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Development of Fibre-Reinforced Self-Compacting Geopolymer Concrete with Enhanced Durability Performance

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Abstract:

The demand for environmentally responsible construction materials has accelerated research into alternatives to ordinary Portland cement–based concrete. Self-compacting geopolymer concrete (SCGC) has gained attention due to its low carbon footprint and excellent workability; however, its brittle nature, cracking susceptibility, and durability concerns under aggressive environments limit its wider application. This study presents the development of an ambient-cured fibre-reinforced self-compacting geopolymer concrete (FRSCGC) incorporating stainless steel fibres to enhance mechanical performance, dimensional stability, and resistance to chemical attacks. Fly ash and ground granulated blast furnace slag were used as aluminosilicate precursors, while a sodium-based alkaline activator facilitated geopolymerisation at room temperature. The durability performance of SCGC and FRSCGC was evaluated through sulphate resistance, acid resistance, rapid chloride permeability, drying shrinkage, and microstructural investigations. Experimental results demonstrated that the inclusion of stainless steel fibres significantly reduced mass loss, expansion, and permeability while improving compressive strength and ductility. Drying shrinkage was substantially reduced in FRSCGC compared to the control mix, indicating superior dimensional stability. Microstructural observations confirmed effective crack-bridging and a denser interfacial transition zone, contributing to enhanced durability. The outcomes highlight FRSCGC as a sustainable and durable material suitable for infrastructure exposed to aggressive environments.

Keywords: Self-compacting geopolymer concrete; stainless steel fibres; chemical durability; drying shrinkage; sustainable construction

1. Introduction

Concrete remains the backbone of modern infrastructure; however, its long-term durability is often compromised when exposed to aggressive environments such as sulphate-rich soils, acidic conditions, and chloride-laden marine atmospheres. Chemical ingress can trigger expansive reactions, leaching, and microstructural degradation, leading to cracking and premature failure of structures. Although ordinary Portland cement concrete is widely used, its vulnerability to chemical attack and high carbon emissions have driven the search for sustainable alternatives.

Geopolymer concrete has emerged as a promising substitute due to its reduced greenhouse gas emissions and improved resistance to chemical deterioration. Nevertheless, conventional geopolymer systems frequently require heat curing and mechanical vibration, limiting their field applicability. Recent developments in self-compacting geopolymer concrete combine the advantages of geopolymer binders with the superior flowability of self-compacting concrete, enabling placement without vibration under ambient curing conditions. Despite these benefits, SCGC still exhibits brittle behaviour and susceptibility to cracking, particularly under chemical exposure.

Fibre reinforcement has been widely recognised as an effective approach to enhance ductility and crack control in cementitious composites. Among various fibre types, stainless steel fibres offer high tensile strength and excellent corrosion resistance, making them suitable for aggressive environments. This study aims to develop a high-strength, ambient-cured FRSCGC incorporating stainless steel fibres and to systematically evaluate its durability and mechanical performance in comparison with conventional SCGC.

2. Materials and Mix Proportions

Fly ash and ground granulated blast furnace slag were used as the primary binder materials to promote ambient curing and achieve adequate early-age strength. Natural river sand and crushed gravel served as fine and coarse aggregates, respectively. A sodium hydroxide and sodium silicate solution was adopted as the alkaline activator system. Hooked-end stainless steel fibres of micro and macro lengths were incorporated to improve crack resistance and post-peak behaviour.

The mix design was optimised to ensure high flowability and stability required for self-compacting behaviour. A hybrid fibre dosage of 2% by volume, consisting of equal proportions of micro and macro fibres, was selected to balance workability and mechanical enhancement.

