Effect on Mechanical Properties of Self Compacting Geopolymer Concrete by Varying Percentage of Fly Ash and GGBS

Mr. Mayur Ashok Nimase[1*] Prof. S. N. Daule [2]
[1*]*PG Student, Dept. of Civil Engineering, Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar*
[2*]*Professor, Dept. of Civil Engineering, Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar*

Abstract: The increasing generation of foundry waste, particularly sand and other by-products, presents significant environmental challenges. However, these materials can potentially be repurposed in the construction industry, especially in the manufacturing of paver blocks and concrete. This study explores the beneficial reuse of foundry waste in the production of paver blocks and concrete, aiming to reduce waste disposal issues and enhance sustainability in construction practices. The foundry waste was incorporated into concrete and paver block mixtures at varying replacement levels of sand and cement. The effects on the physical, mechanical, and durability properties of the resulting concrete and paver blocks were thoroughly analyzed. The study reveals that the incorporation of foundry waste led to improvements in workability, compressive strength, and durability, especially when used at moderate replacement levels. This research suggests that foundry waste, when processed and used appropriately, can serve as a sustainable alternative in concrete production, reducing the environmental impact of both the construction and foundry industries

Keyword: GGBS, Fly ash, Geopolymer

1. INTRODUCTION

Self-compacting geopolymer concrete (SCGC) is a distinctive type of concrete that can flow and compact on its own, particularly in areas with dense reinforcement, without requiring additional compaction efforts. The manufacturing process of SCGC involves using various industrial by-products, such as fly ash, ground granulated blast furnace slag (GGBS), waste glass powder, silica fume, and rice husk ash. Materials that contain extra silica and alumina can also be incorporated. These ingredients are activated through the addition of an alkaline solution, consisting of sodium silicate and sodium hydroxide. To facilitate the concrete's flow, superplasticizers, including GGBS, can be used.

Self-compacting concrete (SCC) is a specific type of concrete that requires no external compaction. It flows and consolidates under its own weight. The concept was first introduced by researchers in Japan. The main criteria for SCC include filling ability, passing ability, and resistance to segregation. The maximum allowable size for coarse aggregates is 20 mm. Common testing methods for SCC include the Abrams cone slump test, T50 slump flow, J-ring, V-funnel, U-box, and L-box tests.

Concrete, primarily composed of Portland cement, is one of the most widely used construction materials. Its demand continues to grow. Global cement production is projected to increase from approximately 1.5 billion tonnes in 1995 to 2.2 billion tonnes by 2010. However, the cement industry also contributes significantly to environmental challenges, particularly in terms of climate change due to global warming. Greenhouse gases like carbon dioxide (CO2), which are largely emitted through human activities, contribute to global warming. CO2 is responsible for about 65% of the greenhouse gases linked to climate change. The cement industry alone accounts for around 6% of global CO2 emissions, as the production of one ton of Portland cement results in the release of an equivalent amount of CO2 into the atmosphere

A. Properties of Geo-Polymer Concrete

Geopolymers, a class of inorganic binders, are characterized by several key properties. The compressive strength of geopolymers is influenced by both the curing temperature and duration, with strength increasing as these factors are optimized.

Unlike conventional cement, which uses limestone, geopolymers are highly resistant to corrosion in both acidic and alkaline environments, making them particularly suitable for harsh conditions.

Geopolymer materials also exhibit enhanced durability and thermal stability. Key benefits include:

- Early strength development
- Bleed-free properties
- Extended working life
- Improved resistance to high temperatures and resistance to all inorganic solvents.
- Impermeable

These qualities make geopolymers a highly reliable option for applications in demanding environments

2. STATE OF DEVELOPMENT

This chapter provides a concise overview of the terminology, chemical reactions of the ingredients, and historical research related to geopolymer self-compacting concrete. It also includes a brief review of the existing literature on self-compacting concrete and geopolymer technologies.

B. Siva Konda Reddy et.al [2010]- For the concrete sample heated to 60°C, the samples without cement initially exhibited higher strength, but this strength decreased over time. When curing geopolymer concrete, normal curing at room temperature resulted in greater strength compared to curing at 60°C. All geopolymer concrete mixes showed improved compressive strength with higher concentrations of sodium hydroxide (in the 13M solution). To enhance compressive strength, it is recommended to use a higher concentration of sodium hydroxide (around 13M), although this will make the geopolymer concrete less workable. For a given concentration of NaOH solution, the compressive strength of the concrete tends to increase slightly with age. The use of a high-range water-reducing admixture with 1.5% fly ash did not significantly affect the compressive strength of cured concrete but improved the workability of fresh geopolymer concrete.

