



# AN EXPERIMENTAL INVESTIGATION ON PROPERTIES OF GEOPOLYMER CONCRETE USING COMPOSITE FIBERS

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**ABSTRACT:** Geopolymer technology represents a significant advancement in concrete production, especially in mitigating the environmental concerns that arise from the use of conventional cement materials that emit significant amounts of CO<sub>2</sub>. By substituting cement with alternative ingredients such as Fly ash and Ground Granulated Blast Furnace slag (GGBFS), a more environmentally friendly approach is possible. Geopolymer concrete, utilizing a synthetic resin binder that reacts with alkaline solutions like sodium hydroxide and sodium silicate, emerges as a viable alternative. This project aims to enhance the properties of fly ash and slag-based Geopolymer concrete by incorporating composite fibers. It seeks to investigate the effects of Crimped steel, Polypropylene, and Glass fibers on the compressive, split tensile, and flexural strength of Geopolymer concrete. By introducing varying proportions of fibers, ranging from 0.5% to 1.5% of the concrete volume, the study intends to determine their impact on the mechanical properties of concrete. These investigative efforts hold significant potential for broadening the application of Geopolymer concrete, providing an efficient alternative to traditional cement concrete for a wide range of construction applications.

**Key words:** Crimped steel fibers, Fly ash, Geopolymer concrete, Ground Granulated Blast Furnace Slag (GGBFS), Glass fibers, Polypropylene fibers, Sodium silicate, Sodium hydroxide.

## I. INTRODUCTION

Concrete, a fundamental material in global construction, relies heavily on cement. However, cement production contributes significantly to greenhouse gas emissions. To address this, researchers have explored alternative binding materials, including non-crystalline alkali-aluminosilicate geopolymers. Geopolymer concrete, made from byproduct waste, reduces direct carbon dioxide emissions during production. Geopolymer concrete is an innovative alternative to traditional cement-based concrete, where pozzolanic materials rich in silica and alumina, such as fly ash or blast furnace slag, are activated by alkaline liquids to act as binders. This substitution reduces the carbon footprint of concrete production. Geopolymerization, the chemical process behind geopolymer concrete, involves exposing alumina-silicate materials to high-alkaline environments, typically sodium or potassium hydroxide solutions. This results in the formation of a strong binder characterized by a Si-O-Al structure. The reaction involves breaking valency bonds between silicon, aluminium, and oxygen atoms, leading to the formation of three-dimensional polymeric chains and ring structures. Alkaline cations like sodium and potassium compensate for charge imbalances caused by aluminium in the gel product. The rate of dissolution and the resulting properties of geopolymers are influenced by factors such as the quantity and content of materials used and the pH of the activating solution. Geopolymer concrete utilizes thermally activated natural resources or industrial by-products as sources of silicon and aluminium. Despite its advantages, geopolymer concrete exhibits brittleness. To overcome this limitation, we turn to fibers. By reinforcing geopolymer concrete with fibers, we aim to enhance its toughness, durability, and applicability across a wide range of construction scenarios. This review sheds light on the promising future of fibre-reinforced geopolymer concrete and emphasizes the need for standardized manufacturing processes.

The objective of this journal paper is to present the results of an experimental investigation on Geopolymer concrete, formulated using fly ash and Ground Granulated Blast Furnace Slag (GGBFS), along with sodium silicate, sodium hydroxide, crimped steel fibers, polypropylene fibers, glass fibers, and a chemical admixture. Specifically, the study utilizes the PCE-based super plasticizer AURAMIX 450 to achieve the desired properties of Geopolymer concrete. The chemical admixture is dosed at 1.4% by weight of binder content based on a trial method, while maintaining a constant water-to-binder ratio of 0.45. The mix design and proportioning of ingredients for the Geopolymer concrete involve maintaining a fixed ratio of 2 for sodium silicate and sodium hydroxide, along with the use of a 12M alkaline solution. The mechanical properties under investigation include compressive strength, split tensile strength, and flexural strength of the concrete specimens. To further enhance the mechanical properties and observe changes, crimped steel fibers, polypropylene fibers, and glass fibers are added in varying percentages (0%, 0.5%, 0.75%, and 1%) collectively. This addition aims to investigate the effects of fiber reinforcement on the Geopolymer concrete's performance. By systematically varying the fiber content and assessing the resulting mechanical properties, the study aims to provide insights into the optimization of Geopolymer concrete formulations for enhanced performance and durability in various engineering applications.

