Physico-mechanical Properties of Low-density Geopolymer Mortar Synthesized Using Inexpensive Foam Agent

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Abstract. Low-density geopolymer (LDG) mortars have been synthesized through the use of an inexpensive car-wash foaming agent. LDG mortars were made by mixing coal fly ash and sand with activator solution of NaOH and Na2SiO3. The slurry mixture was then mixed with a thick foam and stirred using a hand mixer. During the stirring process, the ordinary Portland cement (OPC) was added to the mixture as additive. Once homogeneous, the slurry mixture was then poured into mortar molds and left overnight at room temperature before heat treatment at 60 ºC for 24 h. The geopolymer mortars formed were then characterized. The density measurement showed that the density of geopolymer decreased to about half from the original density at the OPC compositions of 5-15% and the activator solution compositions of 20-26%. In this composition range, the highest compressive strength (2.15 MPa) was shown by the LDG synthesized using a 23% activator solution and 15% OPC. Further addition of activator solution decreased the compressive strength due to the increase of porosity. The thermal durability test indicated that the LDG structure was relatively stable up to a temperature of 300 ºC. A further increase in temperature would cause structural degradation.

1. Introduction
Research on low-density geopolymers (LDG) or lightweight geopolymers has attracted the attention of researchers [1, 2]. It is driven by various needs, including the desire to expand its applications, such as acoustic panels, thermal insulation, building wall materials, etc. Alvarezayuso et al. and Chengetal. in [2] reported that the low-density geopolymers had several characteristics including excellent mechanical properties, good thermal resistance, good adsorption ability of toxic metals, as well as high acid resistance and fire resistance. Apart from these advantages, the raw materials are easily obtained and cheap from an electric power plant fly ash waste or other agro-industrial fly ash.

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The choice of manufacturing method will affect the quality of low-density geopolymer produced. There are two techniques in preparing of foam mortar, namely pre-foaming and mix-foaming techniques. In the pre-foaming technique, the foam is made separately from the mortar paste. The next step is mixing the paste and foam; meanwhile, the mix-foaming technique, from the beginning, the foam and paste are mixed. Ducman and Korat[1] conducted a study on the manufacture of fly ash-based low-density geopolymers by comparing the addition of aluminum powder and hydrogen peroxide (H2O2) foaming agents. The results of this study indicated that the hydrogen peroxide (H2O2) had a better effect than aluminum powder, and the porosity test showed that the porosity of aluminum powder washer higher than the hydrogen peroxide (H2O2) by 59% and 48%, respectively. Wu et al., [2] have created fly ash - metakaolin based ultra-lightweight foamed geopolymer (UFG) with the addition of H2O2 foaming agent. The results of this study indicated that the lightweight geopolymer showed better mechanical properties than the portland cement-based foam concrete at the same density. However, materials such as aluminum powder and hydrogen peroxide are quite expensive. Besides, hydrogen peroxide (H2O2) is quite dangerous for health if inhaled and exposed to the body and environment.

This work tries to create a low-density geopolymervia a pre-foaming technique using a car-wash foam agent that is cheap and safe for the environment. The effects of an increasing amount of activator solution and OPC additivel were studied. The results showed that the density of the geopolymer decreased to about half of its original density at 5-15% of OPCand 20-26% activator solution compositions. The compositions are a crucial factor in obtaining optimal density and compressive strength values.

2. Experimental

2.1 Geopolymers preparation
The activator solution was made by mixing 10 M NaOH and Na2SiO3 solutions with a ratio of Na2SiO3: NaOH of 2.5. The car-wash foam was prepared through the pre-foaming technique by mixing the car-wash foaming agent with water in a ratio of 1:30 and then fed into foam generator equipment. Solid fly ash and sand were mixed with activator solution with a solid to liquid ratio of around 4:1. This mixture was then poured into a container that already contained thick car-wash foam. Stirring was done quickly using a hand mixer while adding the OPC little by little to the dough until homogeneous. This dough was then poured into molds (10x10x10 cm3) and left overnight. The geopolymer mortar formed was then heated in an oven at 60 °C for 24 hours and then cooled. The amount of activator solution and the amount of OPC used were varied and repeated three times (by triplo)

2.2. Characterization
The density of the formed geopolymer was determined by dividing the dry mass by volume. The compressive strength of geopolymers was tested using a compressive testing machine following ASTM C579-01 (2012). The thermal durability test was performed by monitoring of compressive strength of geopolymer after heating to high temperatures at 300 °C, 500 °C, and 700 °C in a furnace for 1 hour 30 minutes.

3. Results and Discussions

3.1 Density of Geopolymer
Table 1 and Figure 1 show the densities of geopolymers produced by various percentages of activator solution used and OPC added. It can be seen that the geopolymers have a reasonably low density compared to the control sample by about half. The decrease of density is due to the high porosity in the geopolymers matrix created by the foam integrated into the matrix at the molding process. The formation of pores initiated by the foam is then maintained by OPC, which has a fast setting time of
hardening. This pores formation is difficult to be reached without the addition of OPC due to the slow geopolymers setting time.

