An investigation on Fly Ash Geopolymer Concrete with Hybrid Fibres

Ravi Shankar Singh

M. Tech. Scholar in Structural Engineering, CBS Group of Institutions, India.

Dr. Abhishek Sharma

Assistant Professor, Department of Structural Engineering, CBS Group of Institutions, India.

ABSTRACT

This study focused on the strength performance of fly ash-based geopolymer concrete reinforced with steel and glass fibres. Geopolymer concrete was prepared as a sustainable alternative to conventional cement concrete by using fly ash as the main binder material activated with alkaline solutions. The investigation evaluated the effect of hybrid fibre reinforcement on workability, compressive strength, split tensile strength, and flexural strength. Steel fibres were varied in different proportions, while glass fibre content was kept constant. The results showed that the addition of fibres reduced the slump value due to increased internal resistance in the fresh concrete mix. However, the hardened properties improved significantly with fibre addition. Among all mixes, mix 3 containing 0.75% steel fibre and 0.03% glass fibre showed the best performance under both ambient and heat curing conditions. The study concluded that hybrid fibre reinforced geopolymer concrete provides better crack resistance, load-carrying capacity, and durability.

Keywords: *Geopolymer Concrete, Fly Ash, Hybrid Fibres.*

1. INTRODUCCTION

Concrete is one of the most widely used construction materials due to its strength, durability, and suitability for different types of structures. However, ordinary Portland cement, which is the main binding material in conventional concrete, causes serious environmental problems because its production releases a large amount of carbon dioxide. Therefore, researchers are focusing on sustainable alternatives that can reduce cement consumption and improve concrete performance. Geopolymer concrete is one such eco-friendly material, in which industrial by-products such as fly ash are activated by alkaline solutions like sodium hydroxide and sodium silicate to form a strong binding matrix.

Fly ash-based geopolymer concrete not only helps in reducing environmental pollution but also provides good strength and durability. However, concrete is weak in tension and may develop cracks under loading. To overcome this limitation, fibres are added to improve its mechanical behaviour. Steel fibres increase toughness, crack resistance, and load-carrying capacity, while glass fibres help in improving tensile strength and controlling micro-cracks. The combined use of steel and glass fibres in geopolymer concrete can enhance compressive strength, split tensile strength, and flexural strength. Therefore, this study focuses on the strength performance of fly ash-based geopolymer concrete reinforced with steel and glass fibres.

2. LITERATURE REVIEWS

Vijai, Kumutha, and Vishnuram had studied the properties of glass fibre reinforced geopolymer concrete composites as an alternative to ordinary Portland cement concrete. The study had used fly ash, alkaline liquids, ordinary Portland cement, and glass fibres to prepare geopolymer concrete composites. The authors had examined density, compressive strength, split tensile strength, and flexural strength. Glass fibres were added in different volume fractions, and the results had shown improvement in mechanical properties. The study had concluded that glass fibre addition helped in improving tensile and flexural behaviour of geopolymer concrete.

Vijai, Kumutha, and Vishnuram had also investigated the effect of steel fibres on geopolymer concrete composites. The study had included fly ash, alkaline activators, 10% ordinary Portland cement replacement, and steel fibres. Steel fibres were added in different volume fractions from 0.25% to 0.75%. The results had indicated that compressive strength, split tensile strength, and flexural strength increased with the increase in steel fibre content. The study had reported that steel fibres improved crack resistance, load carrying capacity, and flexural performance of geopolymer concrete composites.

Nematollahi, Sanjayan, Chai, and Lu had evaluated the fresh and hardened properties of glass fibre reinforced fly ash-based geopolymer concrete. The geopolymer concrete had been activated using sodium hydroxide and sodium silicate solutions. Glass fibres were added at 0.50%, 0.75%, 1.00%, and 1.25% by volume of concrete. The study had shown that the addition of glass fibres reduced workability but increased density, compressive strength, and flexural strength. The research had proved that glass fibres could effectively enhance the strength performance of fly ash-based geopolymer concrete.

Sathanandam, Awoyera, Vijayan, and Sathishkumar had studied the use of fly ash and glass fibre for producing low-carbon geopolymer concrete. The study had used sodium hydroxide and sodium silicate as alkaline activators with different molar concentrations. Glass fibres were added in varying proportions, and specimens were cured under both oven curing and ambient curing conditions. The results had shown that heat-cured specimens performed better than ambient-cured specimens. The maximum compressive strength was obtained with 0.3% glass fibre and 16M NaOH, while tensile strength also improved due to fibre addition.