## II. OBJECTIVES

The following are the objectives of this experimental investigation:

1. To find the optimum percentage of Steel fibers in developing the strength of the Geopolymer concrete and to mitigate the brittleness of GPC
2. To develop the strength of Geopolymer concrete using Steel fibers and Polypropylene fibers in various percentages from the optimum percentage of Steel fibers and to observe the changes in properties of GPC.
3. To develop the strength of Geopolymer concrete using Steel fibers and Glass fibers in various percentages from the optimum percentage of Steel fibers and to observe the changes in properties of GPC.
4. To determine the mechanical properties of Geopolymer concrete such as compressive strength, split tensile strength and flexural strength by the addition of various percentages of fibers in Geopolymer concrete.
5. To compare the properties of Geopolymer concrete with fibers and without fibers.

## III. MATERIALS

In this experimental investigation the following materials are used

### 3.1 Fly Ash

Fly ash, derived from the combustion of pulverized coal in coal-fired thermal power plants, is a by-product extensively utilized in hydraulic-cement concrete. Class F fly ash, specifically chosen for this experimental investigation, possesses a specific gravity of 2.12.

### 3.2 Ground Granulated Blast Furnace Slag (GGBFS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product of the iron-making process in blast furnaces. With a specific gravity ranging between 2.80 and 3.00, slag holds the distinction of having the highest specific gravity among all mineral admixtures. As a processed material, its fineness can be finely adjusted to meet specific requirements. In numerous applications, the fineness of slag closely resembles that of cement. GGBS primarily consists of calcium silicates and alumino-silicates. Its specific gravity is measured at 2.9.

### 3.3 Fine Aggregate

River sand sourced locally, adhering to the IS: 383-1970 specifications, was utilized as the fine aggregate in the concrete mix. The sand particles pass through a 4.75mm sieve and are retained on a 75 $\mu$ m sieve. Table 3.1 provides details regarding the physical properties of the fine aggregate.

Table 3.1: Physical properties of Fine aggregate

Particulars	Values
Specific gravity	2.58
Fineness modulus	3.15
Grading	Zone II

### 3.4 Coarse aggregate

For this investigation, well-graded coarse aggregate consistent with the specifications outlined in IS: 383-2016 will be utilized. The coarse aggregate, sourced from local quarry units and conforming to IS: 383-1970 standards, has been selected for this study. The maximum size of the coarse aggregate employed is 12.5mm. The physical properties of the coarse aggregate are detailed in Table 3.2.

Table 3.2: Physical properties of Coarse aggregate

Particulars	Values
Specific gravity	2.60
Fineness modulus	6.30
Water absorption (%)	0.72

### 3.5 Sodium Hydroxide Flakes

Sodium hydroxide (NaOH) is commonly available in solid forms such as pellets or flakes. Its price varies based on purity. Solutions of NaOH are prepared by dissolving pellets in water to achieve different molarities. It is advised to prepare the NaOH solution at least 24 hours before use and to use it within 36 hours to prevent it from solidifying.

### 3.6 Sodium Silicate

Sodium metasilicate, also referred to as sodium silicate, is an industrial-grade compound containing 31.12% SiO<sub>2</sub> and 14.2% Na<sub>2</sub>O by mass. Manufacturers commonly utilize it as a bonding agent in detergent and textile industries. Sodium silicate is typically found in liquid form.

### 3.7 Chemical Admixture

Polycarboxylate ether (PCE) based superplasticiser AURAMIX 450 was used.

### 3.8 Crimped steel fibers

In this study, crimped steel fibers with a length of 35mm and a diameter of 0.5mm are utilized, resulting in an aspect ratio of 70.

### 3.9 Polypropylene fiber

In this study, FIBERCRETE MF, a synthetic monofilament fiber is used. Polypropylene fibers with a length of 12mm and a diameter of 0.02 mm are utilized, resulting in an aspect ratio of 600.

### 3.10 Glass fibers

In this study, glass fibers with a length of 12mm and a diameter of 0.014mm are utilized, resulting in an aspect ratio of 857.

## IV. EXPERIMENTAL INVESTIGATION

### 4.1 Mix proportions

In this experimental investigation, the binder content, obtained from a mix design referenced in prior literature, is 496 kg/m<sup>3</sup>. This composition consists of 80% fly ash and 20% GGBFS. For the 12M solution, the NaOH content is measured at 74.5 kg/m<sup>3</sup>, while the Na<sub>2</sub>SiO<sub>3</sub> content is taken as 149 kg/m<sup>3</sup>. To achieve the desired fresh properties of Geopolymer concrete, a water-to-binder ratio of 0.45 is selected, alongside a chemical admixture dosage of 1.4% by weight of the binder content, determined through trials. The study assesses the impact of crimped steel fibers on Geopolymer concrete, identifying the optimal percentage, and then explores substitutions with glass and polypropylene fibers at varying proportions of 0.5%, 0.75%, and 1% by weight of the binder content. Table 6 summarizes the concrete mixture proportions for Geopolymer concrete.

