

Effect Of Elevated Temperature Curing on the Compressive Strength of Geopolymer Concrete

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Abstract: Geopolymer concrete is an eco-friendly alternative to conventional Portland cement concrete due to its reduced carbon emissions and utilization of industrial by-products. This study investigates the effect of heat curing on the compressive strength of geopolymer concrete using fly ash as the primary binder and Palm Oil Shell Ash (POSH) as a partial replacement material. Two alkaline activators to fly ash ratios were considered, namely 0.55 and 0.825. Specimens were cured under ambient conditions and heat curing at 60°C for 24 hours. Experimental results indicate that heat curing significantly enhances compressive strength compared to room temperature curing. The incorporation of POSH also contributed to strength improvement and sustainable waste utilization. The findings demonstrate that controlled heat curing is an effective technique for improving geopolymer concrete performance.

Keywords: Geopolymer concrete, Heat curing, Fly ash, Palm Oil Shell Ash, Sustainable materials.

I. Introduction

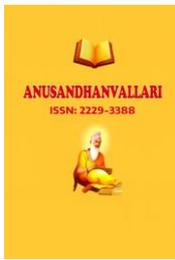
The construction industry is one of the major contributors to global carbon dioxide emissions due to the extensive use of Portland cement. Geopolymer concrete has emerged as a sustainable alternative by utilizing industrial by-products such as fly ash and slag activated by alkaline solutions. Unlike conventional cement hydration, geopolymerization involves chemical reactions between aluminosilicate materials and alkaline activators, resulting in a hardened binder.

Heat curing plays a significant role in accelerating geopolymerization and improving mechanical properties. Previous studies have shown that elevated curing temperatures enhance early strength development and reduce setting time. This research focuses on evaluating the influence of heat curing on compressive strength and the effect of Palm Oil Shell Ash as a supplementary material.

II Literature Review

Hardjito and Rangan [1] reported the development and engineering properties of low-calcium fly ash-based geopolymer concrete and demonstrated that geopolymer binders can achieve comparable or even superior mechanical properties compared to conventional Portland cement concrete. Their study highlighted the importance of alkaline activator concentration, curing temperature, and mix proportions in achieving optimal compressive strength and durability performance. Davidovits [2] introduced the fundamental concept of geopolymer chemistry and explained the polymerization process of aluminosilicate materials in an alkaline environment, establishing the theoretical foundation for geopolymer-based construction materials. The author emphasized the environmental benefits of geopolymer technology, particularly the reduction in carbon dioxide emissions compared to cement production.

Bakharev [6] investigated the influence of elevated temperature curing on geopolymer materials prepared using Class F fly ash and reported that heat curing significantly accelerates geopolymerization reactions, resulting in improved early-age strength and enhanced microstructural development. The study also indicated that higher



curing temperatures contribute to reduced porosity and increased material density. Singh et al. [7] presented a comprehensive review of geopolymer concrete research and highlighted recent advancements in mechanical properties, durability characteristics, and practical applications. Their findings confirmed that geopolymer concrete exhibits excellent resistance to chemical attack, sulfate exposure, and high-temperature environments compared to conventional concrete.

Komnitsas and Zaharaki [8] discussed the geopolymerization mechanisms in detail and explored potential industrial applications of geopolymer materials, emphasizing their suitability for sustainable construction and waste utilization. Olivia and Nikraz [9] analyzed the engineering properties of fly ash-based geopolymer concrete using statistical optimization techniques such as the Taguchi method and demonstrated that proper control of mix parameters significantly enhances compressive strength and workability. Anuradha et al. [10] proposed modified mix design guidelines for geopolymer concrete based on Indian standards, providing practical recommendations for material proportions and activator concentrations suitable for field applications.

Gorhan and Kurkul [11] studied the influence of sodium hydroxide concentration and curing temperature on geopolymer mortar properties and observed that both parameters play a critical role in determining mechanical performance and microstructural characteristics. Patankar et al. [12] investigated the effect of sodium hydroxide molarity on the flow behaviour and compressive strength of fly ash-based geopolymer mortar and concluded that an optimum activator concentration is essential to achieve maximum strength and durability performance.

Overall, the literature indicates that curing temperature, alkaline activator concentration, and material composition are the key factors influencing the strength development and performance of geopolymer concrete. However, limited research has been reported on the combined effect of heat curing and supplementary waste materials such as Palm Oil Shell Ash, which forms the motivation for the present study.