Aswathi and Shahla had investigated the mechanical properties of hybrid fibre reinforced geopolymer concrete using steel and glass fibres. The study had compared normal concrete, geopolymer concrete, steel fibre reinforced geopolymer concrete, and hybrid steel-glass fibre reinforced geopolymer concrete. The total fibre volume was fixed at 0.5%, and different steel-glass fibre combinations were tested. The results had shown that the mix containing 0.35% steel fibre and 0.15% glass fibre gave better performance. The study had reported improvement in compressive strength, split tensile strength, and flexural strength of hybrid fibre reinforced geopolymer concrete.

3. METHODOLOGY AND MATERIALS UTILISED

Methodology of the Investigation: The methodology of the present investigation was planned in a systematic manner to study the strength behaviour of fly ash-based geopolymer concrete reinforced with steel and glass fibres. The first stage of the work included a detailed literature study to understand the concept of geopolymer concrete, alkaline activation, fibre reinforcement, and the strength performance of fly ash-based concrete. After this, the required materials were collected, including fly ash, fine aggregate, coarse aggregate, sodium hydroxide, sodium silicate, water, superplasticizer, steel fibre, and glass fibre. The physical and chemical properties of these materials were then tested according to relevant IS codes. Fly ash was tested for specific gravity and fineness, while fine and coarse aggregates were tested for specific gravity, sieve analysis, and fineness modulus. These preliminary tests helped in selecting suitable materials for preparing geopolymer concrete mixes.

Materials Used in the Study: In this investigation, low-calcium fly ash was used as the main source material for preparing geopolymer concrete. Fly ash contained a high percentage of silica, alumina, and iron oxide, which made it suitable for geopolymerization. River sand available near Warangal was used as fine aggregate, and locally available crushed stone aggregate of 20 mm passing and 10 mm retained size was used as coarse aggregate. Portable water was used for mixing purposes as per IS 456:2000. Sodium hydroxide and sodium silicate solutions were used as alkaline activators to activate the fly ash and form the geopolymer binder. Sodium hydroxide pellets of about 97% purity were used, while sodium silicate was used in liquid gel form. Conplast SP430 superplasticizer was added to improve workability and reduce slump loss. Steel fibres of 50 mm length and 1 mm diameter with an aspect ratio of 50 were used to improve toughness and crack resistance. AR glass fibres of 12 mm length were also added to control micro-cracks and improve tensile behaviour.

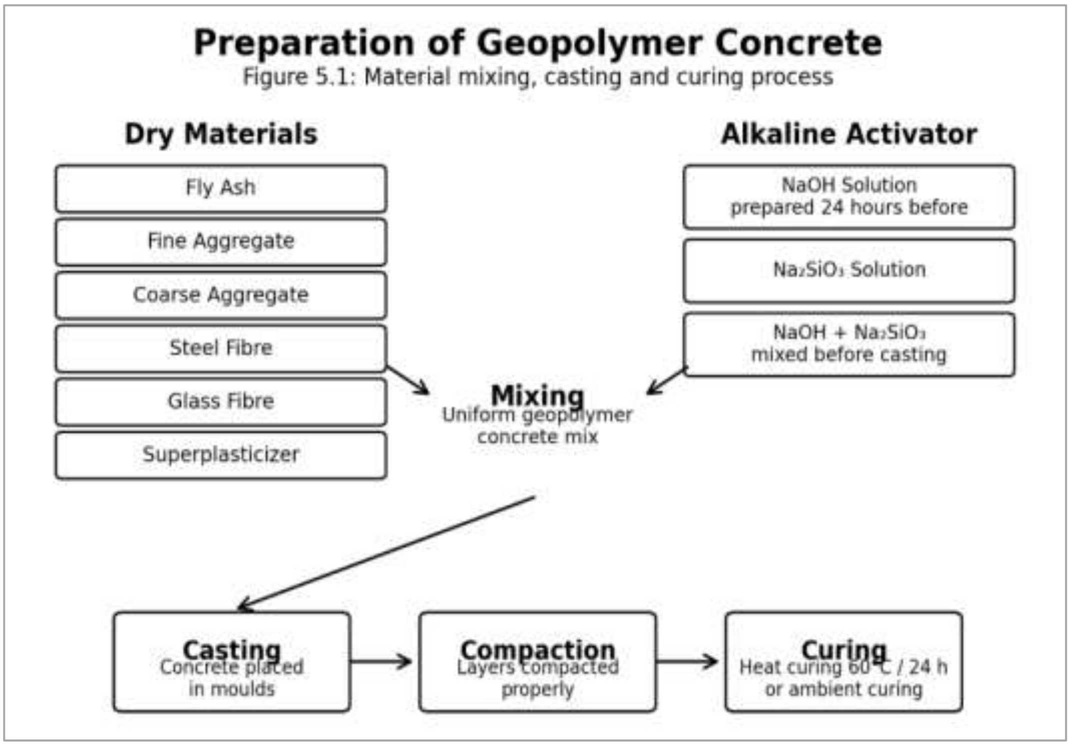
Testing Procedure and Strength Evaluation: After the selection and testing of materials, geopolymer concrete mixes were prepared by combining fly ash, aggregates, alkaline solution, water, superplasticizer, steel fibres, and glass fibres in required proportions. The fresh concrete was tested using the slump cone test to check its workability before casting. Specimens were then cast in standard moulds for different strength tests. After casting, the specimens were properly compacted and cured as per the selected curing method. The hardened concrete specimens were tested to evaluate their mechanical properties. The main tests included compressive strength, split tensile strength, and flexural strength. Compressive strength was used to determine the load-carrying capacity of concrete, split tensile strength was used to measure resistance against cracking under tensile force, and flexural strength was used to assess the bending resistance of the concrete. The results obtained from these tests were compared for different mixes to study the influence of steel and glass fibres on fly ash-based geopolymer concrete. Finally, the results were analysed, compared through charts, and conclusions were drawn regarding the strength performance of hybrid fibre reinforced geopolymer concrete.