From Figure 1, it can also be seen that the density of geopolymers increases as the increase of OPC content in all variations of activator solution addition. It is understandable because OPC is the adhesive between the components in the matrix and, at the same time, solidifies them. Likewise, the densities of geopolymers also increase as the increase of activator solution up to 23%. It is due to the rise of NaOH and Na$_2$SiO$_3$ activator solution can disturb the stability of the foam bubbles, so they are easily broken into the liquid, which leads to a decrease in the number of pores and ends up with a higher density. However, when the activator solution increases to 26%, a strange phenomenon is observed, in which the density again decreases. So far, this is not fully understood. However, this is likely due to the high water content when the percentage of activator solution increases. In a specific composition, this water will counteract or offset the negative influence of NaOH and Na$_2$SiO$_3$ on the foam, so that it will lead to foam stability. Therefore, the amount of foam, activator solution and OPC used must be precise to obtain optimal strength of lightweight geopolymers.

| Activator solution (% wt) | OPC (% wt) | Density (kg/m$^3$) |
|---------------------------|------------|---------------------|
| 20%                       | 5%         | 1.150               |
|                           | 10%        | 1.158               |
|                           | 15%        | 1.175               |
|                           | 5%         | 1.149               |
| 23%                       | 10%        | 1.185               |
|                           | 15%        | 1.193               |
|                           | 5%         | 1.037               |
| 26%                       | 10%        | 1.072               |
|                           | 15%        | 1.087               |
| Geopolymers (without foam addition) as control |          | 2.070               |

**Figure 1.** Densities of the produced geopolymers at various percentages of OPC addition and activator solution

3.2 **Compressive strength**

Figure 2 shows the compressive strength of low-density geopolymers (LDG) synthesized by various percentages of OPC addition and activator solution. It can be seen that the compressive strength of LDG increases with the increase of OPC addition for all activator solution compositions. It is well-
understood that the more cement is added, the more compressive strength of the material will be[3]. The highest compressive strength (2.15 MPa) is shown by LDG synthesized by OPC addition of 15% and activator solution of 23%. Linear to the densities data as discussed in the previous section, the compressive strength of LDG synthesized using activator solution of 26% is lower compared to the LDG synthesized using activator solution of 20% and 23%. It is, of course, because their densities are the lowest than the others.

According to its nature and without being associated with the addition of foam or formation of pores, the addition of too much activator solution that passes through a certain composition can decrease the compressive strength of LDG[4]. Phoon-ngernkham et al.[5] stated that the addition of excess activator solution could cause a decrease in the mechanical properties of geopolymers. It is similar to an increase in the ratio of water to cement. Special for LDG formation, the results of this study are also consistent with the work by Wu et al.[2]. They said that the addition of excess activator solution to the matrix will make the LDG tend to flow easily and thin, causing foam bubbles to move freely to form large cavities. These cavities can cause a decrease in mechanical properties of geopolymers, and when the curing process is applied, there is a shrinkage of LDG, resulting in cracks in the matrix, which will reduce the compressive strength of LDG. Based on the results, it can be concluded that the addition of OPC and activator solution at a certain maximum amount can increase the compressive strength of LDG.

3.3 Thermal durability
To obtain a low-density geopolymer (LDG) that can be applied for various practical applications, besides testing the compressive strength at room temperature, it is also necessary to know the effect of heat treatment on the geopolymers compressive strength (thermal durability). Figure 3 shows the compressive strength of LDG, which is heat-treated for 1.5 hours at different temperatures. Geopolymers tested are geopolymers with a composition of 15% OPC and 23% activator solution, which gave the best compressive strength values, as discussed in Section 3.2. From the figure, it can be seen that the structure of the low-density geopolymer is relatively stable up to a temperature of 300 ºC, which is indicated by a slight degradation in compressive strength of 11.62%. When heating exceeds a temperature of 300 ºC, the low-density geopolymer begins to experience a significant degradation of strength, with a decrease in compressive strength of 35% at 500 ºC and 72% at 700 ºC. This decrease in compressive strength is due to the dehydroxylation reaction of the geopolymer. Where when applying high heat, the bonds to the geopolymer will be broken.

A visual inspection of the heat treatment results shows that the low-density geopolymer cracked only after heating above 500 ºC. It is consistent with what was reported by Syamsidar et al. in [6], which said that the geopolymer has excellent heat resistance up to a temperature of 600 C. They also
noted that the use of fly ash with high SiO$_2$ content and silica in the activator fluid (Na$_2$SiO$_3$) could provide excellent stability in maintaining the geopolymer structure. These results indicate that the low-density geopolymer has excellent resistance to high temperatures. Besides, the addition of OPC has a positive effect on durability [3]. Overall, based on the results in this work, it can be concluded that the produced low-density geopolymer can be used for conventional applications such as building wall materials or other low-temperature applications.

![Figure 3](image.png)

**Figure 3.** Compressive strength of lightweight geopolymer after heat treatment for 1.5 h at different temperatures

4. **Conclusions**

Low-density geopolymer (LDG) mortars have been synthesized by adding car-wash foam agent and adjusting the composition of ordinary Portland cement (OPC) as well as activator solutions of NaOH and Na2SiO3. The density of the LDG decreased to half of the initial density at the OPC composition between 5-15% and 20-26% activator solution. In this composition range, the highest compressive strength (2.15 MPa) was shown by the geopolymer synthesized using a 23% activator solution and 15% OPC additions. Further addition of activator solution decreased the compressive strength due to increased porosity. The thermal durability test indicated that the geopolymer structure was relatively stable up to a temperature of 300 C. A further increase in temperature would cause the structural degradation of the geopolymer.

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