III. Methodology

A. Materials

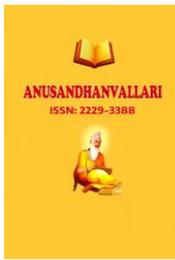
Low-calcium fly ash was used as the primary binder material for the preparation of geopolymer concrete due to its high silica and alumina content, which are essential for geopolymerization. Palm Oil Shell Ash (POSH) was incorporated as a partial replacement material to evaluate its influence on strength and sustainability performance. Locally available fine aggregates and coarse aggregates were used in accordance with standard concrete mix requirements. The alkaline activator solution consisted of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions, which play a crucial role in initiating and sustaining the geopolymerization process.

B. Preparation of Alkaline Solution

The sodium hydroxide solution of the required molarity was prepared by dissolving NaOH pellets in distilled water under controlled conditions. Since the dissolution process is exothermic, the solution was allowed to cool to room temperature before use. The alkaline activator solution was then prepared by mixing sodium hydroxide and sodium silicate solutions in a predetermined ratio. The prepared activator solution was kept undisturbed for approximately 24 hours to allow proper equilibration and stabilization before being used in concrete mixing.

C. Mix Design

The mix proportions were designed based on alkaline activator to fly ash ratios of 0.55:1 and 0.825:1 to study the influence of activator concentration on compressive strength development. Palm Oil Shell Ash was incorporated at different replacement levels of 0%, 5%, 10%, and 15% by weight of fly ash to evaluate its effect on mechanical performance. The proportions of aggregates and binder materials were selected to achieve workable geopolymer concrete with adequate strength characteristics.



D. Specimen Preparation

All dry materials, including fly ash, POSH, and aggregates, were initially mixed thoroughly in a pan mixer to achieve uniform distribution. The alkaline activator solution was then added gradually to the dry mix while continuous mixing was carried out until a homogeneous and workable concrete mixture was obtained. The fresh geopolymer concrete was placed into cube moulds of size 150 mm × 150 mm × 150 mm in three equal layers, with each layer compacted properly using a tamping rod to eliminate entrapped air. The specimens were kept undisturbed for 24 hours and then demoulded carefully prior to curing.

E. Curing Procedure

Two different curing conditions were adopted to evaluate the influence of temperature on strength development. The first set of specimens was subjected to ambient curing at room temperature, while the second set was subjected to heat curing at 60°C for 24 hours in a controlled oven environment. After heat curing, the specimens were allowed to cool naturally to room temperature before testing at the specified ages.

F. Testing Procedure

Compressive strength tests were conducted using a calibrated Compression Testing Machine (CTM) in accordance with relevant standard testing procedures. The specimens were tested at different curing ages of 1, 3, 7, and 28 days to evaluate strength development over time. The average value of three specimens was considered for each test condition to ensure accuracy and reliability of the experimental results.

IV. Results and Discussion

A. Effect of Heat Curing

Heat-cured specimens exhibited significantly higher compressive strength compared to specimens cured under ambient room temperature conditions. The strength improvement ranged from approximately 2 to 3.5 times higher than the corresponding room-temperature cured samples, clearly indicating the beneficial effect of elevated temperature on geopolymer concrete performance.

The enhancement in strength can be attributed to the acceleration of geopolymerization reactions at higher temperatures, which promotes faster dissolution of aluminosilicate species from fly ash and facilitates the formation of a dense three-dimensional polymeric network structure. Heat curing also reduces the setting time and enhances early-age strength development by improving the bonding between binder and aggregates. Furthermore, elevated curing temperature contributes to reduced porosity and improved microstructural compactness, which collectively result in higher compressive strength values.

B. Effect of POSH Addition

The incorporation of Palm Oil Shell Ash (POSH) as a partial replacement material demonstrated a noticeable improvement in compressive strength compared to the control mix without POSH. This improvement can be attributed to the pozzolanic nature of POSH, which reacts with alkaline activators and contributes to additional geopolymeric gel formation. The fine particle size of POSH also helps in filling micro-voids within the matrix, leading to enhanced densification of the microstructure and improved interfacial transition zone (ITZ) between aggregates and binder paste.

However, it was observed that excessive replacement levels of POSH may lead to a slight reduction in workability due to increased water demand and higher surface area of the particles. Therefore, an optimum percentage of POSH replacement is necessary to achieve a balance between mechanical performance and workability characteristics.

C. Comparison of Mix Ratios

The comparison between alkaline activator to fly ash ratios revealed that the ratio of 0.55 produced slightly higher compressive strength compared to the 0.825 ratio under heat curing conditions. This observation suggests that an optimum activator concentration exists for effective geopolymerization. A lower activator ratio may provide adequate alkalinity for dissolution and polymerization while maintaining a balanced water content, resulting in improved matrix formation and strength development.

