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Experimental Study in Compressive Strength of Geopolymer Concrete Using Sodium Hydroxide and Sodium Silicate Solution

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Abstract: Concrete is one of the most widely used construction materials in the civil engineering industry because of its strength, durability, versatility and suitability for a wide range of structural applications. However, the production of Ordinary Portland Cement (OPC), which acts as the principal binding material in conventional concrete, is associated with significant carbon dioxide (CO_2) emissions, high energy consumption and environmental degradation. The increasing demand for sustainable construction materials has encouraged researchers to investigate alternative binders that can reduce the environmental impact of conventional cement-based concrete. Geopolymer concrete is one such alternative, in which aluminosilicate-rich materials are activated using alkaline solutions to form a hardened binder. Industrial by-products such as fly ash and Ground Granulated Blast Furnace Slag (GGBS) can be utilized as source materials, thereby promoting waste utilization and reducing dependence on conventional cement.

The present research work, entitled "Experimental Study in Compressive Strength of Geopolymer Concrete Using Sodium Hydroxide and Sodium Silicate Solution," focuses on the experimental investigation of the compressive strength of geopolymer concrete prepared using fly ash and GGBS as binder materials and sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as alkaline activators. Particular emphasis is placed on the use of a 14 molarity sodium hydroxide solution to investigate the strength development of the geopolymer concrete. Fine aggregate and coarse aggregate are incorporated to produce the concrete mixture, while the alkaline activators initiate the geopolymerization process by dissolving and reacting with the silica- and alumina-containing source materials.

The experimental programme involves the selection and proportioning of constituent materials, preparation of the alkaline activator solution, mixing of geopolymer concrete, casting of standard concrete cubes of 150 mm × 150 mm × 150 mm, curing, and determination of compressive strength. The compressive strength of geopolymer concrete is evaluated at 7, 14 and 28 days to understand its strength development with age. The results are compared with the corresponding strength values of conventional M25 grade concrete to assess the suitability of geopolymer concrete as an alternative construction material. In addition to mechanical performance, the study considers the material cost of geopolymer concrete and conventional concrete, including the influence of binder materials, alkaline activators and aggregates on the overall cost.

The recorded compressive strengths of geopolymer concrete are 14.38 N/mm² at 7 days, 20.22 N/mm² at 14 days and 23.45 N/mm² at 28 days. The corresponding reference values for conventional M25 grade concrete are 16.25 N/mm², 22.50 N/mm² and 25.00 N/mm², respectively. The 28-day strength of 23.45 N/mm² demonstrates the potential of the investigated mixture while also indicating the need for further mix optimization to achieve or exceed the target strength of M25 grade concrete.

The study highlights the potential environmental benefits of utilizing fly ash and GGBS as alternative binder materials and reducing the consumption of Ordinary Portland Cement. It also emphasizes that the performance and economic feasibility of geopolymer concrete depend on material proportions, alkaline activator concentration, solution ratio, water content, curing conditions and the prevailing cost of raw materials. The findings contribute to understanding the compressive strength development of geopolymer concrete prepared with sodium hydroxide and sodium silicate solutions and provide a basis for further investigations into sustainable concrete technology and its potential applications in the construction industry.

Keywords: Geopolymer concrete, fly ash, GGBS, sodium hydroxide, sodium silicate, compressive strength.

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I. INTRODUCTION

Concrete is one of the most widely used construction materials in civil engineering because of its strength, durability, versatility, and ability to be moulded into different shapes. It is extensively used in residential buildings, commercial structures, bridges, roads, foundations, and other infrastructure projects. Conventional concrete generally consists of cement, fine aggregate, coarse aggregate, and water. Ordinary Portland cement (OPC) acts as the primary binding material and plays an important role in the development of concrete strength.

Despite its widespread use, cement production has significant environmental impacts. The manufacturing process requires considerable energy and releases carbon dioxide due to the decomposition of limestone and the combustion of fuels. Increasing demand for concrete in infrastructure development has encouraged researchers to investigate alternative binding materials that can reduce cement consumption and promote sustainable construction practices.

