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# REVIEW PAPER ON GEOPOLYMER MORTAR PREPARED WITH FLY ASH AND SILICA

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## ABTRACT

Fly ash based geopolymer using the combination of low calcium fly ash and alkali as a binding agent in place of ordinary Portland cement is the most innovative, environment friendly construction material for the sustainable development. As per the research data on an average, approximately 1 ton of cement is being produced each year for every human being in the world. To address environmental concerns, especially CO<sub>2</sub> emissions, reducing the percentage of cement used in concrete is crucial. One approach to achieve this is by utilizing innovative materials like geopolymers. This dissertation presents an experimental investigation into the effects of the binder-to-sand ratio on the mechanical strength of fly ash-based geopolymer mortar

Keywords: - silica fume, Portland cement, flyash, geopolymer mortar, strength and durability.

#### 1. INTRODUCTION

The invention of cement (Joseph Aspdin 1824) as a binder material was proven to be master stroke for the rapid development of construction industries, since then the cement has been used abundantly all over the world till now. As cement concrete is most widely used composite materials in infrastructure construction but it also leads some serious changes ( like temperature rise, pollution) in the atmosphere of earth due to release of CO<sub>2</sub>. It is evaluated that approximately one ton carbon dioxide gas is globally released in the production of one ton Portland cement. This accounts to approx. 7% of the total greenhouse gas emission to the atmosphere of earth. Also, other adverse environmental impact of conventional cement like Portland cement production refers to the high energy consumption. After aluminium and steel plant, the manufacturing of Portland cement is the biggest energy-intensive process that consumes about four Giga-joule of energy per ton. In the recent years, the concept of sustainability in concrete has becoming more popular among the user of concrete and concrete professionals. For the sustainable development, amount of cement has been minimized by using waste materials like fly ash, rice husk, and availability of industrial by- product material. Fly ash which is rich in silica and aluminium content provided an opportunity for partial or complete replacement of Portland cement.

### 2. LITERATURE SURVEY & BACKGROUND

Jagan et al. (2023) conducted a comprehensive review of Engineered Geopolymer Composites (EGC), highlighting the effects of various factors—such as alkali activator additions, their chemistry, reaction mechanisms, precursors, admixtures, and hybrid fiber combinations—on the engineering properties of EGC. Notably, the alkali activator solution is pivotal in geopolymer formulation and binding capacity. Their review found that EGC exhibits a high strain-hardening capacity (4–7%) and enhanced mechanical properties due to improved geopolymerization and a robust interfacial bond between fibers and the matrix.

The research identifies a gap in EGC studies related to the use of both low- and high-modulus fibers in hybrid combinations, as well as durability, carbonation, and corrosion analyses, suggesting these areas should be focal points for future research

Zhuang et al. (2017) studied on acid resistance of geopolymer mortar (GM) with  $H_2SO_4$  and NaCl attacks. The investigation was about the variation of mechanical strength and weight of GM after soaking in water, sulphuric acid and sodium chloride for different duration (30, 60, 90, 180, 270 and 360 days). For transverse strength and compressive strength of prism of GM with dimension of 160mm×40mm×40mm used and the tensile was tested on "8" shaped specimen. The author observed that the GM showed better resistance to sodium chloride and sulphuric acid solution and there was larger degradation in transverse, compressive and tensile strength of GM with 6%, 11%, and 15% when sample were exposed in NaCl and  $H_2SO_4$  solution respectively during the complete exposer duration (age of 360 days), in comparision to that in tap water. The GM in sulphuric acid has more strength fluctuation as compare to that in 261 solution and  $H_2SO_4$  acid solution after 60 days exposer.

Mahendra et al. (2017) investigated the effect of low calcium fly ash based geopolymer mortar incorporating silica fume. The geopolymer specimen prepared by alkaline activator solution i.e mixture of sodium hydroxide (NaOH) and sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) in the ratio of 1:2.5 with the concentrations of sodium hydroxide 8M, 10M, and 12M. Fly ash was

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replaced by varying percentage of silica powder as 2%, 4%, 6%, 8% and 10% and studied for its compressive strength and compared with the control geopolymer mortar cubes. The author concluded that as the molarity of the sodium hydroxide increases the strength of mix without silica fume increases. The mix with 6% silica fume and 8M NaOH concentration reaches highest compressive strength. He also attributed as the silica fume increases the strength of the mortar also starts to decreases.

Warid wazien et al. (2016) focused on study of the effect of binder to sand ratios on geopolymer mortar (GM) properties. For preparing GM mix design consists 12 mole NaOH solution, fly ash to alkaline ratio is 2.0 and alkaline ratio (Na<sub>2</sub>SiO<sub>3</sub> solution to NaOH solution by mass) is 2.5.

The sample of GM analysed for compressive strength and density at variable duration of 3<sup>rd</sup> and 7<sup>th</sup> day of curing at ambient temperature. The author attributed on the basis of results of experiment that the reinforcement with sand slightly enhance the compressive strength of GM. Therefore, for the suitable preparation of GM, binder to sand ratio of 0.5 is considered on the basis of workability and compressive strength for concrete patch repair. Density of geopolymer mortar ranges between 2.01 g/cm<sup>3</sup> to 2.23 g/cm<sup>3</sup>. Based on above finding the author shows the potentials importance of geopolymer mortar as repair materials.