Table 6: Mix proportions of Geopolymer concrete addition with percentage of Crimped Steel fibers, Polypropylene fibers & Glass fibers

Materials kg/m <sup>3</sup> Mix No.	Fly Ash & GGBS	Sodium Hydroxide	Sodium Silicate	Fine Aggregate	Coarse Aggregate	Super plasticizer	Crimped steel fibers (%)	Polypropylene fibers (%)	Glass fibers (%)
M <sub>1</sub>	496	74.5	149	756	924	6.9	0	0	0
M <sub>2</sub>	496	74.5	149	756	924	6.9	1.5	0	0
M <sub>3</sub>	496	74.5	149	756	924	6.9	1	0.5	0
M <sub>4</sub>	496	74.5	149	756	924	6.9	0.75	0.75	0
M <sub>5</sub>	496	74.5	149	756	924	6.9	0.5	1	0
M <sub>6</sub>	496	74.5	149	756	924	6.9	1	0	0.5
M <sub>7</sub>	496	74.5	149	756	924	6.9	0.75	0	0.75
M <sub>8</sub>	496	74.5	149	756	924	6.9	0.5	0	1
M <sub>9</sub>	496	74.5	149	756	924	6.9	0.5	0.5	0.5

### 4.2 Mix procedure

For the experimental investigation, materials such as fly ash, GGBS, aggregates, sodium silicate, and sodium hydroxide are procured and tested to determine the properties such as specific gravity and water absorption. Mix design for Geopolymer concrete (GPC) is done, considering the desired proportions of the materials. Additionally, different volumes of fibers are incorporated into the mix to assess their impact on the concrete's performance. Following the mix design, concrete samples in the form of cubes, cylinders, and prisms are casted and cured for 24 hours before demolding. Subsequently, the specimens undergo an air-curing process at ambient temperature for durations of 7, 28, and 56 days to facilitate concrete strength development. Mechanical properties including compressive strength, split tensile strength, and flexural strength are then determined at the designated curing ages of 7, 28, and 56 days to analyze the performance of the Geopolymer concrete specimens.

### 4.3 Test procedure on Hardened concrete

The following tests are conducted to find the mechanical properties on hardened concrete:

**Compressive Strength:** The compressive strength of Geopolymer concrete is determined by casting the specimens of size 100\*100\*100mm. These samples undergo testing at ages of 7, 28, and 56 days using a compressive testing machine (CTM) with a capacity of 3000kN, as per IS 516:1959, as shown in Fig 1a.

**Split Tensile Strength:** The split tensile strength of Geopolymer concrete is determined by casting the cylinders of size 100\*200mm. These samples undergo testing at 28 days using a compressive testing machine (CTM) with a capacity of 3000kN, as per IS 516:1959, as shown in Fig 1b.

**Flexural Strength:** The flexural strength of Geopolymer concrete is determined by casting the beam specimens of size 100\*100\*500mm. These samples undergo testing at 28 days, as per IS 516:1959, as shown in Fig 1c.



Fig. 1a Compression test



Fig. 1b Split tensile



Fig. 1c Flexure test

## V. RESULTS AND DISCUSSION

### 5.1 Mechanical properties of Geopolymer concrete:

The following are the test results of compressive, split tensile and flexural strength tests to determine the mechanical properties of Geopolymer concrete.

#### 5.1.1 Compressive strength test

Figure 2 illustrates the compressive strength variations of Geopolymer concrete mixes denoted as M1 to M9, each incorporating different types of fibers including crimped steel, polypropylene, and glass fibers. For the control mix (M1), the compressive strength at 7, 28, and 56 days was determined as 34.88, 39.15, and 40.8 N/mm<sup>2</sup>, respectively. Upon introducing crimped steel fibers in mix M2, a notable increase in strength was observed compared to the control mix. Of note, mixes M2 and M8 exhibit nearly equal compressive strengths. This suggests that the combination of steel and glass fibers in mix M8 yields a compressive strength similar to that achieved with crimped steel fibers alone.