Geopolymer concrete is one such alternative. It is produced by using aluminosilicate rich materials, such as fly ash and ground granulated blast furnace slag (GGBS), which react with alkaline solutions to form a hardened binding matrix. Sodium hydroxide and sodium silicate solutions are commonly used as alkaline activators in this process. By utilizing suitable industrial by-products, geopolymer concrete has the potential to reduce dependence on conventional cement and improve the utilization of industrial waste materials.

The present research investigates the compressive strength of geopolymer concrete prepared using fly ash, GGBS, sodium hydroxide, and sodium silicate solution. Particular attention is given to the use of a 14 molarity sodium hydroxide solution and the development of compressive strength at different curing ages. The experimental results are compared with reference compressive strength values for conventional M25 grade concrete to evaluate the performance of the investigated geopolymer mix.

II. LITERATURE REVIEW

[1]. **Nehatrao et al. (2026)** studied geopolymer self-compacting concrete incorporating fly ash, GGBS and steel slag. Their study investigated fresh properties and compressive strength under different curing conditions.
[2]. **Ajay K. A. and Shyam Prasad (2025)** investigated hybrid-fibre-reinforced geopolymer concrete slabs under impact loading, highlighting the influence of binder composition and alkaline activation on performance.
[3]. **S. Kavipriya et al. (2026)** Examined self-healing geopolymer concrete using ceramic waste and bacteria. The study reported promising mechanical properties and potential improvement in self-healing behaviour.
[4]. **Bhukya Prakash et al. (2025)** examined the effects of binder index and alkaline concentration on geopolymer concrete and reported improvements in strength with suitable binder and activator proportions.
[5]. **Adnan and Muhammad Anas (2025)** Compared geopolymer concrete with OPC concrete. The study reported promising strength performance and identified activator cost and curing requirements as important practical factors.
[6]. **Rihan et al. (2024)** reviewed mix-design approaches for eco-friendly geopolymer concrete and identified source materials, activator ratios, water content and curing conditions as important factors affecting performance.
[7]. **Pandey et al. (2024)** investigated fly ash–GGBS geopolymer concrete under different curing conditions and reported that suitable curing and alkaline activation influence strength development.
[8]. **Rafeek et al. (2023)** studied fly ash–GGBS geopolymer concrete and highlighted the contribution of GGBS to strength development under different curing conditions.
[9]. **Sathvik et al. (2023)** investigated geopolymer concrete for thin white-topping pavement and found that curing conditions and activator proportions affected mechanical properties.
[10]. **Patel and Patel (2022)** examined the role of calcium content in ambient-cured fly ash–GGBS geopolymer concrete and highlighted the importance of GGBS in strength development.
[11]. **Patil et al. (2022)** studied sodium hydroxide and sodium silicate as alkaline activators and examined their influence on compressive strength.
[12]. **Pruthviraj and Anadinni (2022)** investigated mix-design procedures for fly ash–GGBS geopolymer concrete and emphasised the importance of activator concentration and material proportions.
[13]. **Parmar et al. (2021)** investigated different alkaline-activator proportions and their effects on workability, density and compressive strength.
[14]. **Sasi Rekha and Sumathy (2021)** studied geopolymer concrete prepared using different NaOH molarities under ambient curing and examined its mechanical properties.
[15]. **Brightlin and Kala (2020)** investigated the use of thermal ash aggregate in geopolymer concrete beams as a potential alternative aggregate material.

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[16]. **Sahebagouda and Shahapur (2020)** studied geopolymer concrete containing GGBS and marble powder and evaluated the influence of material proportions on strength.

[17]. **Abd Alftah et al. (2020)** investigated GGBS–fly ash geopolymer concrete and highlighted the importance of binder composition**.**

[18]. **Abhilash (2020)** studied bagasse ash–GGBS geopolymer concrete and reported that GGBS content influenced compressive, split tensile and flexural strength.

[19]. **Garg and Singhal (2020)** investigated the durability of geopolymer concrete under marine and sulphate exposure conditions.

[20]. **Negi (2020)** studied the microstructure of geopolymer concrete using SEM and EDAX to understand its relationship with mechanical performance.

[21]. **Naje et al. (2020)** examined the partial replacement of fine aggregate with tyre-rubber particles in fly ash geopolymer concrete and investigated its influence on strength.

