JTE HCMUTE
ISSN: 2615-9740

JOURNAL OF TECHNICAL EDUCATION SCIENCE
Ho Chi Minh City University of Technology and Education
Website: https://jte.edu.vn/
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# Use Recycled Glass As Fine Aggregate in Slag-Blended Fly Ash-Based Geopolymer Mortar

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**ARTICLE INFO**

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|---|---|
| Received: | 02/08/2022 |
| Revised: | 30/09/2022 |
| Accepted: | 31/10/2022 |
| Published: | 28/08/2023 |

**KEYWORDS**

Geopolymer;
Fly ash;
Glass waste;
Workability;
Mechanical strength;
Drying shrinkage.

**ABSTRACT**

Geopolymer has emerged as the potential alternative to Portland cement in recent years. In addition, fly ash and recycled glass are abundant by-products derived from the industry. The purpose of this study was to evaluate the potential of using recycled glass to replace the sand aggregate in slag-blended fly ash-based geopolymer mortar. For geopolymer synthesis, the mixture of water glass ($Na_2SiO_3$) and sodium hydroxide (NaOH) solution with a NaOH concentration of 14 mol/l was used as an activator. In the mortar mixture, the recycled glass's investigated replacement level of the sand aggregate was up to 100 %. Using recycled glass (RG) as fine aggregate was seen to increase the mechanical strength compressive strength and flexural strength of mortar after 28 days of curing. Otherwise, there was a reduction in the drying shrinkage of mortar samples with a high recycled glass content of 80 and 100 %.

Doi: https://doi.org/10.54644/jte.78B.2023.1253



## 1. Introduction

In recent years, alkali-activated materials such as Geopolymers have garnered attention from researchers around the world due to their low carbon footprint and minimal energy consumption [1], [2]. Geopolymer materials can be resulted from dissolving the rich aluminosilicate materials termed precursors, and highly alkaline liquids such as sodium hydroxide (NaOH) solution, and sodium silicate solution [3]. Industrial products (fly ash, rice husk ash, calcium carbide residue, etc.) or calcined clays (metakaolin) have been known as the widely used aluminosilicate materials for Geopolymer formation [4]. Owing to the highly alkaline environment, the alumina and silica components can be released from the precursors, and then carry out the polymerization process for Geopolymer formation [5]. Similar to Portland cement hydration, the Geopolymer products were pointed out to be cementitious compounds, which can bind loose aggregates into a strong composite material [2]. In addition, the Geopolymer's properties have been reported to be dependent on the nature of the curing condition and alkaline solution [6], [7]. For instance, Geopolymers material can achieve higher mechanical strength at higher temperatures condition [8]. In addition, using the alkaline solution with high a $Na_2O$ concentration also promote the strength of Geopolymers material [9].

Fly ash (FA), the abundant industrial by-product, is generated from the coal combustion of power plants [3]. In the civil engineering field, only a small fraction of FA is used as a pozzolanic additive, or structural filling material in Portland cement concrete [10]. Otherwise, FA was also known as one of the most widely used precursors for Geopolymer formation due to its high amorphous aluminosilicate content [11]. However, the tremendous quantity of FA was not utilized and becomes solid waste as a landfill.

Glass is one of the most used materials for daily human life from household appliances (beakers, bottles, etc.) to construction materials (doors, windows, etc.) [12], [13]. Glass could be recycled to create new glass products [14]. Nevertheless, the large quantity of used glass was reported to be either landfilled or stockpiled instead of recycled into the new ones [15], [16]. In this respect, glass waste can be used for other applications such as concrete [13]. Indeed, used glass with small-sized particles can be used as the aggregate in concrete [3]. In addition, the finely ground glass waste with high amorphous silica content can be used as a cement addition or a precursor for the alkali-activated material [17], [18].

The purpose of this study is to evaluate the potential to use recycled glass (RG) as the fine aggregate in slag-blended fly ash-based geopolymer mortar. Therefore, the material properties including workability, compressive and flexural strength, and drying shrinkage are determined in this research.

