Experimental Study on Fly Ash-Based Geo Polymer Concrete Using Bentonite and Gypsum

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Abstract. The production of Portland cement accounts for approximately 8% of the 37 billion tonnes of carbon dioxide released into the atmosphere annually. Unlike traditional concrete, geopolymer concrete significantly reduces greenhouse gas emissions by up to 80% due to the absence of calcium carbonate conversion in its process. This study explores the impact of incorporating bentonite and gypsum as additives into fly ash-based geopolymer concrete to enhance its mechanical properties. By utilizing industrial by-products, the research aims to optimize the performance of geopolymer concrete. A variety of mix ratios, combining Fly-Ash, sodium silicate, sodium hydroxide solution, bentonite, and gypsum, were tested to determine the most effective composition. The experimental evaluation included compressive, flexural, and tensile strength tests. Results indicate inclusion of bentonite and gypsum improved the mechanical characteristics of geopolymer concrete. Furthermore, the study highlights how these additives influence the microstructure and hydration mechanisms, contributing to the advancement of eco-friendly construction materials.

Keywords: Fly Ash, Geopolymer concrete, Bentonite, Gypsum.

1 Introduction

Concrete is a fundamental material in construction, valued for its strength, energy efficiency, low maintenance, and resistance to fire. However, the manufacturing of Ordinary Portland Cement (OPC) significantly contributes to environmental pollution, releasing large amounts of CO2. Geopolymer concrete emerges as a sustainable alternative, producing up to 80% fewer greenhouse gas emissions and reducing CO2 release by a factor of five compared to OPC. Geopolymer describes materials synthesized from fly ash through a process called geopolymerization, which creates polymeric Si-O-Al bonds from aluminosilicate oxides and alkali polysilicates.Studies by Hardjito and Rangan revealed that geopolymer concrete exhibits superior mechanical properties compared to traditional cement concrete. It is formulated using alumina- and silica-rich raw materials activated with solutions like sodium hydroxide and sodium silicate. Further research by Palomo et al. demonstrated that incorporating calcium-rich fly ash enhances the compressive strength and promotes rapid setting and

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hardening in geopolymers.Recent advancements in geopolymer concrete include integrating natural fibers, such as Brown Coir, Banana, and Golden Raw Jute, to improve environmental performance and mechanical properties. These fibers enhance resistance to cracking, energy absorption, and fatigue while minimizing shrinkage issues during drying and plastic deformation. Geopolymer concrete, often made with waste products like fly ash or iron slag, forms a robust silicon-aluminum-oxygen network, achieving strength without requiring heat or emitting carbon dioxide.This eco-friendly material has been employed in notable projects such as the Delhi Metro and the Global Change Institute at The University of Queensland, underscoring its economic and environmental benefits over traditional cement in India. FA based GPC substitutes fly ash for OPC, while additives like bentonite powder and gypsum find applications in various industries, including construction and environmental management.

2 Literature Review

This study outlines key research findings related to the application of FA based GPC. Chen et al. (2024) explored the use of gypsum and bentonite in geopolymer concrete, highlighting how variations in design mixes and curing methods can enhance mechanical strength and durability. They proposed future research directions, including the development of alternative raw materials and innovative synthesis techniques to advance geopolymer technology.Liu et al. (2024) investigated the combined effects of bentonite and gypsum, demonstrating how their interaction with the geopolymer matrix improves strength, durability, and resistance to extreme conditions. Their findings suggest that further studies should focus on optimizing these synergistic properties to enhance geopolymer formulations.Zhang et al. (2023) provided a comprehensive review of bentonite in geopolymer concrete, emphasizing novel synthesis approaches and their influence on strength and durability. They also addressed the environmental benefits of bentonite, emphasizing its role in sustainable construction materials. Similarly, Kim et al. (2023) examined advancements in the use of gypsum for geopolymer concrete. Their study highlighted gypsum's contributions to controlling setting time, improving workability, and enhancing mechanical strength. They also discussed challenges such as sulphate attack and alkali-silica reactions, offering recommendations for mitigating these issues and optimizing gypsum's effectiveness.Ahmed S. Eisa et al. (2022) conducted a detailed investigation into geopolymer concrete composed of fly ash as a binder, with sodium hydroxide and sodium silicate as activators. Their work specified the dimensions of structural elements like beams, columns, and slabs, maintaining consistent ratios of alkaline solution to fly ash and Na_2SiO_3 to NaOH, with a fly ash content of 350 kg/m^3.Patel et al. (2023) critically analyzed the integration of sustainable additives, such as bentonite and gypsum, into geopolymer concrete. Their research focused on utilizing industrial by-products to enhance both performance and sustainability. They highlighted key challenges, including scalability, standardization, and compatibility of materials, and provided guidance for future research and development in this area.