[22]. **Abd El Hafez et al. (2019)** studied the behaviour of geopolymer concrete at elevated temperatures and examined changes in its mechanical properties.

[23]. **Ali et al. (2018)** investigated the effects of nano-slag and curing methods on fly ash geopolymer concrete and reported improvements in strength under the studied conditions**.**

[24]. **Mavroulidou and Martynkova (2018)** examined alkali-activated concrete containing GGBS and assessed the effects of activator type, molarity and curing conditions.

[25]. **Dange and Suryawanshi (2017)** reviewed geopolymer concrete and discussed its mechanical performance, environmental benefits and potential construction applications.

[26]. **Guru Jawahar and Mounika (2016)** investigated fly ash–GGBS geopolymer concrete using sodium hydroxide and sodium silicate solutions. Their findings indicated that increasing GGBS content improved compressive, split tensile and flexural strength in the mixes studied.

[27]. **Pithadiya and Nakum (2015)** investigated geopolymer concrete incorporating GGBS under oven and ambient curing conditions and reported that GGBS helped improve strength and reduce dependence on heat curing.

Overall, the reviewed studies indicate that geopolymer concrete performance depends on fly ash and GGBS proportions, sodium hydroxide molarity, sodium silicate content, activator ratio and curing conditions. However, the suitable combination of these parameters varies with the materials and mix proportions used. Therefore, the present study investigates geopolymer concrete prepared using fly ash, GGBS, sodium hydroxide and sodium silicate solution, with particular emphasis on 14 M sodium hydroxide solution. The compressive strength is evaluated at 7, 14 and 28 days and compared with conventional M25-grade concrete.

III. AIM AND OBJECTIVES

[1] To study the compressive strength developed in the geopolymer concrete.
[2] To evaluate the performance of geopolymer concrete through experimental testing, including compressive strength.
[3] To determine the compressive strength of geopolymer concrete at 7, 14 and 28 days.
[4] To compare the compressive strength of geopolymer concrete and conventional M25 grade concrete.
[5] To Analyse the cost comparison between geopolymer concrete and conventional M25 grade concrete based on strength criteria.
[6] To identify the major factors affecting the cost and performance of geopolymer concrete.
[7] To investigate the effect of 14 Molarity sodium hydroxide solution on the strength of geopolymer concrete.
[8] To study the role of sodium silicate and sodium hydroxide as alkaline activators.
[9] To utilize industrial by-products such as fly ash and GGBS in concrete production.
[10] To reduce the dependence on ordinary Portland cement (OPC).
[11] To evaluate the potential use of geopolymer concrete in structural and construction applications.

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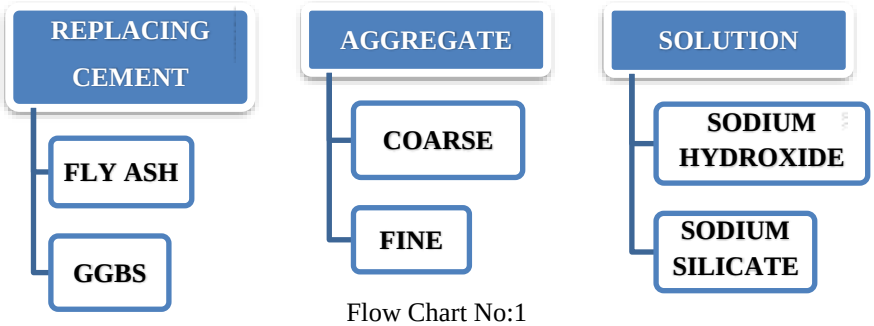
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IV. MATERIALS AND EXPERIMENTAL METHODOLOGY



Flow Chart No:1
Proposed Geopolymer Concrete Mixing Ingredients

[1]. **Fly Ash:** Used as a supplementary binder material to improve the strength and sustainability of geopolymer concrete.
[2]. **GGBS:** Ground Granulated Blast Furnace Slag is used with fly ash to enhance strength development.
[3]. **Coarse Aggregate:** Coarse aggregates of 20 mm and 12.5 mm sizes are selected to improve the load-bearing capacity and stability of geopolymer concrete.
[4]. **Fine Aggregate:** Sand is used to fill voids and improve the workability of concrete.
[5]. **Sodium Hydroxide (NaOH):** A 14 Molarity sodium hydroxide solution is used as an alkaline activator to initiate geopolymerization.
[6]. **Sodium Silicate (Na_2SiO_3):** Used with sodium hydroxide to activate fly ash and GGBS and develop binding properties.