## 2. Materials and method

### *2.1. Material characterization*

*a)* *(b)* *(c)*

**Figure 1.** *Solid materials: (a) Glass waste; (b) FA; and (c) GGBFS*

Figure 1 describes the visual appearance of glass waste aggregate, fly ash, and ground granulated blast furnace slag. Fly ash, the by-product of a combustion coal power plant in Vietnam, was used as the source material for Geopolymer synthesis. Fly ash was classified as low–lime class F due to ASTM C618 [19] and has a density of 2.27 g/cm$^3$. Otherwise, ground granulated blast furnace slag (GGBFS) was used to accelerate the hardening process of the geopolymer mortar. GGBFS, the by-product from the Hoa Phat steel factory in Vietnam, has a density of 2.9 g/cm$^3$ and its surface area from the Blaine method is approximately 435 m$^2$/kg. Table 1 presents the chemical composition of FA and GGBFS. On the other hand, glass waste was collected from a recycling site in Ho Chi Minh City, Vietnam. Afterward, glass waste was crushed by the grinding ball mill in the laboratory, and then sieved to obtain the target-size material. Used glass waste has a maximum size smaller than 5 mm, and a density of 2.5 g/cm$^3$, and its chemical composition is described in Table 1. Additionally, Portland cement used in the current research is typed as PCB40.

**Table 1.** *Chemical composition of FA, GGBFS, and RG*

| Oxide composition | FA (%) | GGBFS (%) | Glass waste (%) |
|---|---|---|---|
| $SiO_2$ | 51.7 | 33.81 | 65 |
| CaO | 1.21 | 41.24 | 8 |
| $Al_2O_3$ | 31.9 | 15.19 | 2 |
| $Fe_2O_3$ | 3.48 | 0.41 | 0.15 |
| MgO | 0.81 | 5.54 | 2.5 |
| $SO_3$ | 0.25 | 2.51 | - |
| $Na_2O$ | 1.02 | 0.25 | 14 |
| $K_2O$ | - | 0.61 | - |
| LOI | 9.63 | 0.18 | - |

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For Geopolymer formation, the used alkaline liquid was a mixture including the sodium hydroxide (NaOH) solution and water glass. The NaOH pellets (97% purity) were dissolved into distilled water to obtain the NaOH concentration of 14 mol/l. In addition, the chemical composition of the water glass includes 30.1 % $SiO_2$, 9.4 % $Na_2O$, and 60.5 % $H_2O$. The alkaline liquid preparation was made before mixing for 24 hours.

### 2.2. Mixture proportion

In the mortar mixture, the ratio of fine aggregate and solid material was 2.75. For Geopolymer mortar, the ratio of alkaline solution to solid material is 5.5, and water glass is 2.5 times as much as NaOH solution by weight. The amount of GGBFS is used as 5 % of fly ash weight. The water to solid material is 0.45 for both Geopolymer and Portland cement mortar. The glass waste was used to replace the river sand aggregate in Geopolymer mortar with five different percentages of 0, 20, 40, 60, 80, and 100 %, named G0, G20, G40, G60, G80, and G100, respectively, whilst the Portland cement mortar was named as PC.

### 2.3. Experiment method

The 5 L capacity planetary machine was used to mix the mortar mixtures. After mixing, the fresh mortar was tested for workability according to ASTM C1437 [19]. Then, fresh mortar mixtures were cast into the prismatic steel molds with different dimensions including 40x40x160 mm for the strength test, and 25x25x285 mm for the drying shrinkage test, respectively. The demolded samples were kept in the ambient curing condition (20 ± 5 ºC, 60 ± 5 % RH) until testing.

The test for flexural strength and compressive strength determination was made at the age of 3, 7, and 28 days in accordance with ASTM C348 and C349 [20], [21]. Both portions from each prism broken in the flexural strength test were used for compressive strength determination.

The drying shrinkage measurement was performed by using a length comparator according to ASTM C596 [22]. The first read of the sample length was carried out immediately after demolding. Figure 2 shows the experimental tests including the flexural strength and drying shrinkage test.


*(a)* *(b)*

**Figure 2.** *Experimental test: (a) Flexural strength; (b) Drying shrinkage*

## 3. Results and Discussion

### *3.1. Workability of fresh mortar*

The workability of fresh mortar is determined by the flow table test according to ASTM C1437. The diameter alteration of the fresh mortar on the flow table before and after dropping expresses the flow value of the mortar. Figure 3 shows the flow of all Geopolymer and Portland cement mortar according to RG (Recycled glass) content. Generally, the flow value of mixtures was observed to be higher with higher RG content. For instance, the flow of samples increased by 3.5, 11.8, 23.5, 41.2, and 47.1 %, respectively, compared with the controlled samples without RG. These values are 2.2, 16.7, 22.2, 28.9, and 35.6 % for samples, respectively. The mortar mixture using 100 % RG as fine aggregate attained the highest value of the mortar flow. The increase in workability of the fresh mortar using RG as fine aggregate could be caused by the released water in the matrix, resulting from the smooth – surface of RG particles [3]. On the other hand, it is noted that the fresh Geopolymer mortar exhibited a higher flow value than PC mortar when the replacement level was 80, and 100 %. In the Geopolymer mixture, the existence of the sphere particles like fly ash also had a positive influence on the mortar flow. The result reveals that the simultaneous influence of both RG and fly ash was more effective in Geopolymer mortar with higher level RG content of 80, and 100 %.

