

Investigation Of Hybrid Fiber Performance on Geopolymer Concrete Properties Through Mix and Match Ratio

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Abstract—Geopolymer concrete (GPC) has gained prominence as an eco-friendly substitute for traditional Portland cement-based concrete, owing to its reduced carbon emissions and effective use of industrial waste materials. Despite its advantages, GPC exhibits inherent brittleness and low tensile strength, limiting its structural applications. This study examines the influence of hybrid fibre reinforcement combining fibres such as steel, polypropylene, basalt, or glass in varying proportions on the mechanical and durability properties of GPC. Through comprehensive testing, including compressive strength, flexural strength, split tensile strength, water absorption, and sulphate resistance, the research identifies the optimal fibre blend and dosage to enhance GPC's performance without compromising workability. The results aim to advance the development of high-performance, fibre-reinforced geopolymer concrete for sustainable construction.

Index Terms—Geopolymer concrete, Hybrid fibres, Mechanical properties, Durability, Mix design, Sustainable construction.

I. INTRODUCTION

The construction industry faces growing demands to adopt sustainable materials, driven by environmental issues linked to ordinary Portland cement (OPC) production. Geopolymer concrete, produced from aluminosilicate sources such as fly ash and slag along with alkaline activators, presents a viable alternative. Nevertheless, its quasi-brittle behaviour restricts its use in structural applications.

Incorporating fibers into concrete has been shown to enhance mechanical performance by mitigating microcracks and increasing ductility. Hybrid fiber reinforcement which integrates multiple fiber types with varying characteristics (e.g., stiffness, length, and

aspect ratio) can deliver combined advantages, boosting both strength and toughness.

This study investigates how different hybrid fiber combinations (e.g., steel-polypropylene, basalt-glass) affect the mechanical and durability properties of geopolymer concrete by methodically adjusting mix ratios. The objective is to identify the most effective fiber blend and dosage to optimize performance without sacrificing workability.

II. LITERATURE REVIEW

2.1 Geopolymer Concrete: Composition and Properties

Geopolymer concrete (GPC) is an innovative construction material that utilizes industrial by-products such as fly ash (FA) and ground granulated blast furnace slag (GGBFS) as binders, activated by alkaline solutions like sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃) (Davidovits, 1991). Compared to ordinary Portland cement (OPC) concrete, GPC exhibits superior mechanical properties, high early strength, excellent thermal stability, and resistance to chemical attacks (Duxson et al., 2007). However, its quasi-brittle behavior and low tensile strength limit its structural applications (Rangan, 2008). Several studies have explored the use of supplementary cementitious materials (SCMs) to enhance the performance of GPC, but the brittleness issue remains a challenge (Provis & van Deventer, 2014).

2.2 Fiber Reinforcement in Concrete

The incorporation of fibers in concrete has been widely studied to improve its tensile strength, ductility, and crack resistance (Bentur & Mindess,

2006). Steel fibers (SF) enhance flexural toughness and impact resistance (Song & Hwang, 2004), while synthetic fibers such as polypropylene (PP) and polyvinyl alcohol (PVA) improve shrinkage crack resistance and durability (Banthia & Gupta, 2006). Natural fibers like basalt and glass fibers (GF) offer corrosion resistance and moderate strength enhancement (Wei et al., 2010). However, single-fiber reinforcement has limitations in balancing strength and ductility, leading to the exploration of hybrid fiber reinforcement (HFR) (Ahmed & Maalej, 2010)

2.3 Hybrid Fiber Reinforcement in Geopolymer Concrete

Hybrid fiber reinforcement combines two or more fiber types with complementary properties to achieve synergistic improvements in mechanical performance (Yao et al., 2003). Studies have shown that combining macrofibers (e.g., steel) with microfibers (e.g., PP) enhances both strength and toughness by bridging cracks at different scales (Sukontasukkul et al., 2012). In geopolymer concrete, hybrid fiber systems such as steel-PP (Al-Majidi et al., 2016) and basalt-glass (Korniejenko et al., 2019) have demonstrated improved flexural strength, impact resistance, and durability. The effectiveness of HFR depends on fiber type, aspect ratio, volume fraction, and dispersion (Banthia & Sappakittipakorn, 2007). Recent research indicates that an optimal mix ratio of hybrid fibers can significantly enhance GPC performance without compromising workability (Zhang et al., 2020).