MIX QUANTITIES OF M25 GRADE CONVENTIONAL CONCRETE AND GEOPOLYMER CONCRETE

Table No: 1
M25 Grade Conventional Concrete Mix

Material	Ratio	Volume (m^3)	Estimated Weight (kg)
Cement	1	0.0043	6.2 kg
Fine Aggregate	1	0.0043	6.9 kg
Coarse Aggregate	2	0.0086	12.9 kg
Water	W/C 0.45	-	2.8 Liters

Table No: 2
Proposed Geopolymer Concrete Mix

Material	Ratio	Volume (m^3)	Final Mass (kg)
GGBFS	0.5	-	3.07692 kg
Fly Ash	0.5	-	3.07692 kg
Sand (Fine Aggregate)	1.0	0.0042735	6.8376 kg
Gravel (Coarse Aggregate)	2.0	0.008547	12.8205 kg
Sodium Silicate Solution	0.32500	-	2 kg
Sodium Hydroxide	0.07280	-	0.448 kg
Water	0.05720	-	0.352 kg

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SPECIMEN PREPARATION AND TESTING



Image No: 1
Adding Chemicals



Image No: 2
Wet Mixing



Image No: 3
Specimen Ready



Image No: 4
Curing



Image No: 5
Applying Load CTM



Image No: 6
Visible Crack

V. RESULTS AND DISCUSSION

Table No: 3
Compressive Strength Comparison Between Geopolymer Concrete and M25 Grade Conventional Concrete

Curing Age	Geopolymer Concrete (N/mm^2)	M25 Grade Conventional Concrete Reference (N/mm^2)
7 days	14.38	16.25
14 days	20.22	22.50
28 days	23.45	25.00

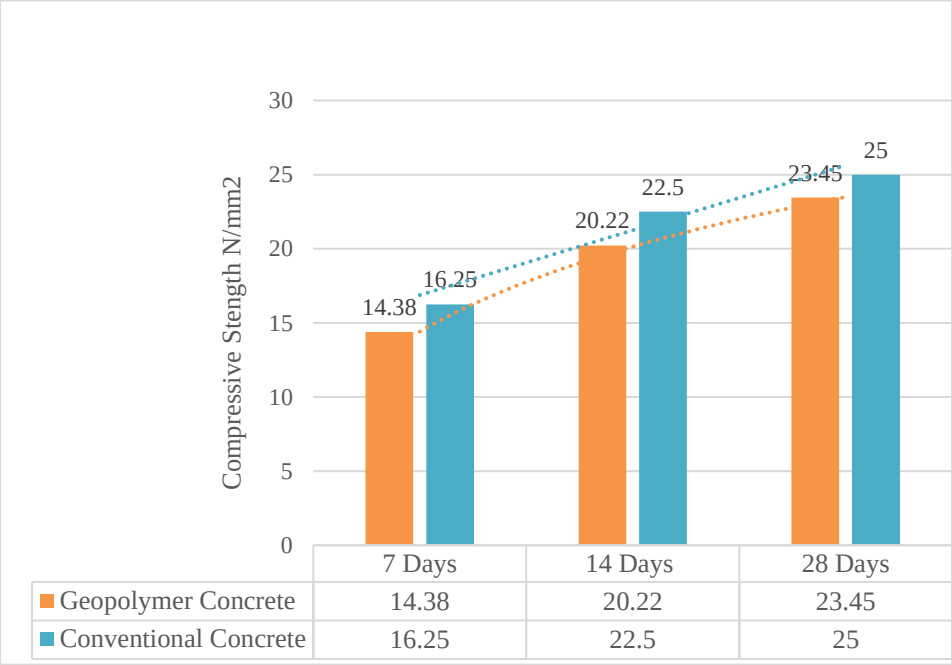
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Graph No: 1
Compressive Strength Comparison Between Geopolymer Concrete and M25 Grade Conventional Concrete