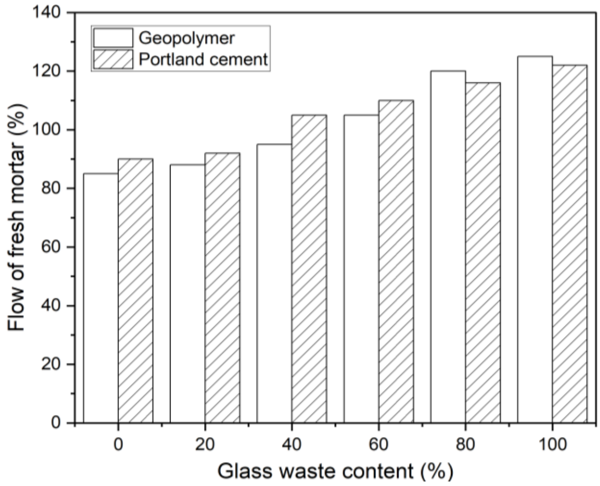


**Figure 3.** *The flow of fresh mortar*

### *3.2. Compressive strength*

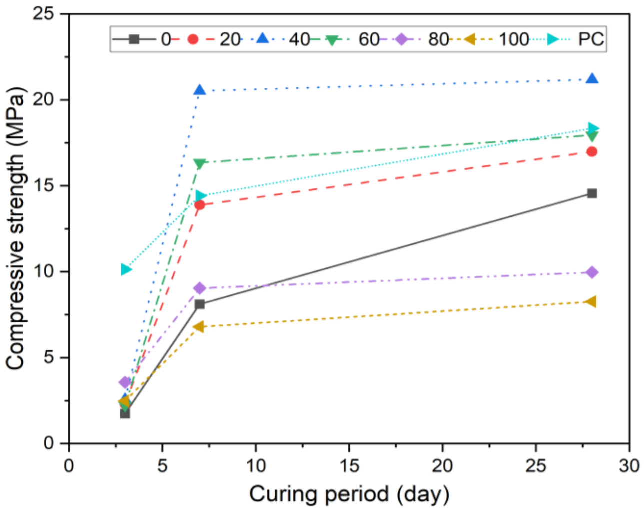


**Figure 4.** *Compressive strength of mortar*

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Figure 4 presents the compressive strength results of hardened mortar samples after 3, 7, and 28 days of curing. Figure 4 reveals that the strength development of Geopolymer mortar is different from that of Portland cement mortar. Evidently, at 3 days, Portland cement mortar could attain the strength value of approximately 10 MPa, whilst the strength of Geopolymer samples was about 2 MPa. Nevertheless, the latter samples exhibited a significant rise in compressive strength after 4 curing days (from 3 days to 7 days). For instance, the 7-day compressive strength of the sample was observed to be 8 times as high as its strength at 3 days. This value was 6.1, 7.4, 2.5, 2.7, and 1.4 for samples. In addition, the strength gain of mortar from 7 to 28 days was seen to be negligible except for samples without RG. Indeed, the strength gain of the sample was approximately 79.6 % after the curing period from 7 days to 28 days.