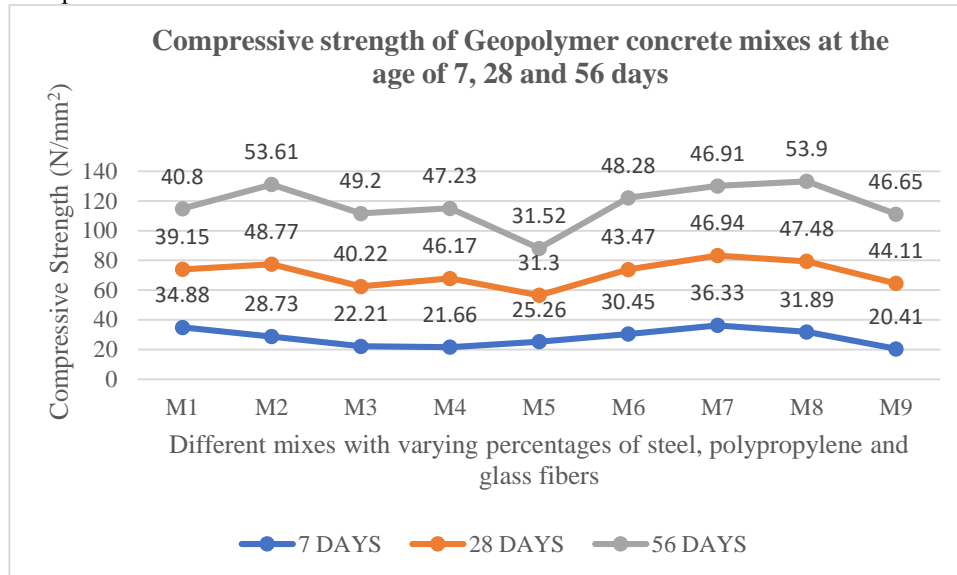


Fig. 2 Variation compressive strength of different mixes

#### 5.1.2 Split tensile strength test

Figure 3 displays the split tensile strength variations of Geopolymer concrete mixes denoted as M1 to M9, incorporating different types of fibers such as crimped steel, polypropylene, and glass fibers. For the control mix, denoted as M1, the 28-day split tensile strength was recorded as 1.705 N/mm<sup>2</sup>. With the addition of 1.5% crimped steel fibers (the optimum percentage), this strength increased to 4.605 N/mm<sup>2</sup> in mix M2. Remarkably, mix M8 exhibits a split tensile strength similar to that of mix M2. This suggests that the combination of steel and glass fibers in mix M8 yields a split tensile strength comparable to that achieved with crimped steel fibers alone.

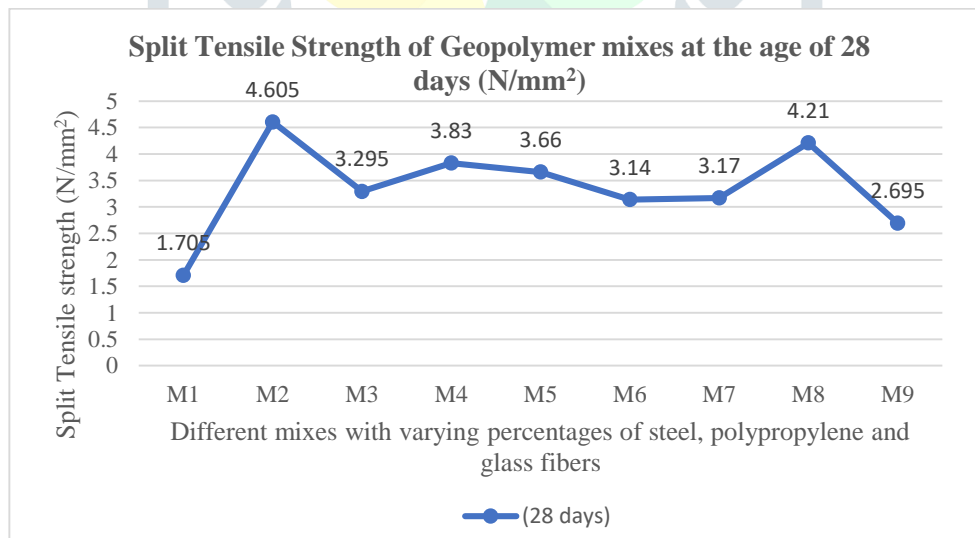


Fig. 3 Variation Split tensile strength of different mixes

#### 5.1.3 Flexural strength test

Figure 4 displays the flexural strength variations of Geopolymer concrete mixes denoted as M1 to M9, incorporating different types of fibers such as crimped steel, polypropylene, and glass fibers. For the control mix, denoted as M1, the 28-day flexural strength was recorded as 4.27 N/mm<sup>2</sup>. With the addition of 1.5% crimped steel fibers (the optimum percentage), this strength increased to 6.69 N/mm<sup>2</sup> in mix M2. Remarkably, mix M8 exhibits a flexural strength similar to that of mix M2. This suggests that the combination of steel and glass fibers in mix M8 yields a flexural strength comparable to that achieved with crimped steel fibers alone.

