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Effect Of Water-To-Binder Ratio on One-Part Geopolymer Mortar Performance

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KEYWORDS

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ABSTRACT

This study investigates a one-part geopolymer mortar made from fly ash and Ground Granulated Blast-furnace Slag (GGBS), activated with anhydrous sodium metasilicate. Various water-to-binder (w/b) ratios ranging from 0.26 to 0.34 were tested to evaluate compressive strength and water absorption over periods of 7 and 28 days. The results indicated that both compressive strength increased and water absorption decreased with longer curing times and higher w/b ratios. The optimal performance was achieved at a w/b ratio of 0.34, resulting in a compressive strength of 40.45 MPa and a water absorption rate of 13.98%. These findings underscore the potential of this material as a durable, low-carbon alternative to conventional cement for sustainable construction.

1. INTRODUCTION

Geopolymer is produced by mixing an alkaline solution with precursors that are high in alumina and/or aluminosilicates, such as metakaolin and fly ash. These two components must be blended thoroughly. Recently, laterite has emerged as a promising precursor due to its abundance and excellent performance(Al-Noaimat et al., 2023). Geopolymers have the potential to reduce CO_2 emissions from the cement and concrete industries by 80% to 90%, while also decreasing energy consumption during production. Additionally, geopolymers are highly valuable as green building materials since they can be created using a variety of waste materials, including both industrial and agricultural waste (Asim et al., 2024).

However, the use of the alkali solution presents safety hazards for engineers on-site because it is corrosive and viscous. Additionally, there are challenges associated with storing, transporting, and using this solution in various situations (K. yu Chen et al., 2024). To address these limitations, one-part geopolymers—also known as "just-add-water" geopolymers—have been developed.

One-part geopolymer is considered an effective approach to mitigate certain drawbacks associated with conventional geopolymer synthesis. The production of one-part geopolymers involves using constituents that are rich in silicon and aluminum compounds, along with solid activators and water. In contrast, two-part geopolymers primarily depend on liquid activators. One-part geopolymers are advantageous for storage, transportation, and testing purposes(M. Chen et al., 2025). In this study, with FA and GGBS as raw materials, solid anhydrous sodium silicate (Na_2SiO_3) as solid alkali-activator to prepare one-part geopolymer.

2. EXPERIMENTAL PROCEDURE

2.1 Materials and Mix Design

Ground granulated blast furnace slag (GGBS) provided by Macro Dimension Concrete (MDC) at the Pauh Plant and fly ash provided by by Macro Dimension Concrete (MDC) at the Cendana Plant were employed as a solid precursor to produce alkali-activated materials in this study. Anhydrous Na_2SiO_3 was supplied by R&M Chemicals were used as alkaline activators in this study.

The proportions of the one-part geopolymer mixtures were 0.26 to 0.34 in terms of water-to-binder (W/B). The anhydrous sodium metasilicate, was dry-blended with the solid precursors, fly ash and ground-granulated blast-furnace slag (GGBS), in a mechanical mixer set until the mixture was homogenous. To create a consistent paste with a working consistency, tap water was then added gradually while the mixture was being mixed. After mixing, the fresh geopolymer mixture was immediately casted in 50mm mold and allowed to cure for 24 h at room temperature. After demolding, the samples were cured for 7 and 28 days.

2.2 Determination Properties of Geopolymer Mortar

The water absorption of geopolymer mortar was determined based on ASTM C140.The strength of geopolymer mortar was determined by using Universal Testing Machine (UTM) as compliance with BS 1881-116 (1983).

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3. RESULTS AND DISCUSSION

3.1 Water Absorption

As being illustrated in Figure 1, the water absorption behavior of one-part geopolymer incorporating blended fly ash and ground granulated blast furnace slag (GGBS) was evaluated at varying water-to-binder (w/b) ratios over curing durations of 7 and 28 days.