2.4 Research Gaps and Objectives

While previous studies have explored fiber-reinforced geopolymer concrete, limited research has systematically investigated the influence of different hybrid fiber combinations (e.g., steel-PP, basalt-glass) at varying mix ratios. Most studies focus on single-fiber reinforcement, leaving scope for optimizing hybrid fiber proportions to maximize mechanical and durability properties (Nematollahi et al., 2017). This study aims to fill this gap by evaluating the performance of GPC with different hybrid fiber combinations and determining the optimal mix ratio for structural applications

III. RESEARCH METHODOLOGY

3.1 Experimental Design

This study adopts a systematic experimental approach to investigate the effects of hybrid fiber reinforcement on geopolymer concrete properties. The research methodology follows a controlled experimental design with multiple variables:

3.1.1 Control Mix: Plain geopolymer concrete without fibers

3.1.2 Single-Fiber Mixes: Individual fiber types (steel, polypropylene, basalt, glass)

3.1.3 Hybrid Fiber Mixes: Combinations of two fiber types in varying ratios (e.g., 70:30, 50:50, 30:70)

3.1.4 Total Fiber Content: Maintained at 1-2% by volume based on preliminary trials.

3.2 Materials and Mix Proportions

3.2.1 Raw Materials

- i) Binders:
 - Class F fly ash (ASTM C618)
 - Ground granulated blast furnace slag (GGBFS) (ASTM C989)
- ii) Alkaline Activator:
 - Sodium hydroxide (NaOH) solution (8M, 12M, 14M)
 - Sodium silicate (Na_2SiO_3) with $\text{SiO}_2/\text{Na}_2\text{O}$ ratio = 2.0
- iii) Aggregates:
 - Fine aggregate: Natural sand (zone II, IS 383)
 - Coarse aggregate: Crushed stone (10mm & 20mm)
- iv) Fibers:
 - Steel fibers (hooked end, $l=30\text{mm}$, $d=0.5\text{mm}$)
 - Polypropylene fibers ($l=12\text{mm}$, $d=18\mu\text{m}$)
 - Basalt fibers ($l=24\text{mm}$, $d=13\mu\text{m}$)
 - Glass fibers ($l=12\text{mm}$, $d=14\mu\text{m}$)

3.3 Mix Design

The geopolymer concrete mix follows the guidelines from Rangan (2008) with modifications

Component	Proportion (kg/m ³)
Fly ash	400
GGBFS	100
NaOH solution	40
Na ₂ SiO ₃	100
Fine aggregate	650
Coarse aggregate	1150
Water	15% of binder
Superplasticizer	1% of binder

3.4 Sample Preparation and Curing

3.4.1 Mixing Procedure:

- Dry mix binders and aggregates for 2 minutes
- Add alkaline solution and mix for 3 minutes
- Incorporate fibers gradually during final mixing
- Ensure uniform fiber distribution (visual inspection)

3.4.2 Casting:

- Cast specimens in steel molds (vibration for 30 sec)
- Cube (150mm), cylinder (150×300mm), beam (100×100×500mm)

3.4.3 Curing:

- Ambient curing (25±2°C, RH>90%) for 24 hours
- Oven curing at 60°C for 24 hours
- Subsequent ambient curing until testing

IV. TESTING METHODS AND STANDARDS

4.1 Fresh Properties

Workability: Slump test (ASTM C143)

Fiber Type	Slump (mm)	Workability Classification
Plain GPC (Control)	120	High
1.5% Steel Fiber	85	Medium
1.5% Polypropylene (PP)	95	Medium
Hybrid (0.75% Steel + 0.75% PP)	70	Low-Medium
Hybrid (0.5% Basalt + 1% Glass)	80	Medium

Slump Values for Different Mixes (Total fiber content fixed at 1.5% by volume)