The compressive strength of geopolymer concrete prepared using fly ash, Ground Granulated Blast Furnace Slag (GGBS), sodium hydroxide solution of 14 molarity, and sodium silicate solution was compared with conventional M25 grade concrete. The experimental results showed that the compressive strength of geopolymer concrete increased with curing age, reaching 14.38 N/mm² at 7 days, 20.22 N/mm² at 14 days, and 23.45 N/mm² at 28 days. In comparison, conventional M25 grade concrete recorded reference compressive strength values of 16.25 N/mm², 22.50 N/mm², and 25.00 N/mm² at the respective curing ages. The results indicate that geopolymer concrete achieved approximately 93.8% of the 28-day reference strength of M25 grade concrete, although its strength remained slightly lower. The use of fly ash and GGBS offers environmental benefits by reducing dependence on ordinary Portland cement and promoting industrial waste utilization. Further optimization of the mix proportions, alkaline activator ratio, water content, and curing conditions may improve the compressive strength of geopolymer concrete and help it achieve the target strength of M25 grade conventional concrete.

MATERIAL COST COMPARISON

Table No: 4
Cost Analysis of Proposed Geopolymer Concrete

Materials	Quantity for 3 cubes (kg)	Assumed Rate (₹/kg)	Cost for 3 cubes (₹)
GGBS	3.07692 kg	3.00	9.23
Fly Ash	3.07692 kg	2.00	6.15
Fine Aggregate	6.8376 kg	2.10	14.36
Coarse Aggregate	12.8205 kg	1.388	17.79
Sodium Silicate	2.000 kg	65.00	130.00
Sodium Hydroxide	0.448 kg	51.00	22.85
Total Material Cost			200.39

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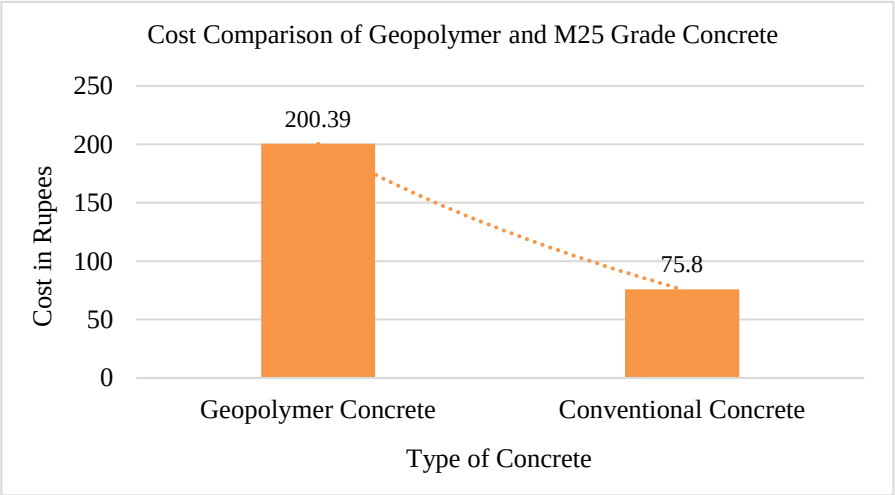
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Table No: 5
Cost Analysis of M25 Grade Conventional Concrete

Materials	Quantity for 3 cubes (Kg)	Assumed Rate (₹/kg)	Cost for 3 cubes (₹)
Cement	6.2 kg	7.00	43.40
Fine Aggregate	6.9 kg	2.10	14.49
Coarse Aggregate	12.9 kg	1.388	17.91
Total Material Cost			75.80

The material cost comparison between geopolymer concrete and conventional M25 grade concrete was carried out for three concrete cubes. The total material cost of geopolymer concrete was ₹200.39, whereas the total material cost of conventional M25 grade concrete was ₹75.80. The cost of geopolymer concrete was therefore ₹124.59 higher, approximately 2.64 times the cost of conventional concrete. The major contribution to the geopolymer concrete cost was sodium silicate solution, costing ₹130.00, followed by sodium hydroxide at ₹22.85. In conventional concrete, cement was the major cost component, amounting to ₹43.40. Although geopolymer concrete utilizes industrial by-products such as fly ash and GGBS and reduces dependence on ordinary Portland cement, the higher cost of alkaline activators increases its overall material cost. The cost of geopolymer concrete may be reduced through optimization of activator proportions, efficient mix design, and the use of locally available materials.



