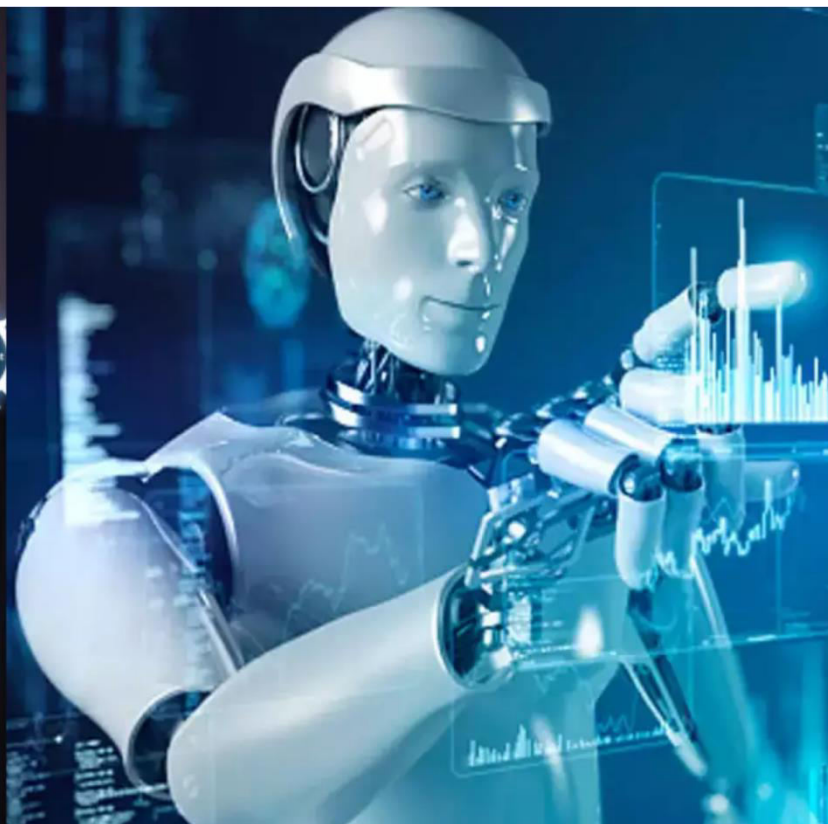




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An Experimental Investigation on Self Compacting Geopolymer Concrete with Steel Fibers

Dumpala Hareesha, I.V. Ramana Reddy

PG Student, Department of Civil Engineering, S.V. University College of Engineering Tirupati, Andhra Pradesh, India

Professor, Department of Civil Engineering, S.V. University College of Engineering Tirupati, Andhra Pradesh, India

ABSTRACT: Ordinary Portland Cement (OPC) is widely used in concrete production but contributes significantly to CO₂ emissions due to its energy-intensive manufacturing process. Geopolymers, synthesized through the alkali activation of aluminosilicate-rich materials, present an eco-friendly alternative with reduced carbon footprint and high mechanical performance. This study investigates the fresh and mechanical properties of Self-Compacting Geopolymer Concrete (SCGPC) reinforced with steel fibers. The binder system comprised fly ash, Ground Granulated Blast Furnace Slag (GGBS), and silica fume, which were activated using a combination of sodium hydroxide and sodium silicate. Mixes were prepared with a constant 40% GGBS, and the remaining 60% of fly ash was partially replaced with silica fume (0-15%), with (50F40G10S) identified as optimum based on strength and Steel fibers (0–2% by volume) were to enhance structural properties. Fresh property tests (such as slump flow, T_{50cm} slump flow, V-funnel, L-box and U-box) confirmed compliance with EFNARC standards. Mechanical tests showed that 1.5% steel fibers provided maximum improvement in compressive, split tensile, and flexural strength while maintaining acceptable flowability. Finally, beam specimens were cast with and without stirrups under reinforced conditions, using mixes with and without steel fibers. The results demonstrated significant enhancement in flexural performance and overall structural behaviour, highlighting the potential of SCGPC with steel fibers as a sustainable and high-performance construction material, a sustainable alternative to OPC concrete in structural applications.