Table 1. Materials and Mix Proportions

Mix ID	Fly Ash (kg/m³)	GGBS (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Activator/Binder Ratio	Steel Fibres (%)
SCGC	350	150	720	780	0.45	0.0
FRSCGC	350	150	710	760	0.45	2.0

3. Experimental Program

3.1 Workability and Mechanical Testing

Fresh-state behaviour of the developed concretes was evaluated through slump flow diameter, T500 flow time, and J-ring passing ability tests to confirm self-compacting performance. These tests ensured adequate filling ability, flowability, and resistance to segregation. Compressive strength was determined using cylindrical specimens after 28 days of ambient curing to assess the load-bearing capacity of both mixes.

Table 2. Mechanical Properties

Mix	28-day Compressive Strength (MPa)
SCGC	48.2
FRSCGC	56.8

3.2 Durability Assessment

Durability characteristics were investigated using sulphate resistance, acid resistance, rapid chloride permeability, and drying shrinkage tests. Specimens were exposed to aggressive chemical environments for an extended duration to simulate severe service conditions. Changes in mass, dimensional stability, ultrasonic pulse velocity, and stress–strain response were recorded to evaluate degradation mechanisms.

3.3 Microstructural Analysis

Scanning electron microscopy was used to examine the internal morphology and fibre–matrix interaction before and after chemical exposure. Emphasis was placed on crack development, pore distribution, and the integrity of the interfacial transition zone.

4. Results and Discussion

4.1 Workability and Strength

The incorporation of stainless steel fibres resulted in a marginal reduction in flowability; however, all fibre-reinforced mixes satisfied the acceptance criteria for self-compacting concrete. The observed increase in flow resistance was attributed to fibre interlocking and increased internal friction. Despite this, uniform filling and passing ability were maintained without segregation.

Fibre-reinforced specimens exhibited enhanced compressive strength compared to the control mix. The improvement was primarily associated with the crack-bridging action of stainless steel fibres and improved stress transfer across microcracks.

4.2 Sulphate and Acid Resistance

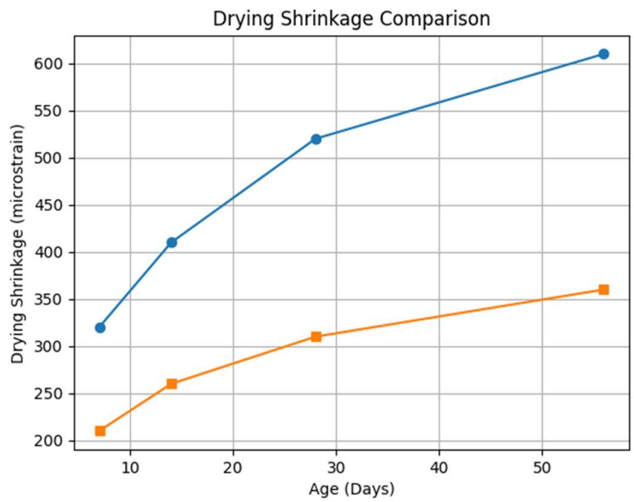
Fibre-reinforced specimens demonstrated superior resistance to sulphate and acid environments compared to the control mix. Reduced surface deterioration, lower expansion, and diminished mass loss were observed in FRSCGC specimens throughout the exposure period.

Ultrasonic pulse velocity measurements further confirmed the enhanced internal integrity of fibre-reinforced mixes. FRSCGC retained higher pulse velocity values, suggesting limited microstructural damage.

4.3 Chloride Penetration and Drying Shrinkage

Rapid chloride permeability results indicated a substantial reduction in ionic charge passed through FRSCGC specimens, reflecting a denser and less permeable matrix. Fibre reinforcement effectively restricted crack formation, thereby limiting pathways for chloride ingress.

Drying shrinkage measurements revealed that fibre-reinforced mixes experienced significantly lower shrinkage strains throughout the monitoring period. Stainless steel fibres restrained volumetric contraction by bridging microcracks and redistributing tensile stresses.



4.4 Microstructural Observations

SEM analysis confirmed a denser geopolymer matrix and enhanced interfacial transition zone in FRSCGC. Fibres bridged microcracks and delayed crack coalescence, contributing to improved durability and toughness.

