture 6 (foaming agent of 2.0wt.%) was 0.072 W/ m. K while, the thermal conductivity of other mixtures ranged between 0.077 W/ m. K to 0.087 W/ m. K. Moreover, moisture content and porosity structure affects the thermal conductivity values.

Figure 3. Thermal Conductivity of lightweight aggregate foamed geopolymer concretes (LWAFGC) for Mixture 1 – 6 after 28 days.
4. Conclusions
From the research, we can conclude several conclusions, which are;
1. Bulk density decreased with the increasing of addition of hydrogen peroxide (H₂O₂).
2. Strength of LWAFGC obtained is below than 20 MPa. The maximum strength at Mixture 1 (19 MPa) with foaming agent of 0.2% by weight in the mixtures.
3. Geopolymer concretes with addition of foaming agent could lowering thermal conductivity value (< 1.0 W/ m. K).

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