KEYWORDS: Self-compacting Geopolymer concrete (SCGPC), Steel fibers, fly ash, GGBS, Silica fume, fresh properties and Mechanical properties.

I. INTRODUCTION

Concrete, primarily made using Ordinary Portland Cement (OPC), stands as the most commonly utilized construction material worldwide. However, OPC production is responsible for approximately 6% of global CO₂ emissions, releasing nearly one ton of CO₂ per ton of cement produced. The search for alternative binders has led to the development of geopolymer technology, first proposed by Davidovits in 1978. Geopolymers utilize industrial by-products such as fly ash, silica fume, and GGBS, activated by alkaline solutions, to produce a durable, high-strength, and environmentally friendly binder.

Self-Compacting Geopolymer Concrete (SCGPC) combines the advantages of self-compacting concrete (SCC) — excellent flowability and consolidation without vibration — with the sustainability of geopolymer binders. However, due to the brittle nature of concrete, the incorporation of fibers, particularly steel fibers, can improve toughness, crack resistance, and post-cracking behavior

This research investigates the influence of varying silica fume content and steel fibers dosage on the fresh and mechanical properties of SCGPC. Furthermore, it examines the structural performance of SCGPC beams with and without shear reinforcement.

II. LITERATURE SURVEY

Edris et al. [1], in their enchanted laboratory of self-compacting magical concretes, brewed mixtures of metakaolin and silica fume at 0%, 10%, and 15%, adding steel fibers like tiny wands at 0.25%, 0.5%, and 1%. They discovered that the 10% silica fume potion cast the perfect spell between workability and strength. Compressive might rose by 23% in 28 days, and split tensile resilience improved by 17%. But beware, at 15% silica fume, the mixture became stubborn and

unyielding, a consequence of too many fine particles. Steel fibers enchanted the concrete with extraordinary post-cracking toughness, especially at the 0.5% dosage. Vigneshkumar et al. [2] concocted self-compacting geopolymer elixirs from fly ash and GGBS in ratios of 70:30, 60:40, and 50:50. They observed that adding more GGBS hastened early strength, though it also shortened the time before the potion set. Infusing steel fibers at 0.5% and 1% created a magical balance of strength and flow, with the 0.5% dose proving most harmonious. These mixtures glided smoothly in the L-box test, like enchanted brooms on a racetrack, meeting the sacred EFNARC standards. Eltantawi et al. [3] conjured a legendary ternary blend of fly ash, GGBS, and silica fume to craft ultra-high-performance geopolymer concrete. Their creation was stronger than many dragons' scales (>90 MPa) and exhibited a dense, impenetrable microstructure, thanks to the mystical bonding of Si-Al polymers. Its durability was remarkable, and water barely dared penetrate its defenses. Sharma, Gupta, Bahrami, and Islam [4] cast a scholarly review of fiber-reinforced geopolymer spells, detailing steel, basalt, glass, and polypropylene fibers. Steel fibers wielded the wand of flexural strength and crack control, while hybrid systems created a perfect potion of toughness and smooth casting. They noted that these fibers not only enhanced performance but also allowed for more sustainable brewing with less cement. Luo and Zhang [5] examined metakaolin-fly ash-GGBS composites, finding that metakaolin refined the tiny pores and conjured early strength. Their samples surpassed 70 MPa, with SEM and XRD revealing dense gels and homogeneity worthy of a master potion-maker's approval. Kiran Kumar and Ramana Reddy [6] experimented with NaOH potions of varying molarity (8M–14M). Higher molarity dissolved more silica and alumina, enhancing the magic of geopolymerization, especially at 12M. Beyond this, the mixture became too quick-tempering, reducing workability as if bewitched. Davidovits [7] penned the sacred tome Geopolymer Chemistry and Applications, elucidating the alchemy of geopolymer formation, structure, and magical bonds, serving as the cornerstone of all modern concrete.