4. MIX DESIGN

The mix design of geopolymer concrete was selected mainly through trial mix proportions, because standard codal methods are not available as in conventional concrete. In ordinary concrete, the required strength can be achieved by following design codes, but in geopolymer concrete the suitable proportion is finalized after preparing and testing trial mixes. In this study, the mix proportion was selected based on previous research on steel fibre reinforced geopolymer concrete. The adopted mix ratio was 1:1.4:3.28, with an alkaline liquid to fly ash ratio of 0.4. The ratio of sodium silicate solution to sodium hydroxide solution was kept as 2.5. The glass fibre content was kept constant at 0.03% in all fibre mixes. Steel fibre was varied as 0.25%, 0.50%, and 0.75% for Mix 1, Mix 2, and Mix 3 respectively. The selected proportions were used to study strength behaviour.

5. PREPARATION OF GEOPOLYMER CONCRETE

The preparation of geopolymer concrete was carried out carefully because the strength development mainly depends on the proper preparation of alkaline liquid, mixing, casting, and curing. Sodium hydroxide solution was prepared by dissolving sodium hydroxide pellets in water according to the required molarity. For 16 molar concentration, 640 g of sodium hydroxide pellets were required for one litre of water. Since the reaction between sodium hydroxide and water produces a large amount of heat, the solution was prepared 24 hours before casting.



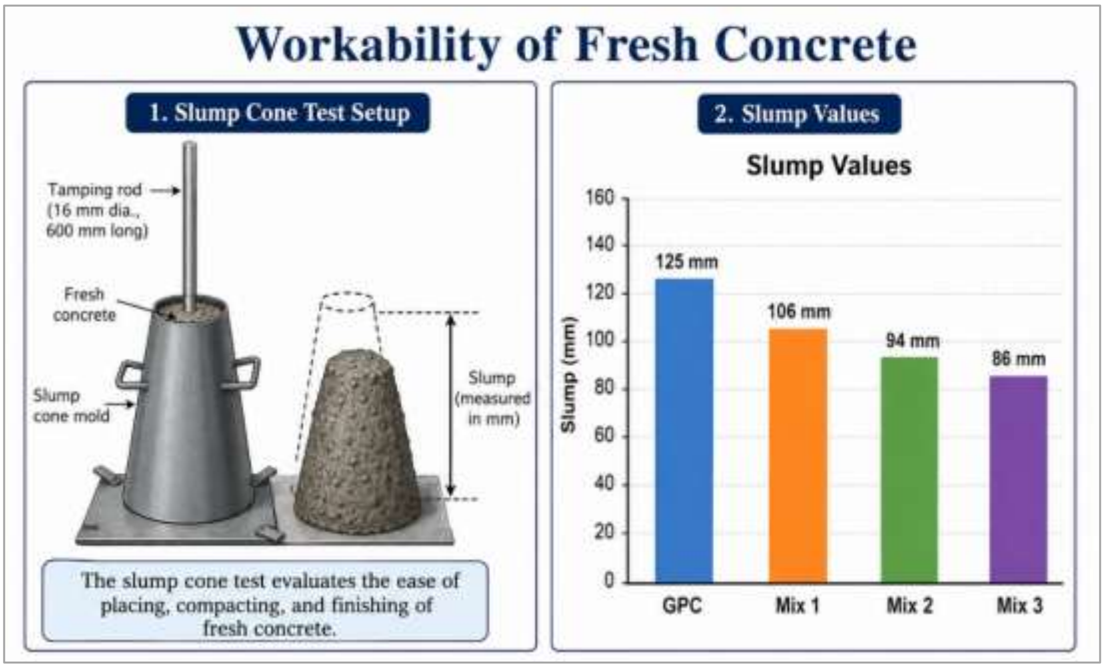
The alkaline liquid was prepared by mixing sodium hydroxide solution with sodium silicate solution at room temperature. This mixture acted as the activating solution for fly ash and helped in the formation of geopolymer binder. During mixing, fine aggregate, coarse aggregate, fly ash, steel fibres, and glass fibres were first mixed in dry condition. After that, alkaline liquid and superplasticizer were added and mixed until a uniform concrete mix was obtained. The prepared concrete was placed into moulds in layers and compacted properly. The specimens were cured either by heat curing at 60°C for 24 hours or by ambient curing at laboratory temperature.