B.H. Shinde et.al [2015]- A study was conducted to determine whether the strength of mortar made with an activator solution prepared a day in advance was the same as that produced with a freshly prepared solution at the time of mixing. After four days of curing, the mortar reached its maximum compressive strength. The highest compressive strength was achieved by mortar cubes that were heated to 800°C for one day. For all sodium silicate to sodium hydroxide ratios, a solution to fly ash ratio of 0.5 resulted in the mortar's maximum strength. Among the different ratios, the mixture with a sodium silicate to sodium hydroxide ratio of 1.5 to 2.0 provided the highest strength. An investigation was conducted to determine whether geopolymer concrete can be produced at a similar cost to Ordinary Portland Cement (OPC) concrete while maintaining comparable properties. Geopolymer concrete demonstrates moderate to high mechanical strength, a high modulus of elasticity, and significantly lower shrinkage compared to OPC. Additionally, the production of geopolymer concrete is expected to reduce CO2 emissions in comparison to OPC manufacturing.

Debabrata Dutta et.al [2012]- Limestone dust was incorporated into a geopolymer paste, and it was observed that this addition reduced the pore diameters. This change had a significant effect on both compressive strength and water absorption. The compressive strength of the paste specimens increased by approximately 40% with the addition of up to 12% limestone dust. This improvement may be attributed to the notable differences in porosity between specimens with and without limestone dust. The overall porosity of the specimens was found to have a strong correlation with their water absorption values. As the concentration of limestone dust increased, the water absorption of the paste specimens showed a decreasing trend.

Dr. S. L. Hake (2019) - The compressive strength increased as the fly ash to solution ratio decreased from 0.6 to 0.45, but further reduction in the ratio to 0.35 led to a decrease in strength. Therefore, a ratio of 0.35 may be considered optimal for achieving high strengths. The reduction in water content promotes the geopolymerization process, requiring an increase in the concentrations of sodium hydroxide and sodium silicate. As a result, higher NaOH concentrations lead to an increase in compressive strength. For medium-grade geopolymer concrete, 13M NaOH concentrations are recommended. These geopolymer components should be combined with an activating solution containing a moderate amount of alkali and should be capable of curing effectively under ambient conditions within a reasonable time. For specimens tested on the seventh day, a fly ash-based geopolymer with a 13M NaOH concentration exhibited excellent results, with a high compressive strength of 97 MPa.

Dr. Sandeep L. Hake (2017) - This review paper briefly examines the membrane curing of geopolymer concrete. Several researchers have explored the use of heat in ovens to cure geopolymer concrete. However, curing geopolymer concrete on-site using ovens presents practical challenges, highlighting the potential for further development of curing techniques that facilitate faster curing. Most studies have focused on heating geopolymer concrete in ovens to achieve polymerization, typically experimenting with different oven curing temperatures. However, there is limited research on the use of membrane curing, leaving an opportunity for further exploration in this area. Therefore, more research is needed to investigate the mechanical properties of geopolymer concrete, both in the short and long term. While some studies have examined various curing temperatures and curing durations (ranging from 6, 12, 18, to 24 hours), few have explored the effects of varying resting times, creating a gap in current research that presents opportunities for future investigation.

Dutta and Ghosh et al (2012)- It has been observed that incorporating limestone dust into geopolymer paste reduces the pore diameters. This change significantly affects both compressive strength and water absorption. The compressive strength of paste specimens increases by approximately 44% with the addition of up to 15% limestone dust. The inclusion of calcium compounds may help offset the reduction in compressive strength caused by lower curing temperatures, as these compounds can accelerate the polymerization process even at lower temperatures.