From the literature, it is evident that the inclusion of silica fume and GGBS enhances the mechanical strength and durability of geopolymer concrete, while steel fibers significantly improve ductility, toughness, and crack resistance. However, limited research is available on the combined effect of varying silica fume content and steel-fiber dosage in self-compacting geopolymer concrete. Hence, the present study aims to investigate this combined influence experimentally.

III. METHODOLOGY

This study was conducted to examine the fresh and mechanical behavior of Self-Compacting Geopolymer Concrete (SCGPC) reinforced with steel fibers.

The experimental procedure was organized into the following stages:

1. Selection and characterization of materials,
2. Design and optimization of mix proportions,
3. Casting and curing of specimens, and
4. Evaluation of fresh and hardened properties.

1. Materials

1.1 Fly Ash

Low-calcium Class-F fly ash, obtained from the Rayalaseema Thermal Power Plant (Andhra Pradesh), was used. It enhanced workability and contributed to long-term strength development.

1.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS from JSW Steel Plant was used as a constant 40% of the total binder. It improved early strength and durability.

1.3 Silica Fume

Silica fume, sourced from Chemi Soft Enterprises, Chennai, conforming to IS 15388:2003, replaced fly ash in the range of 0–15% by mass of binder.

1.4 Aggregates

Fine Aggregate: River sand meeting Zone II specifications of IS 383:1970, with a specific gravity of 2.65.

Coarse Aggregate: Crushed granite with a maximum size of 12 mm and a specific gravity of 2.80.

1.5 Alkaline Activator

A mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) in the mass ratio 1:2 was employed as the activating solution. NaOH pellets of 97–98% purity were dissolved to produce a 12 M solution. The alkaline liquid-to-binder ratio was kept at 0.45.

1.6 Superplasticizer

A polycarboxylate-ether-based (PCE) high-range water reducer was used at 1.5% of binder mass to achieve adequate flowability.

1.7 Steel Fibers

Hooked or crimped steel fibers, 35 mm long and 0.5 mm in diameter, having a tensile strength of about 940 N/mm², were incorporated at dosages of 0%, 0.5%, 1.0%, 1.5%, and 2.0% by volume of concrete.

2. Mix Design

Trial mixes were prepared to achieve self-compaction as per EFNARC (2005) recommendations. The total aggregate content was maintained at about 70% of concrete mass. The ratio of Na_2SiO_3 : NaOH was fixed at 2.0. Six binder combinations were produced by varying the silica-fume replacement (0–15%) from the strength results, the mixture containing 50% fly ash, 40% GGBS, and 10% silica fume was identified as the optimum binder blend (50F40G10S). Steel fibers in the range 0–2% were then added to this optimum mix for further evaluation.

3. Mixing, Casting and curing

1. The dry ingredients (fly ash, GGBS, silica fume, and aggregates) were first mixed in a pan mixer for about 3 minutes.
2. The alkaline solution and superplasticizer were then added gradually, and mixing continued for an additional 3–4 minutes until uniform consistency was obtained.
3. The following specimens were cast:
 - Cubes: 150 × 150 × 150 mm (for compressive strength),
 - Cylinders: 150 × 300 mm (for split-tensile strength) and
 - Beams: 500 × 100 × 100 mm (for flexural strength).
4. All specimens were demoulded after 24 hours of casting.
5. Specimens were cured at ambient laboratory temperature (27 ± 2 °C) until testing at 7, 28, and 90 days. No heat or oven curing was applied so that the results would represent realistic field conditions.

4. Testing of Specimens

4.1 Fresh-Property Tests

Workability and flow characteristics were examined following EFNARC (2002) guidelines using:

- Slump-flow and T_{50} tests,
- V-funnel test,
- L-box test, and
- U-box

test.

These tests confirmed the filling, passing, and segregation resistance of the mixes.