6. PRERATION OF CONCRETE WORK AND TESTING

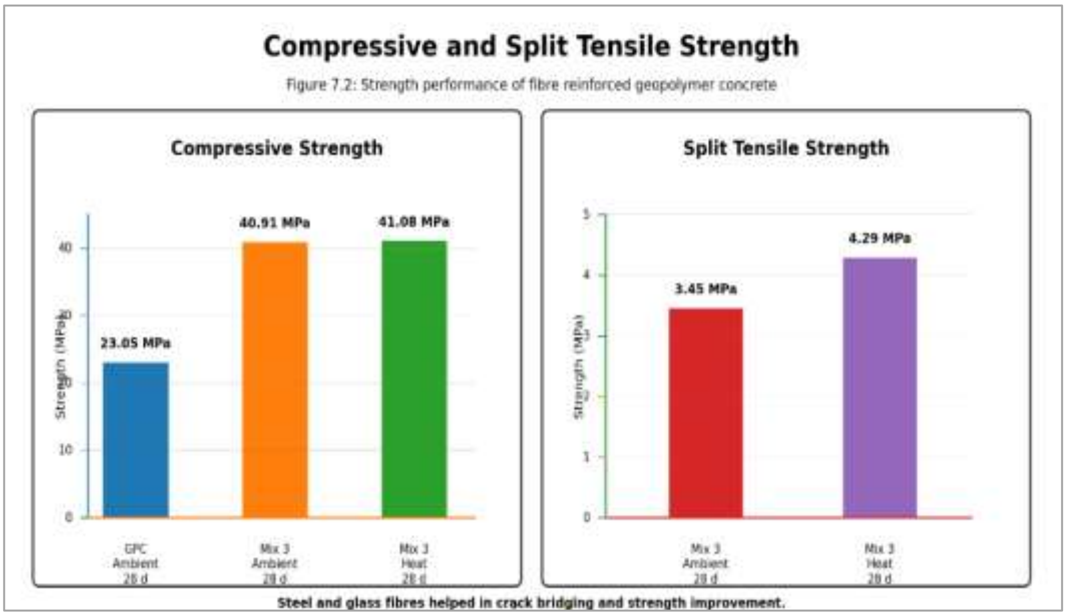
This section presents the total concrete work carried out for testing the strength properties of geopolymer concrete reinforced with steel and glass fibres. As per the objective of the project, different specimens were prepared to determine compressive strength, split tensile strength, and flexural strength. The adopted mix ratio was 1:1.4:3.28, with an alkaline liquid to fly ash ratio of 0.4 and sodium silicate to sodium hydroxide ratio of 2.5. Glass fibre was kept constant at 0.03%, while steel fibre was varied as 0.25%, 0.50%, and 0.75% in three fibre mixes, along with one control geopolymer concrete mix.

For testing, 150 mm cubes were cast for compressive strength, cylinders of 150 mm diameter and 300 mm length were cast for split tensile strength, and prisms of 150 mm × 150 mm × 750 mm were cast for flexural strength. Specimens were tested under ambient curing at 7, 14, and 28 days, and under heat curing at 7 and 28 days. A total of 60 cubes, 60 cylinders, and 60 prisms were prepared. Thus, the total number of specimens was 180, requiring 1.5355 m^3 of geopolymer concrete.