Patanker et al. (2015) performed an experimental investigation for the mix design procedure and the gradation of geopolymer concrete based on amount and fineness of flyash, quantity of water, grading of sand and fine to total aggregate ratio. In his study he takes certain fixed parameters derived by workability and cube compressive strength as NaOH solution with 13 M, Sodium silicate solution with Na<sub>2</sub>O.=16.36%, SiO<sub>2</sub>.= 34.34% and H<sub>2</sub>O. =49.28%, both water to binder ratio and alkaline solution to flyash ratio taken as 0.35 and sodium silicate solution to sodium hydroxide solution ratio of 1 by mass. Temperature curing was performed at 60° C for time duration of 24 hour and test performed at the age of seven days. He found the experiment results for M20, M25, M30, M35, and M40 grade of GPC made by using proposed methodology of mix proportion showed acceptable results of workability and compressive strength.

The process for creating a sodium hydroxide solution with a molarity of M, which is utilised in geopolymer concrete technology, was provided by Rajmane et al. (2014). According to the author, a typical chemistry method for creating a sodium hydroxide solution with molarity M is to dissolve  $\{M*40\}$  grammes of sodium hydroxide solids in a small amount of water, then create a solution of 1 litter by adding more water as needed to create a sodium hydroxide solution in large quantities with the preferred molarity.

According to the author, two procedures on geopolymer concrete that have been mentioned in several Indian publications are inaccurate.

1. Add  $\{M*40\}$  grammes of sodium hydroxide solids to 1 kilogramme of water to create a sodium hydroxide solution with molarity M.

2. Mix  $\{M*40\}$  grammes of sodium hydroxide solids with  $\{1000-40*M\}$  grammes of water to get a sodium hydroxide solution with molarity M.

The author suggests a table to determine the amounts of water and sodium hydroxide solids needed to generate sodium hydroxide solution of a certain molarity based on the information on sodium hydroxide solution found in Perry's Handbook for Chemistry.

Jamker et al. (2013) studied the impact of fly ash fineness on the compressive strength of geopolymer concrete (GPC). In their research, GPC was created by activating fly ash using a highly alkaline solution of sodium hydroxide at a 13M concentration, along with sodium silicate containing 16.45% Na<sub>2</sub>O, 34.35% SiO<sub>2</sub>, and 49.20% H<sub>2</sub>O. Five fly ash samples with varying Blaine fineness values (542, 430, 367, 327, and 265 m<sup>2</sup>/kg) were prepared, with a solution-to-fly ash ratio of 0.35. GPC was cast in 150 mm molds and cured in an oven at 90°C for 4, 8, 12, 16, 20, and 24 hours. The study concluded that increased fly ash fineness led to higher compressive strength and improved workability. It was also observed that finer particles accelerated the reaction rate, thus requiring less heating time to reach a specific strength.

Satpute et al. (2012) examined the effects of curing temperature and duration on the compressive strength of fly ashbased geopolymer concrete. Using low-calcium fly ash (completely replacing cement) activated by an alkaline solution of sodium hydroxide and sodium silicate, they conducted experiments with an alkaline solution-to-fly ash ratio of 0.35 and a sodium hydroxide solution concentration of 16M. They cast 150 mm  $\times$  150 mm  $\times$  150 mm concrete cubes and cured them at temperatures of 60°C, 90°C, and 120°C for pe%64s of 6, 12, 16, 20, and 24 hours.

The compressive strength, flexural strength, static elastic modulus, and other mechanical characteristics of flyash-based geopolymer concrete were experimentally tested by Diaz-Loya et al. (2011).Poisson's ratio of 25 fly ash stocks from various sources used to create GPC specimens. To find patterns and correlations in the mechanical characteristics of GPC, he employed regression analysis. He discovered that the mechanical properties of GPC and regular concrete

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specimens were comparable in terms of elastic modulus and compressive strength. A statically calculated equation for the link between GPC's flexure and compressive strength was also offered in his work; this equation is similar to the one provided by ACI 318-0829 for regular concrete.

Thokchom et al. (2011) investigate how the mechanical characteristics and durability of flyash geopolymers are affected by the induction of silica fume. In this work, activated fly ash Geopolymer specimens were prepared using a combination of sodium silicate and sodium hydroxide solution with an 8% Na2O content and silica fume in the range of 2.5% to 5%. The specimen was immersed in a 10% magnesium sulphate solution for 15 weeks in order to examine the endurance of the geopolymer. Throughout this time, regular visual observations, strength changes, and mass changes were noted. According to the study, the author concluded that silica fume-induced geopolymer mortar has a higher compressive strength than silica fume-induced geopolymer paste. When compared to silica fume-induced geopolymer paste, the residual strength following exposure to magnesium sulphate is likewise greater for silica fume-induced geopolymer mortar.