4.2 Mechanical-Property Tests

- Compressive Strength: Determined on cube specimens at 7, 28, and 90 days.
- Split-Tensile Strength: Measured on cylindrical specimens at 28 days.
- Flexural Strength: Evaluated on beam specimens at 28 days.

4.3 Structural Beam Tests

Beams were examined under two configurations—with and without stirrups, and with and without steel fibers—to assess the influence of fiber reinforcement on flexural load capacity and crack behavior.

IV. EXPERIMENTAL RESULTS

The results of the experimental investigation on Self-Compacting Geopolymer Concrete (SCGPC) incorporating steel fibers are presented in this section. The study evaluated both fresh and mechanical properties, as well as structural beam performance, to determine the optimum fiber dosage.

Fresh Properties:

the variation in flow parameters of SCGPC mixes with and without steel fibers. The slump flow values ranged between 650 mm and 755 mm, satisfying the EFNARC (2002) limits (650–800 mm). The T_{50} times varied between 3.4 s and 4.5 s, and V-funnel times ranged from 6.2 s to 9.0 s, indicating good filling and passing ability. The L-box ratios (0.84–0.95) and U-box height differences (17.5–28 mm) confirmed that all mixes maintained self-compacting characteristics. Workability gradually decreased as the steel-fiber percentage increased, due to the interlocking effect of fibers, yet all mixes remained within the acceptable EFNARC range

Compressive Strength:

Figure (a) illustrates the effect of fiber content on the compressive strength of SCGPC at 7, 28, and 90 days. The optimum mix (50F40G10S) achieved a 28-day strength of 38.06 MPa, while the inclusion of 1.5 % steel fibers increased it to 58.03 MPa, representing a 52 % improvement. Beyond 1.5 %, the strength slightly decreased due to reduced workability and minor void formation. Fig. (a). Compressive strength development of SCGPC mixes with various steel-fiber dosages at 7, 28, and 90 days.

Split Tensile Strength:

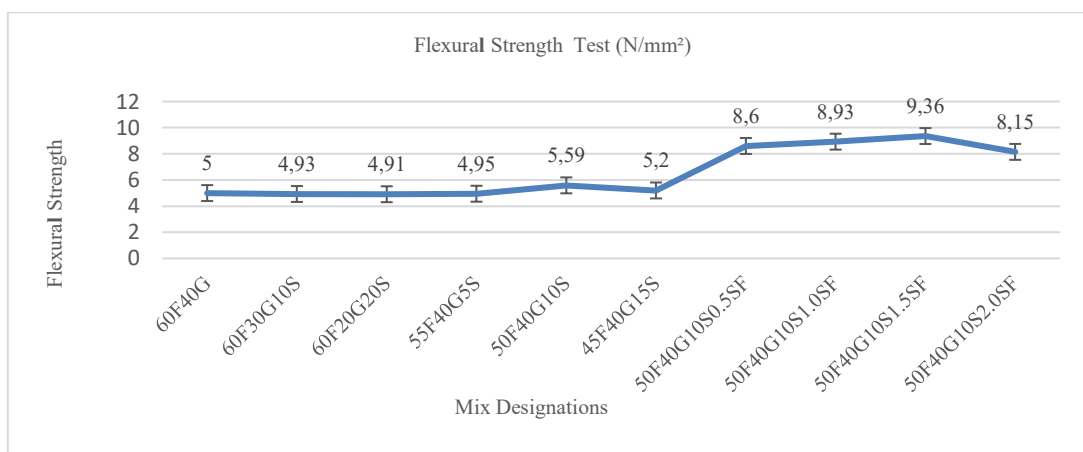
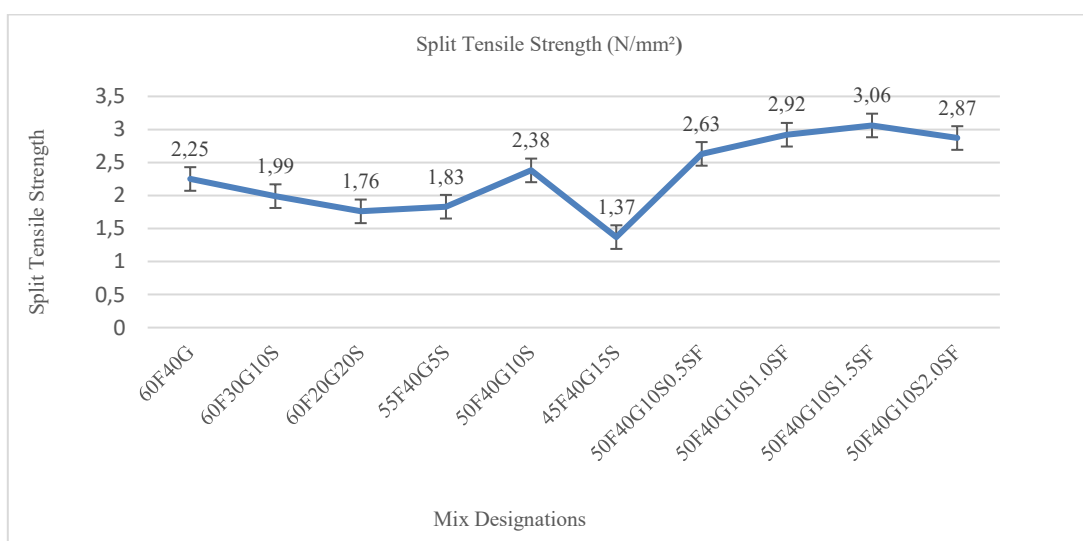
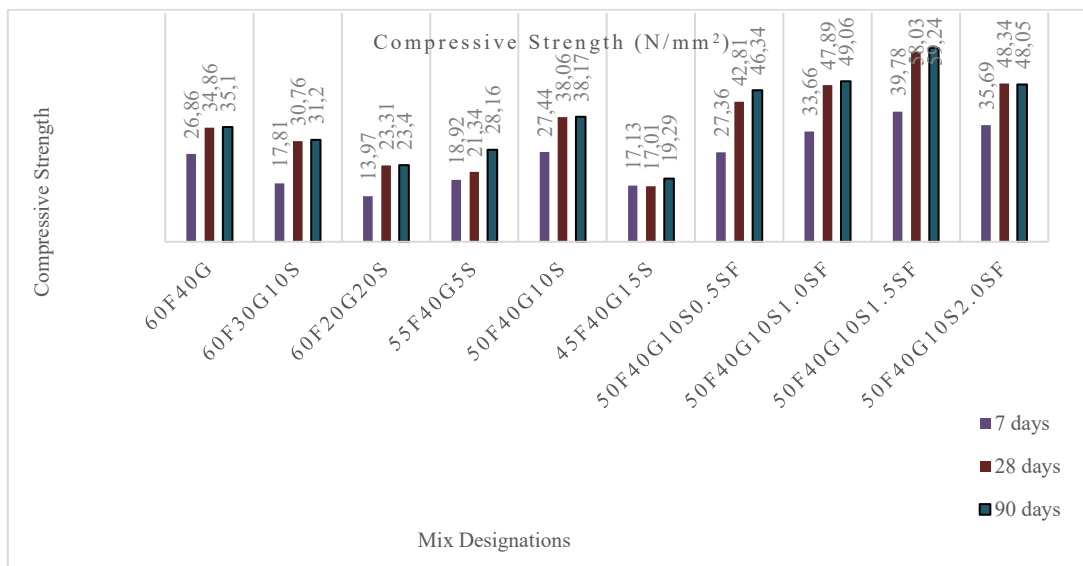
The 28-day split tensile strength of the control mix (50F40G10S) was 2.38 MPa, while the mix containing 1.5 % steel fibers reached 3.06 MPa, marking a 28.6 % increase. The enhancement is attributed to fiber bridging action that delays crack propagation and improves tensile load resistance. Fig. (b). Variation of split tensile strength for SCGPC mixes with different steel-fiber percentages at 28 days.