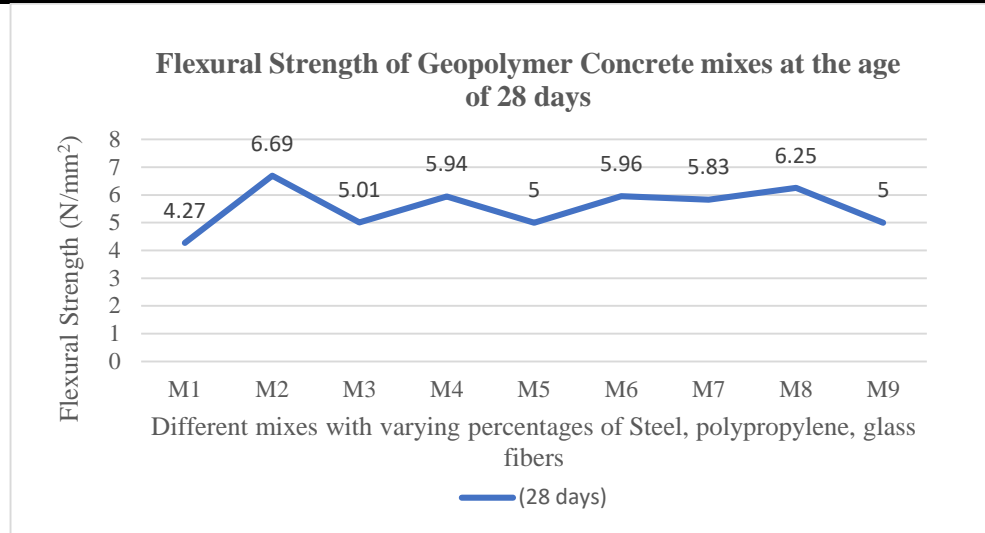


Fig. 4 Variation Flexural strength of different mixes

## VI. CONCLUSIONS

In this research work, nine different mixes of Geopolymer concrete were considered to investigate their strength characteristics, including compressive strength, flexural strength, and split tensile strength, with the incorporation of various fiber types such as crimped steel, polypropylene, and glass fibers.

1. The partial replacement of 20% GGBFS in the Geopolymer concrete mixture effectively mitigates setting delays, particularly during air curing at ambient temperatures.
2. Through experimental analysis, a Geopolymer concrete mix design with a liquid binder ratio of 0.45 and an alkaline solution ratio of 2 was identified, exhibiting desirable strength properties and advantageous environmental and economic benefits.
3. Cube compressive strength assessments revealed that mixes M1 and M2, augmented with crimped steel fibers, demonstrated increased strength at 28 and 56 days, with values escalating from 39.15 MPa to 48.77 N/mm<sup>2</sup> and from 40.8 N/mm<sup>2</sup> to 53.69 N/mm<sup>2</sup>, respectively. Optimal performance was achieved with a 1.5% addition of crimped steel fibers. Similar strength outcomes were observed in mix M8, which featured a combination of 0.5% crimped steel and 1% glass fibers.
4. Split tensile strength evaluations exhibited a similar trend, with mixes M1 and M2 registering enhancements from 1.705 N/mm<sup>2</sup> to 4.605 N/mm<sup>2</sup> at 28 days upon the incorporation of crimped steel fibers. The optimal mix again featured a 1.5% addition of these fibers, with mix M8 showing comparable results due to the combination of 0.5% crimped steel and 1% glass fibers.
5. Flexural strength assessments followed suit, with mixes M1 and M2 displaying increases from 4.27 N/mm<sup>2</sup> to 6.69 N/mm<sup>2</sup> at 28 days with the inclusion of crimped steel fibers. The optimal mix was identified at a 1.5% addition of crimped steel fibers, mirroring the results of mix M8, which combined 0.5% crimped steel and 1% glass fibers.
6. The overall analysis suggests that Geopolymer concrete incorporating 1.5% crimped steel fibers achieves optimal strength performance. Additionally, composite fiber mixes, particularly those combining steel and glass fibers, exhibit superior performance compared to combinations of steel and polypropylene fibers.
7. Despite the enhanced strength provided by steel fibers, their weight and cost implications prompt consideration of alternatives. Replacement of 1% steel fibers with glass fibers yields lighter, more cost-effective Geopolymer concrete with strength levels approaching those of Geopolymer concrete with optimal steel fiber content.

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