3 Experimental program

This study evaluates mortar mixes composed of F.A, GGBS, fine and coarse aggregates, and a 10M sodium silicate/sodium hydroxide solution. The mixtures were cured at room temperature for 28 days. In order to assess the impact of bentonite and gypsum on mechanical qualities such compressive strength, flexural strength, and split tensile strength, they were introduced as partial substitutes for fly ash and GGBS in different quantities between 0% and 15% for bentonite and 0% to 4% for gypsum. These modified mixtures' performance was contrasted with that of regular concrete. To investigate the mechanical characteristics of geopolymer concrete, specimens in the shapes of cubes, prisms, and cylinders were made. For three minutes, fly ash and GGBS were combined with an alkaline activator solution as part of the preparation procedure. After that, the mixtures were put into moulds and allowed to cure for 28 days at room temperature. Pellets of sodium hydroxide were dissolved in water to produce a range of molarities for the alkaline activator solution. 400 grammes of sodium hydroxide pellets were dissolved in one litre of water to create a 10M solution. The solution was then mixed with the concrete after sodium silicate was added.

4 Tests on Hardened Concrete

The various concrete mixes with different proportions of bentonite and gypsum are outlined in Tables 1, 2, and 3 below. To determine the optimal composition, bentonite and gypsum were introduced as partial replacements for fly ash and GGBS in mortar mixes, with percentages ranging from 0%, 5%, 10%, and 15% for bentonite and 0%, 2%, 3%, and 4% for gypsum. For Mix 1, the materials used included sodium hydroxide, sodium silicate solution, fly ash, GGBS, and fine and coarse aggregates. In Mixes 2, 3, and 4, fly ash and GGBS were partially replaced with varying proportions of bentonite and gypsum.

Table 1. Mix proportions for Mix1

Materials	Proportions(kg/m^3)
AAS/FA	0.5
Fly Ash	320
NaOH	80
Na_2SiO_3	120
GGBS	80
Coarse aggregate	1046
Fine aggregate	600

Table 2. Mix proportions for bentonite and gypsum

Mix	Bentonite	Gypsum(kg/m^3)

	(kg/m^3)	
1	0	0
2	16	6.4
3	32	9.6
4	48	12.8

Table 3. Mix proportions of the materials

Mix	AAS/FA	Fly ash (kg/m^3)	GGBS (kg/m^3)	NaOH (kg/m^3)	Na2SiO3 (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
1	0.5	320	80	80	120	600	1046
2	0.5	297.6	80	80	120	600	1046
3	0.5	278.4	80	80	120	600	1046
4	0.5	259.2	80	80	120	600	1046

5 Compressive Strength Test Results

Strength of these concrete mixes, incorporating different percentages of bentonite and gypsum, was measured using a compression testing machine. The results, presented in Figure 1, indicate that compressive strength improves by adding up to 10% bentonite and 3% gypsum. However, further increases in the proportions (15% bentonite and 4% gypsum) lead to a decrease in strength. While gypsum slows down the setting process, it does not fully replace the function of cement. On the other hand, bentonite contributes to increased strength by reducing pore size and promoting calcium binding, enhancing the strength of the geopolymer concrete.