In contrast, higher alkaline activator ratios tend to increase the overall liquid content in the geopolymer mix, which may result in the formation of additional pores and micro-voids after the curing process. This increase in porosity can adversely affect the density and integrity of the geopolymer matrix, thereby causing a marginal reduction in compressive strength.

Moreover, excessive activator content may disturb the optimal balance between dissolution and polymerization reactions, leading to inefficient geopolymeric gel formation. The findings clearly indicate that the selection of an appropriate alkaline activator concentration plays a critical role in achieving maximum mechanical performance, improved microstructural characteristics, and enhanced durability of geopolymer concrete.

Mix Type	Compressive Strength (MPa)
0.55 Ambient	12.5
0.55 Heat	34.2
0.825 Ambient	10.8
0.825 Heat	33.7

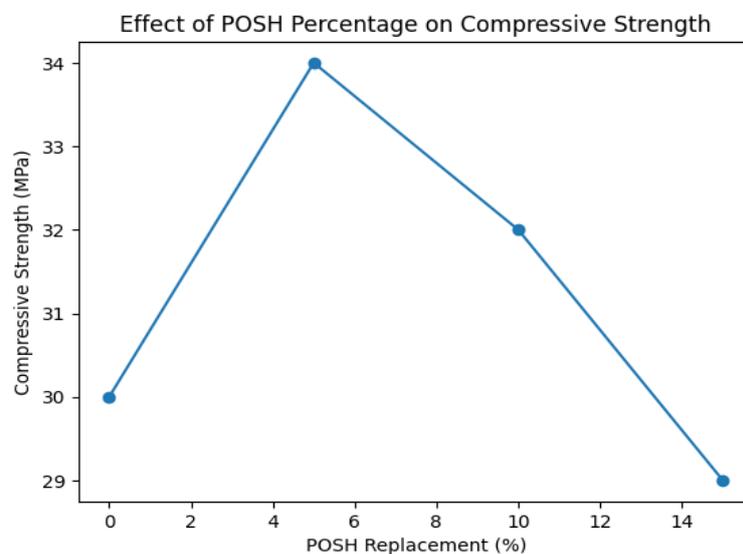


Fig. 1 shows the influence of POSH replacement percentage on compressive strength.

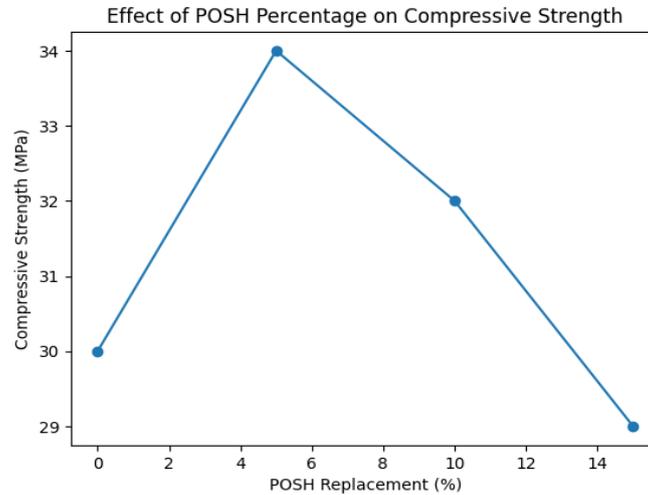


Fig. 2 shows the compressive strength development with curing days.

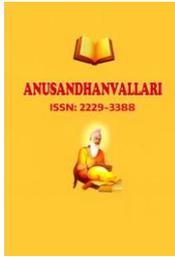
V. Conclusion

The present experimental investigation confirms that heat curing has a significant influence on the compressive strength development of geopolymer concrete. The application of elevated temperature curing accelerates the geopolymerization process, resulting in improved mechanical properties and enhanced matrix densification. In addition, the incorporation of Palm Oil Shell Ash (POSH) contributes not only to strength enhancement but also to sustainable material utilization by promoting the use of industrial and agricultural waste products. Based on the experimental results obtained in this study, the following conclusions can be drawn:

- Heat curing at 60°C for 24 hours substantially increases the compressive strength of geopolymer concrete compared to specimens cured under ambient temperature conditions, indicating accelerated reaction kinetics and improved binder formation.
- Palm Oil Shell Ash can be effectively utilized as a supplementary material in geopolymer concrete, contributing to improved microstructural characteristics and sustainable waste management.
- Lower alkaline activator to fly ash ratios demonstrated comparatively better strength performance under controlled heat curing conditions, suggesting the existence of an optimum activator concentration for efficient geopolymerization.
- Geopolymer concrete subjected to heat curing shows strong potential as an environmentally sustainable construction material due to its reduced carbon footprint, improved strength characteristics, and efficient utilization of waste resources.

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