Graph No: 2
Cost Comparison Between Geopolymer Concrete and M25 Grade Conventional Concrete

VI. KEY FINDINGS

[1]. The reported geopolymer compressive strength increased with curing age, reaching 23.45 N/mm² at 28 days.
[2]. At 7, 14 and 28 days, the geopolymer results were lower than the conventional M25 reference values reported in the project.
[3]. The reported 28-day geopolymer strength was approximately 93.8% of the 25 MPa reference value.
[4]. For three cubes, reported material cost was ₹200.39 for geopolymer concrete and ₹75.80 for conventional concrete.
[5]. Sodium silicate was the largest single contributor to the geopolymer material cost in the stated cost calculation.

VII. LIMITATIONS AND FUTURE WORK

Limitations

The present study is limited to the experimental investigation of geopolymer concrete prepared using fly ash, GGBS, sodium hydroxide solution of 14 M molarity, and sodium silicate solution. The compressive strength was evaluated at 7, 14, and 28 days and compared with the reference values of conventional M25 grade concrete. The 28-day compressive strength of geopolymer concrete was 23.45 N/mm², which was slightly lower than the 25 N/mm² reference strength of M25 concrete. The study primarily focused on compressive strength and material cost; other properties, such as tensile strength, flexural strength, durability, and long-term performance, were not investigated. The higher cost of alkaline

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activators, particularly sodium silicate, was another limitation. Furthermore, the study did not examine different sodium hydroxide molarities, activator ratios, or curing conditions to determine their influence on concrete performance.

Future Work

Future studies can investigate different proportions of fly ash and GGBS, sodium hydroxide molarities, and sodium silicate-to-sodium hydroxide ratios to improve the compressive strength of geopolymer concrete. Further experiments should be conducted to achieve or exceed the target strength of M25 grade conventional concrete. Additional tests, including split tensile strength, flexural strength, water absorption, permeability, and chemical resistance, can be performed to evaluate the mechanical properties and durability of geopolymer concrete. Long-term studies under different environmental conditions are also recommended to assess its suitability for structural applications. Furthermore, optimization of alkaline activator quantities and the use of locally available industrial by-products may help reduce material costs. Future research should also investigate the environmental benefits and practical feasibility of geopolymer concrete for sustainable construction.

VIII. CONCLUSION

1. Geopolymer concrete can be produced using fly ash and GGBS as alternative binder materials for concrete.
2. The geopolymer concrete achieved 14.38 MPa at 7 days, 20.22 MPa at 14 days and 23.45 MPa at 28 days.
3. The 28-day strength of geopolymer concrete was therefore close to the strength of conventional concrete, although it was slightly lower.
4. The cost of geopolymer concrete in this project was ₹200.39 for 3 cubes, compared with ₹75.80 for conventional M25 grade concrete.
5. The higher cost of geopolymer concrete was mainly due to the sodium silicate and sodium hydroxide activators. cost of geopolymer concrete can potentially be reduced through activator optimization, local material availability and improved mix design.
6. The alkaline activators play an important role in the development of strength of geopolymer concrete.
7. Geopolymer concrete has potential to reduce the dependence on OPC.
8. Geopolymer concrete is a sustainable alternative to conventional Portland cement concrete, thereby supporting more sustainable construction.
9. The use of waste materials like fly ash, GGBS promotes resource conservation and industrial waste management.
10. It acts as a low-carbon and lesser energy consumption material and is a better alternative to traditional cement concrete and also reduces the carbon dioxide CO_2 emission.
11. Keeping in view of savings in natural resources, sustainability, environment, and all other GPC properties, it can be recommended as an innovative construction material.
12. Overall, the study shows that geopolymer concrete is a promising alternative construction material, particularly when environmental sustainability and industrial waste utilization are considered.

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