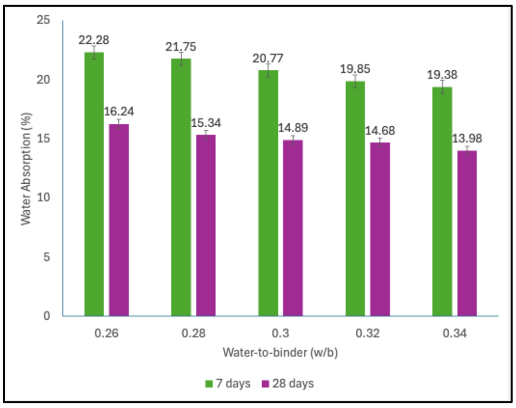

Figure 1. Water absorption for different water-to-binder ratio.

The water absorption values consistently decreased with increasing curing age, as illustrated in Figure 1. This decline indicates that geopolymerization and matrix densification were still actively occurring. The specimens tested at 28 days showed significantly lower absorption values than those tested at 7 days across all water-to-binder (w/b) ratios, with reductions ranging from 26.6% to 27.9%. These findings demonstrate that the ongoing reactivity of aluminosilicate precursors gradually contributes to the development of a denser microstructure (Reyes-Román et al., 2025).

A notable trend is the reduction in water absorption as the w/b ratio increases. The blended use of Ground Granulated Blast Furnace Slag (GGBS), a calcium-rich precursor, accelerates early strength gain and helps refine pores through the formation of C-(A)-S-H gel, complementing the N-A-S-H gel produced from the activation of fly ash (Liu et al., 2024).

The minimum 28-day absorption value of 13.98% at a w/b ratio of 0.34 indicates that an increase in mixing water enhances reactivity and densification without increasing porosity. This may be attributed to the synergistic effects of fly ash and GGBS working together to create a mixed binder system that promotes improved microstructural development.

3.2 Compressive Strength

A clear trend of strength enhancement over time was observed across all mixtures. At 7 days, the compressive strength ranged from 16.74 to 27.14 MPa, which increased to between 23.32 and 40.45 MPa at 28 days. This progression in strength indicates ongoing geopolymerization reactions and the continuous development of aluminosilicate and calcium-silicate-hydrate (C-A-S-H) gel phases, which are facilitated by the combined use of fly ash and ground granulated blast-furnace slag (GGBS) (Jing et al., 2025).

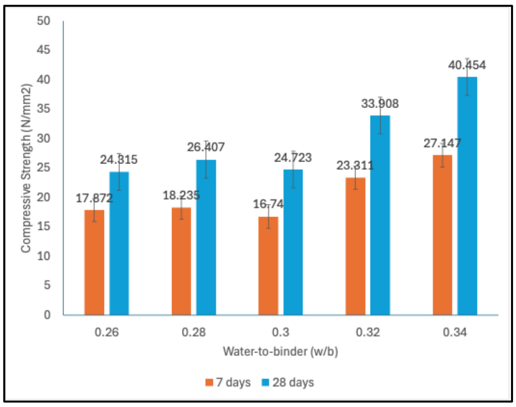

Figure 2. Compressive strength for different water-to-binder ratio.

Interestingly, increasing the water-to-binder ratio above 0.30 led to improved strength, with the highest 28-day strength (40.45 MPa) recorded at a water-to-binder ratio of 0.34, slightly exceeding the strength of the 0.26 mix. This suggests that beyond a certain threshold, a higher water content may enhance ion mobility, facilitate precursor dissolution, and improve reaction kinetics, particularly in the presence of GGBS, which reacts effectively with moderate water content. These findings are consistent with previous research, which indicates that geopolymer systems require an adjustment of the water-to-binder ratio based on the type of precursor and the availability of calcium (Wang et al., 2025).

4. CONCLUSION

In summary, the study confirms that one-part geopolymer formulated from a blend of fly ash and GGBS, can achieve both high early and long-term strength, especially when the water-to-binder (w/b) ratio is optimized. These results underscore the potential of one-part geopolymer (OPG) as a sustainable and high-performance alternative to ordinary Portland cement (OPC) for durable construction applications.

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