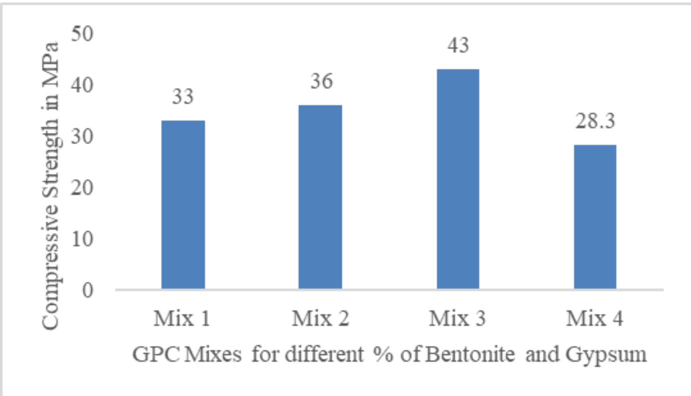

Fig. 1. Compressive Strength of GPC Mixes

6 Split Tensile Strength Results

The Strength of these concrete mixes, incorporating varying percentages of bentonite and gypsum, was evaluated after 28 days using a compression testing machine. The results, summarized in Figure 2, reveal an increase in tensile strength by adding up to 10% bentonite and 3% gypsum. However, further additions (15% bentonite and 4% gypsum) result in a decline in strength. This improvement can be attributed to the interaction between calcium bentonite and the reactive fly ash particles, enhancing the tensile properties. Despite this synergy, bentonite and gypsum, being pozzolanic materials, cannot completely substitute cement in concrete formulations.

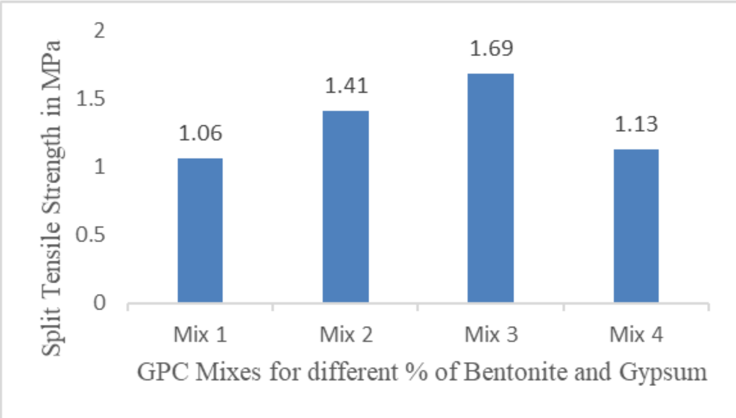

Fig. 2. Split Tensile Strength of GPC Mixes

7 Flexural Strength Results

The Strength of these concrete mixes, incorporating various proportions of bentonite and gypsum, was assessed after 28 days of curing, as shown in Figure 3. The results indicate that flexural strength improves by adding up to 10% bentonite and 3% gypsum. However, a decline in strength is observed at higher proportions, such as 15% bentonite and 4% gypsum. This reduction is likely due to structural alterations caused by the increased bentonite content.

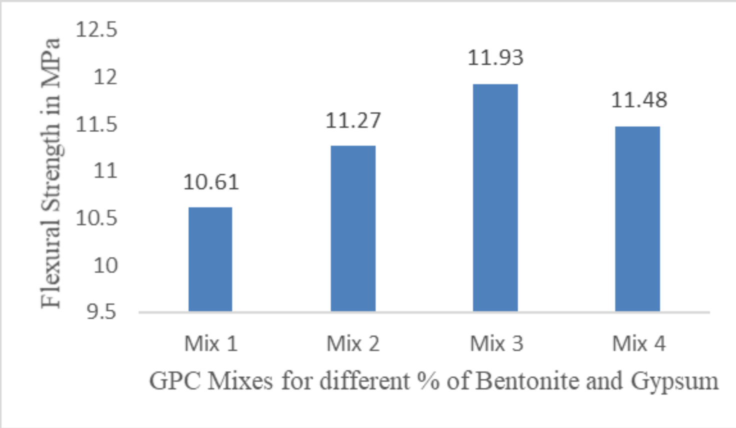

Fig. 3. Flexural Strength of GPC Mixes

8 Conclusions

Experimental analysis demonstrates that incorporating bentonite and gypsum into fly ash-based geopolymer concrete enhances its mechanical properties compared to mixes without these additives.

1. Compressive strength increases with 5% bentonite and 2% gypsum, as well as 10% bentonite and 3% gypsum, but declines when the proportions reach 15% bentonite and 4% gypsum.
2. Split tensile strength also improves with 5% bentonite and 2% gypsum, and peaks at 10% bentonite and 3% gypsum, before diminishing with higher additive levels.
3. Flexural strength follows a similar trend, increasing with 5% bentonite and 2% gypsum, and 10% bentonite and 3% gypsum, but dropping when bentonite and gypsum are added at 15% and 4%, respectively.
4. The highest compressive, tensile, and flexural strengths are achieved with a mix containing 10% bentonite and 3% gypsum. However, excessive amounts of these additives negatively impact the concrete's mechanical performance.

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