Flexural Strength:

The flexural strength results followed a similar pattern. The control mix recorded 5.59 MPa, while the 1.5 % steel fiber mix attained 9.36 MPa, showing a 67 % improvement. This significant enhancement demonstrates the effectiveness of fibers in improving ductility and post-crack load-carrying behavior. Fig.(C) Comparison of flexural strength for SCGPC mixes with 0–2 % steel-fiber content.

Structural Beam Performance:

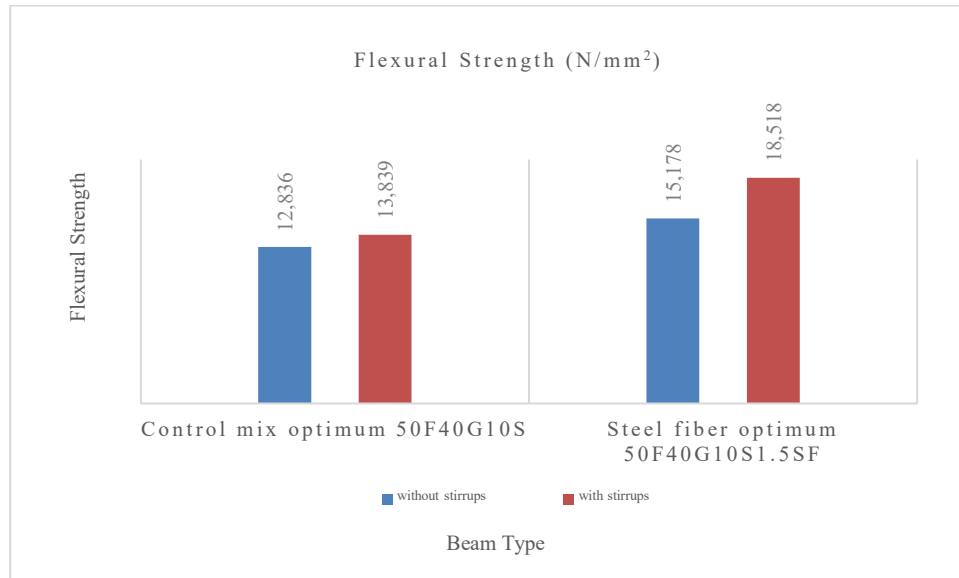
Beams were tested under two conditions — with and without stirrups, and with and without steel fibers — to examine their flexural behavior. The beam containing 1.5 % steel fibers with stirrups exhibited the highest strength, showing about 34 % improvement compared to the control beam with stirrups and 18 % improvement over the beam without stirrups. This increase was due to the crack-bridging and energy-absorbing capacity of steel fibers, which improved ductility and load redistribution after cracking. Fig.(d) Load–deflection response of SCGPC beams with and without steel fibers and stirrups.



(a)

(b)

(c)



(d)

V. CONCLUSION

The present experimental investigation on Self-Compacting Geopolymer Concrete (SCGPC) reinforced with steel fibers demonstrated that the mix containing 50% Fly Ash, 40% GGBS, and 10% Silica Fume (50F40G10S) produced the most balanced performance in terms of strength and workability. The incorporation of steel fibers in varying proportions from 0% to 2% enhanced the overall mechanical behavior, with the 1.5% dosage found to be optimum. Compared with the control mix, the addition of 1.5% steel fibers increased the compressive strength by about 52%, split tensile strength by 28.6%, and flexural strength by 67%. Although the workability slightly reduced with higher fiber content, all mixes satisfied the EFNARC (2005) criteria for self-compacting concrete. Structural beam tests revealed that beams containing 1.5% steel fibers with stirrups exhibited nearly 34% higher flexural strength than the control beam, confirming improved ductility and crack resistance. Overall, the study concludes that Self-Compacting Geopolymer Concrete reinforced with steel fibers provides superior mechanical and structural performance while promoting sustainability through the utilization of industrial by-products, making it a viable eco-friendly alternative to conventional Portland cement concrete.

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