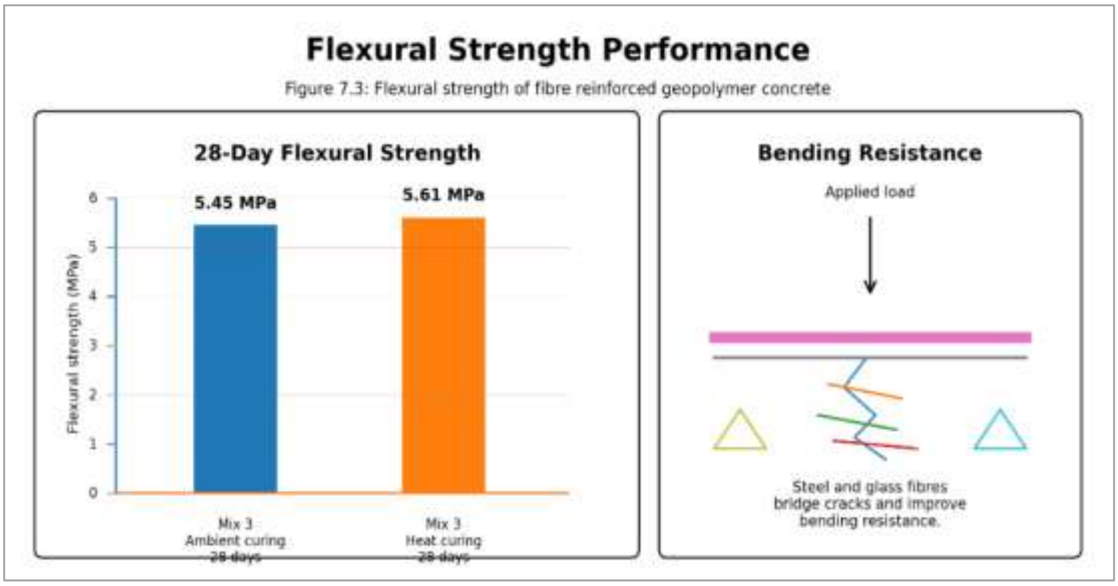
7. ANALYSIS OF TEST RESULTS



Workability of Fresh Concrete: The workability of geopolymer concrete was checked by using the slump cone test. This test was conducted to understand the ease of placing, compacting, and finishing the fresh concrete mix. The slump value of the control geopolymer concrete was 125 mm, which showed better workability. However, when steel and glass fibres were added, the slump value gradually decreased. Mix 1 showed 106 mm, mix 2 showed 94 mm, and Mix 3 showed 86 mm slump. This reduction occurred because fibres increased internal resistance and reduced the flow of concrete.



Compressive and Split Tensile Strength: The compressive strength results showed that strength increased with curing age. In ambient curing, Mix 3 achieved the highest 28-day compressive strength of 40.91 MPa, while the control GPC reached only 23.05 MPa. In heat curing also, Mix 3 showed the highest value of 41.08 MPa at 28 days. Similarly, split tensile strength improved with fibre addition. Under ambient curing, Mix 3 achieved 3.45 MPa at 28 days, while under heat curing it reached 4.29 MPa. This indicated that fibres helped in controlling cracks and improving tensile resistance.



Flexural Strength Performance: The flexural strength results also showed better performance in fibre reinforced geopolymer concrete. In ambient curing, Mix 3 gave the highest 28-day flexural strength of 5.45 MPa. In heat curing, Mix 3 again performed best with 5.61 MPa at 28 days. The addition of steel and glass fibres improved bending resistance and crack bridging capacity. Overall, mix 3 showed the best performance in compressive, split tensile, and flexural strength tests.

8. CONCLUSION

The present study concluded that fly ash-based geopolymer concrete reinforced with steel and glass fibres can be used as an effective alternative to conventional cement concrete. The use of fly ash helped in reducing cement consumption and supported sustainable construction. The addition of steel and glass fibres improved the mechanical properties of geopolymer concrete, especially compressive strength, split tensile strength, and flexural strength. The slump value decreased with the increase in fibre content, which showed that fibres reduced workability by increasing internal resistance in the concrete mix. Among all mixes, Mix 3, containing 0.75% steel fibre and 0.03% glass fibre, gave the best overall performance. It achieved the highest compressive strength, split tensile strength, and flexural strength under both ambient and heat curing conditions. Therefore, hybrid fibre reinforced geopolymer concrete showed better crack resistance, bending resistance, and load-carrying capacity, making it suitable for durable and eco-friendly construction.

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