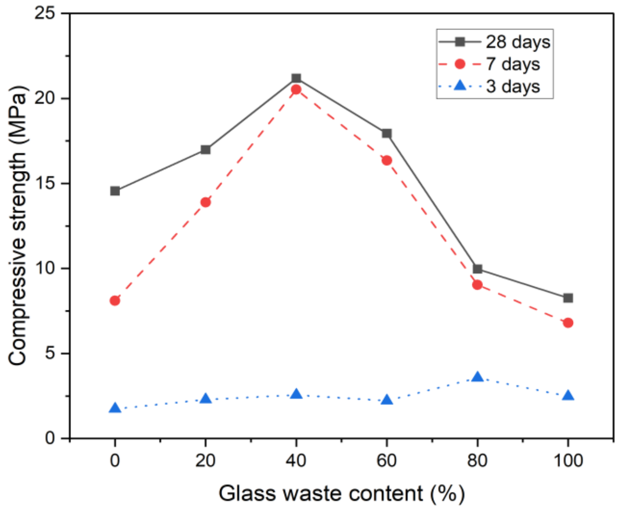


**Figure 5.** *Relation between the glass waste content and compressive strength*

Alteration in compressive strength of Geopolymer mortar as a function of RG content is presented in Figure 5. Remarkably, the influence of RG amount was negligible on the 3-day mortar strength, but considerable on the mortar strength at 7, and 28 days. Raising the RG content to 40 % resulted in a rise in strength, followed by the strength loss when the RG content from 40 to 100 %. The geopolymer mortar achieved the highest compressive strength value at the RG content of 40 %. This result could be attributed to the reaction of the partial fine RG with the alkaline solution for Geopolymer formation. In addition, the increase in workability of the fresh mortar using RG as aggregates led to parking efficiency. Nevertheless, the interfacial zone between RG aggregate and the Geopolymer matrix was weaker than that of sand aggregate due to the smooth surface of RG. As a result, the mortar strength tended to reduce with high content of used RG. On the other hand, the strength of this sample was also greater than that of Portland cement mortar at 7, and 28 days.

### *3.3. Flexural strength*

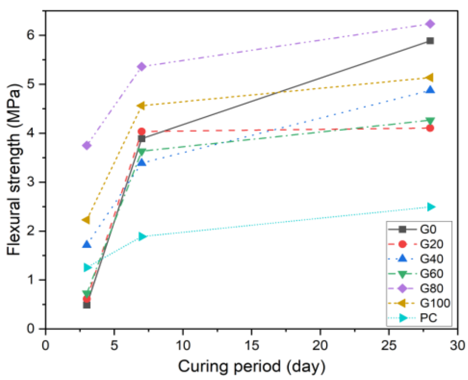


**Figure 6.** *Flexural strength of mortar*

The flexural strength development to 28 days of Geopolymer mortar samples is illustrated in Figure 6. Similar to the compressive strength result, the mortar flexural strength curves had a steep rise from 3 to 7 days and followed by the low strength gain from 7 to 28 days. The same tendency was observed in the strength of Portland cement mortar. It can be seen from Figure 6 that the flexural strength of Portland cement mortar was lower than that of Geopolymer samples at 7 and 28 days.

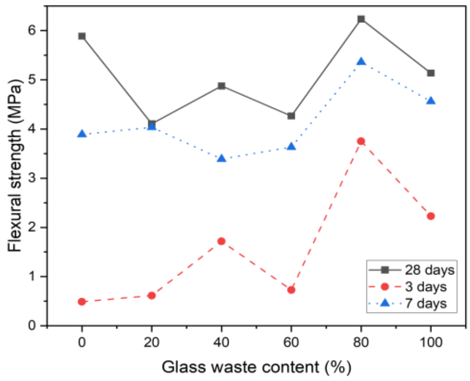


**Figure 7.** *Relation between the glass waste content and flexural strength*

### *3.4. Drying shrinkage*

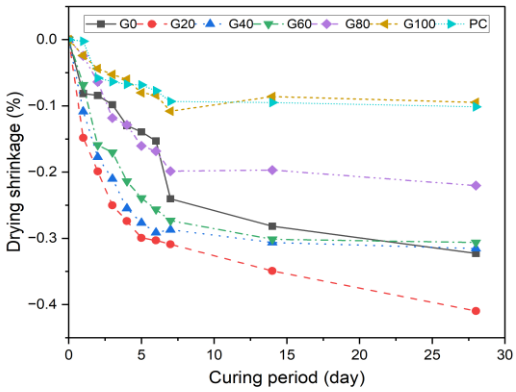


**Figure 8.** *Drying shrinkage of hardened mortar*

## 4. Conclusion

The above experimental results and analysis led to the following conclusions:

- Using RG as fine aggregate increased the workability of fresh mortar.

- The mechanical strength of slag blended fly ash-based Geopolymer mortar exhibited a significant gain in the early curing period from 3 days to 7 days. Afterward, this strength increase was seen to reduce from 7 days to 28 days.

- There was an increase in the compressive strength of geopolymer mortar with the replacement level of RG of 20, 40, and 60 % compared with the referenced specimens. The highest strength was observed in the mortar with an RG content of 40 %.

- The geopolymer mortar attained the highest flexural strength with an RG content of 80 %.

- The replacement of 80, and 100 % fine aggregate by RG resulted in the reduction in drying shrinkage of Geopolymer mortar.

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