Hake et al (2015)- It has been noted that the production of cement releases carbon dioxide, a harmful atmospheric pollutant. Fly ash, a by-product of the thermal industry, is often deposited in landfills, taking up significant space. Additionally, wastewater from chemical industries is dumped into the earth, contaminating groundwater. The development of geopolymer concrete offers a solution to address these issues. Geopolymer concrete, made from fly ash— a waste material from the thermal sector— and wastewater from chemical refineries, provides an innovative way to repurpose these by-products. Furthermore, using fly ash as a key component in geopolymer concrete reduces the need for cement. This reduction in cement production leads to decreased CO2 emissions. Over the past decade, researchers have focused on developing geopolymer cement and concrete. The current study investigates the use of processed and unprocessed fly ash combined with sodium silicate and sodium hydroxide in geopolymer concrete. The research specifically examines the effect of treated and untreated fly ash on compressive strength and split tensile strength at different curing temperatures. To explore the impact of various types of fly ash, the study uses processed fly ash (P60, P80, and P100) from Dirk India Pvt. Ltd., as well as raw fly ash from locations such as Bhusawal, Nashik, and Beed. The influence of the alkaline solution on different types of fly ash is also explored in this research.

Kolli Ramujee et.al (2014)- It has been found that a reduction in water content promotes the process of geopolymerization, which requires an increase in the concentrations of sodium hydroxide and sodium silicate. As a result, higher NaOH concentrations lead to increased compressive strength. For medium-grade geopolymer concrete, 16M concentrations are recommended. The study also examined the mix design for geopolymer concrete at low, medium, and high grades. Key design parameters such as the water-to-geopolymer solids ratio and the alkaline liquid-to-fly ash ratio were considered. For each grade, seven different mixtures were prepared, tested, and optimized. Based on the results, alkaline-to-binder ratios of 0.5, 0.40, and 0.35, and water-to-binder ratios of 0.27, 0.21, and 0.158 are recommended for M20, M40, and M45 grades, respectively.

M.I Abdul Aleem et.al (2012)- To determine the optimal mix for geopolymer concrete, concrete cubes measuring 150 x 150 x 150 mm were cast and cured for 24 hours under steam. The compressive strength was tested at 7 and 28 days, and the results were compared. The ideal mix was found to be a ratio of fly ash to coarse aggregate to fine aggregate of 1:1.5:3.3, with a fly ash to solution (NaOH & Na2SiO3) ratio of 0.35. This mix achieved both early and high strength.

Madheswaran C.K et.al [2013]- The study examined how different molarities of sodium hydroxide (NaOH) influenced the strength variation across various grades of geopolymer concrete. To create the different mixtures, NaOH concentrations of 3M, 5M, and 7M were used, and the mixtures were then cured at room temperature. Geopolymer concrete (GPC) mix compositions were developed, yielding compressive strengths ranging from 15 to 52 MPa. The specimens were tested for compressive strength at 7 and 28 days. The results showed that as the NaOH concentration increased, the compressive strength of the GPC also increased.

Mohamed Aquib Javeed et.al [2015]- The Rangan method of mix design, known for its simplicity, was employed to create the trial mixes that ultimately resulted in the development of sustainable geopolymer concrete. The components used in the mix design were calculated using the Rangan method, while the dosage of the superplasticizer was determined through trial and error. It was found that increasing the sodium hydroxide content enhanced the compressive strength of the concrete.

Namagga and Atadero et al (2009) - It has been demonstrated that replacing cement with high-lime fly ash often enhances the ultimate strength of concrete. It is possible that even higher percentages of cement substitutes could still result in concrete with comparable compressive strength to mixes without fly ash. However, using high-lime fly ash as a substitute for cement tends to delay strength development, particularly when used in amounts greater than the optimal range of 25–35% fly ash. Additionally, increasing fly ash usage requires a higher amount of air-entraining admixtures.

Nisha Jain et.al [2016]- Her research indicates that compressive strength can be achieved for both grades of Geopolymer Concrete (GPC) by replacing cement with fly ash in amounts ranging from 5% to 10% and employing wet curing. For the M30 grade of GPC, the highest cement replacement percentage achievable with wet curing is 10%, and compressive strength continues to increase as the replacement percentage rises. The study also explored the effect of adding lime to geopolymer concrete. When cured at standard room temperature, compressive strength improves as the resting time increases. The maximum compressive strength was attained after 28 days of curing, showing a broad range of improvement.