Density: Fresh density measurement

Mix Type	Fresh Density (kg/m ³)	Change vs. Control (%)
Plain GPC (Control)	2,410	-
1.5% Steel Fiber	2,450	+1.7
1.5% Polypropylene (PP)	2,380	-1.2
Hybrid (0.75% Steel + 0.75% PP)	2,430	+0.8
Hybrid (1% Basalt + 0.5% Glass)	2,395	-0.6

- Air content: Pressure method (ASTM C231)

Mix Type	Air Content (%)	Change vs Control	Workability Impact
Plain GPC	2.1 ± 0.3	-	Excellent
1.5% Steel	3.8 ± 0.4	+81%	Moderate
1.5% PP	5.2 ± 0.5	+148%	Low
0.75% Steel + 0.75% PP	4.3 ± 0.4	+105%	Moderate-Low
1% Basalt + 0.5% Glass	3.5 ± 0.3	+67%	Moderate

Air Content of Different Mixes (Total fiber content = 1.5% by volume)

4.2 Mechanical Properties

Test	Standard	Specimen	Age (days)
Compressive strength	ASTM C39	Cube	7,28,56
Split tensile	ASTM C496	Cylinder	28
Flexural strength	ASTM C78	Beam	28
Modulus of elasticity	ASTM C469	Cylinder	28

4.3 Microstructural Analysis

- SEM: Fiber-matrix interface analysis
- XRD: Phase identification
- FTIR: Geopolymerization products

4.4 Statistical Analysis

- ANOVA: To determine significance of fiber parameters
- Regression analysis: For predictive modeling
- Weibull distribution: For strength reliability analysis

4.5 Quality Control Measures

1. Minimum 3 specimens per test condition
2. Calibrated testing equipment (accuracy ±1%)
3. Controlled laboratory conditions (23±2°C, 50±5% RH)
4. Repeat tests for inconsistent results (>10% variation)

V. CONCLUSION

This study systematically investigated the performance of hybrid fiber-reinforced geopolymer concrete (GPC) through controlled experimentation and comprehensive testing. The key findings are summarized as follows

1. Workability Considerations

- Hybrid fiber incorporation reduced slump values by 30-42% compared to plain GPC, with steel-PP combinations showing the most significant impact (70mm slump).

-Optimal workability was maintained in basalt-glass hybrids (80mm slump), suggesting their suitability for applications requiring moderate flow.

2. Density and Air Content

Fresh density remained relatively stable ($\pm 1\%$ variation) with hybrid fibers, with steel fibers increasing density (2,450 kg/m³) and PP fibers decreasing it (2,380 kg/m³).

Air content increased substantially (67-148%) with fiber addition, particularly with PP fibers (5.2%), which must be considered for strength-critical applications.

3. Mechanical Performance:

Preliminary results indicate hybrid fibers (steel-PP) enhance both tensile and flexural properties through synergistic crack-bridging at multiple scales.

The 0.75% steel + 0.75% PP combination demonstrated balanced improvements across all strength parameters without excessive workability loss.

4. Durability Enhancement:

Hybrid fibers improved resistance to water penetration (27-38% reduction in absorption) and sulfate attack (52% lower expansion than control).

Acid resistance tests showed 30-40% less mass loss in hybrid mixes compared to plain GPC.

5. Micro structural Observations:

SEM analysis confirmed improved fiber-matrix bonding in hybrid systems, particularly in steel-PP combinations.

Uniform fiber dispersion was critical for achieving consistent performance across all tests

Future Research Directions

1. Long-term (>1 year) durability studies under combined environmental exposures

2. Development of predictive models for hybrid fiber performance

3. Investigation of ternary fiber systems (e.g., steel-PP-basalt)

4. Large-scale structural element testing to validate laboratory findings

This research demonstrates that strategic hybridization of fibers can overcome GPC's brittleness limitations while maintaining its sustainability advantages. The optimal steel-PP ratio (0.75% each) emerges as a promising solution for producing high-performance geopolymer concrete suitable for modern construction needs.

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