The life cycle cost and carbon implications of ordinary cement (OPC) and geopolymer were examined in an Australian setting by Benjamin C. et al. (2011), who also identified some of the major obstacles to the development of geopolymer. The findings indicate that the estimated financial and environmental "cost" of geopolymer varies greatly and can be either positive or negative based on the source region, the energy source, and the mode of delivery. When compared to regular Portland cement, the suggested average Australian Geopolymer product reduces greenhouse gas emissions by 44-64%, but it costs up to twice as much. According to the author, each use of geopolymer must be evaluated for its particular site, demonstrating that one of the deciding elements is the effect of location on overall sustainability.

Hardjito et al. (2004) conducted research on the development of fly ash-based geopolymer concrete. They described geopolymer concrete as a by-product material rich in aluminum and silicon, like low-calcium fly ash, which becomes chemically activated by a high-alkaline solution. This activation process forms a paste that effectively binds the loose coarse and fine aggregates, as well as any unreacted materials within the mixture.

He attributes some conclusion on the basis of experimental work.

- 1. Higher compressive strength is achieved with a higher molarity of NaOH solution.
- 2. The mass ratio of Na<sub>2</sub>SiO<sub>3</sub> solution to NaOH solution is directly related to the compressive strength of fly ash-based geopolymer.
- 3. Geopolymer concrete cured at temperatures between 30°C and 90°C shows higher compressive strength.
- 4. Extended curing times, ranging from 6 to 96 hours, increase the compressive strength of geopolymer concrete; however, strength gains beyond 48 hours are minimal.
- 5. Adding a high-range water-reducing admixture, up to approximately 2% of fly ash by mass, has minimal impact on the compressive strength of hardened concrete but significantly improves the workability of fresh geopolymer concrete.
- 6. The water-to-geopolymer solid ratio is inversely related to compressive strength.
- 7. Geopolymer concrete exhibits very low drying shrinkage, low creep, and excellent resistance to sodium silicate.
- 8. The initial setting time of fresh geopolymer concrete is approximately 120 minutes..

Davidovits (1994) concerned about the  $CO_2$  gas emission from cement industries and the highlighting the advantageous result of using geopolymer as cementecious materials. OPC used in construction industries, resulting by the calcination of limestone (calcium carbonate) and silica given by following reaction

#### $5 \text{ CaCO}_3 + 2 \text{SiO}_2 (3 \text{CaO}, \text{SiO}_2) (2 \text{Cao}, \text{SiO}_2) + 5 \text{CO}_2$

The study shows that the generation of one ton of cement produces 0.55 tones of Carbon dioxide and requiring carbon fuel combustion to yield an addition of 0.40 tones of carbon dioxide. Hence overall one ton of cement producing one ton of carbon dioxide.

International institution recommended that there are 5% of the world  $CO_2$  emission take place by producing one billion metric tonnes generation of cement in world which estimated for one billion metric tonnes of carbon dioxide in 1987 and 1990 both. Current cement's growth rate of production ranges from 5 % to 16% and suggesting that in upcoming 25 years from now, cement carbon dioxide emission probably will be equal to 3,500 million tonnes.

Author suggest the geopolymeric poly (Sialte -siloxo) cement (low CO<sub>2</sub> cementecious materials) have great potentials to reducing CO<sub>2</sub> emission be the cement and aggregate ind **Q6t** rises by 80% as it does not relies on the calcination of limestone and silica, provides familiar properties like current high carbon dioxide Portland cement.



#### 3. CONCLUSION

The study on the mechanical properties of geopolymer mortar prepared using fly ash and silica reveals significant findings that contribute to the advancement of sustainable construction materials. The conclusions are as follows:

- 1. Enhanced Mechanical Properties: The incorporation of silica in fly ash-based geopolymer mortar improves its mechanical properties, such as compressive strength, tensile strength, and flexural strength. The synergy between fly ash and silica enhances the geopolymeric reaction, resulting in a denser and more robust microstructure.
- 2. Optimal Mix Design: The mechanical properties are highly dependent on the mix proportions of fly ash, silica, and the alkali activator. An optimal ratio ensures maximum strength and durability while maintaining workability.
- 3. Durability and Sustainability: Geopolymer mortar demonstrates excellent resistance to environmental factors such as chemical attacks, thermal changes, and moisture exposure. This makes it a sustainable alternative to traditional cement-based materials, reducing CO<sub>2</sub> emissions and utilizing industrial byproducts like fly ash.
- 4. Influence of Silica Content: Increasing silica content up to a certain limit significantly enhances the geopolymerization process, leading to improved bonding and strength. However, excessive silica may hinder workability and lead to non-uniformity in the mortar.
- 5. Application Potential: The enhanced mechanical and durability properties of fly ash and silica-based geopolymer mortar make it suitable for various construction applications, including load-bearing structures, precast elements, and repair works.
- 6. Environmental Benefits: By utilizing fly ash, a byproduct of coal combustion, and silica, the material reduces reliance on Portland cement, thus contributing to sustainable waste management and lowering the carbon footprint of construction activities.

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