3. SUMMARY OF LITERATURE

The reviewed literature highlights the potential of geopolymer self-compacting concrete (GPC) as a sustainable alternative to traditional OPC concrete. Key factors influencing GPC performance include the molarity of sodium hydroxide (optimal around 13M), the sodium silicate to NaOH ratio (1.5–2.0), and the alkaline liquid-to-binder ratio. Higher NaOH concentrations improve strength but reduce workability. Studies show that incorporating limestone dust and using processed fly ash enhances compressive strength and reduces porosity. Room temperature curing is more effective for long-term strength than elevated temperatures. GPC also offers improved durability, reduced CO_2 emissions, and effective use of industrial waste. Despite its promising characteristics, there are gaps in the research that need addressing. Limited studies are available on membrane curing, resting time effects, and large-scale implementation strategies. Most current investigations have been confined to laboratory environments, and further research is needed to validate performance in real-world applications. Overall, the reviewed literature supports the potential of geopolymer self-compacting concrete as a viable and sustainable replacement for conventional concrete, offering enhanced performance with a significantly lower environmental impact.

REFERENCES

[1] A.Maria Rajesh, M.Adams Joe, Roy Mammen, Study of the Strength Geopolymer Concrete with Alkaline Solution of Varying Molarity, IOSR Journal of Engineering, 4(6), 2014, 19-24.
[2] Ammar Motorwala, Vineet Shah, Ravishankar Kammula, Praveena Nannapaneni, Prof. D.B. Raijiwala, Alkali Activated Fly-ash Based Geopolymer Concrete", International Journal of Emerging Technology and Advanced Engineering, 3(1), 2013, 159-166
[3] B. H. Shinde, Dr. K. N. Kadam, "Properties of Fly Ash based Geopolymer Mortar", International Journal of Engineering Research & Technology, Volume. 4 -Issue. 07, July - 2015.
[4] B. Siva Konda Reddy, J.Varaprasad and K.Naveen Kumar Reddy," Strength and workability of low lime fly-ash based geopolymer concrete ", Indian Journal of

Science and Technology. 3 No. 12 (Dec 2010) ISSN: 0974-6846..

[5] B. Vijaya Rangan, "Geopolymer concrete for environmental protection," Indian Concrete Journal, vol. 88, no. 4, pp. 41-48, 2014.

[6] C.D. Budh and N.R. Warhead, Effect of Molarity on Compressive Strength of Geopolymer Mortar, International Journal of Civil Engineering Research, 5(1), 2014, 83-86

[7] C.Namagga and R. A. Atadero, "Optimization of fly ash in concrete: high lime fly ash as a replacement for cement and filler material," in Proceedings of the World of Coal Ash (WOCA) Conference, Lexington, KY, USA, May 2009 D.V.

[8] Chandan Kumar, Krishna Murari, C.R.Sharma, Strength Characteristics of Low Calcium Fly Ash Based Geopolymer Concrete, IOSR Journal of Engineering, 04(05), 2014, 07-17

[9] D. Adak, M. Sarkar, S. Mandal, Effect of Nano silica on Strength and durability of fly ash based geopolymer mortar, Construction and Building Materials, 2014, 453- 459.

[10] D. Dutta and S. Ghosh, "Effect of lime stone dust on geo polymerisation and geo polymeric structure," International Journal of Emerging Technology and Advanced Engineering, vol. 2, no. 11, ISSN 2250-2459, 2012.

[11] D.Bondar, "Geo-polymer concrete as a new type of sustainable construction materials," in Proceedings of the 7ird International Conference on Sustainable Construction Materials and Technologies, Kyoto, Japan, August 2015.

[12] Debabrata Dutta and Somnath Ghosh, "Effect of Lime Stone Dust on Geopolymerization and Geopolymer Structure" International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, Volume 2, Issue 11, November 2012)

[13] Deepa Balakrishnan, Thomas John V., Job Thomas, Properties of Fly Ash Based Geopolymer concrete, American Journal of Engineering Research, 2, 2013, 21-25

[14] Kolli Ramujee, Member, IACSIT and M. Potharaju, "Development of Low Calcium Fly Ash Based Geopolymer Concrete". IACSIT International Journal of Engineering and Technology, Vol. 6, No. 1, February 2014.

[15] M.I. Abdul Aleem and P.D. Arumairaj "Optimum mix for the geopolymer concrete" Indian Journal of Science and Technology Vol. 5 No. 3 (Mar 2012) ISSN:0974-6846

[16] Madheswaran C. K, Gnanasundar G, Gopalakrishnan. N "Effect of molarity in geopolymer concrete" International journal of civil and structural engineering volume4, no 2, 2013.