5. Conclusions

This study demonstrated that stainless steel fibre reinforcement significantly enhances the mechanical and durability performance of self-compacting geopolymer concrete cured under ambient conditions. The developed FRSCGC exhibited improved strength, reduced shrinkage, and superior resistance to sulphate, acid, and chloride attacks. The findings support the potential application of FRSCGC as a sustainable and durable construction material for infrastructure in aggressive environments.

References

1. Verma, P., Dhurvey, P., & Sundramurthy, V. P. (2022). Structural Behaviour of Metakaolin Geopolymer Concrete Wall-Type Abutments with Connected Wing Walls. Advances in Materials Science and Engineering, 2022(1), 6103595.
2. Verma, P., Dhurvey, P., & Sundramurthy, V. P. (2022). Potential Assessment of E-Waste Plastic in Metakaolin Based Geopolymer Using Petrography Image Analysis. Advances in Materials Science and Engineering, 2022.
3. Verma, P., Dhurvey, P., & Gour, C. P. (2023). Utilization of E-Waste as Coarse Aggregates in Geopolymer Concrete. In Sustainable Approaches and Strategies for E-Waste Management and Utilization (pp. 224–238). IGI Global.
4. Dhurvey, P., Panthi, H., Verma, P., & Gour, C. P. (2023). Utilization of Waste Ceramic Tiles as Coarse Aggregates in Concrete. In Waste Recovery and Management (Vol. 1, p. 12). CRC Press, Taylor and Francis.
5. Dhurvey, P., Verma, P., & Gour, C. P. (2022, December 22). SOIL COMPACTNESS ANALYSER. IN Patent 120,837.
6. Dhurvey, P., Verma, P., & Gour, C. P. (2023, April 13). CONCRETE MIXER ANALYSING DEVICE. IN Patent 133,127.
7. Dhurvey, P., Verma, P., & Gour, C. P. (2023, June 1). CONSTRUCTION MATERIAL FINENESS ANALYSER. IN Patent 138,639.
8. Sahu, S., Dhurvey, P., Verma, P., Rahim, J., & Bhargav, A. (2023). Behaviour Analysis of Layered Beam Using ANSYS. 135–142.
9. Verma, P. (2024). CONCRETE MIX DESIGN. Godfather Print System.
10. Verma, P. (2024). CONCRETE LABORATORY USER MANUAL. Godfather Print System.
11. Singh, A., Raikwar, S., Dhurvey, P., Verma, P., & Gour, C. P. (2022). Comparative Analysis of Drying Shrinkage of Cement Mortar with Varying Ratio of Fly Ash. The Institution of Engineers (India).
12. Verma, P. (2023). Exploring the Foundations of Civil Engineering: Building the World Around Us. AGROSPHERES E-Newsletter, 4(11), 77–78.
13. Verma, P. (2023). The Role of Civil Engineering in Shaping the Modern World. AGROSPHERES E-Newsletter, 4(11), 79–80.
14. Verma, P. (2023). Advancements in Civil Engineering: Building a Sustainable Future. AGROSPHERES E-Newsletter, 4(11), 81–82.
15. Verma, P. (2023). Next-Gen Transportation: Civil Engineering Innovations Shaping the Future of Mobility. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(11), 68–69.
16. Verma, P. (2023). Reshaping Urban Landscapes: Green Infrastructure in Civil Engineering. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(11), 70–71.
17. Verma, P. (2023). Smart Cities: The Integration of Technology and Civil Engineering for Urban Transformation. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(11), 72–73.
18. Verma, P. (2023). Resilient Infrastructure: Adapting Civil Engineering to Climate Challenges. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(11), 74–75.
19. Verma, P. (2023). Smart Infrastructure Resilience: Civil Engineering Strategies for Megacity Challenges. SUNSHINE AGRICULTURE E-Newsletter, 3(11), 67–68.
20. Verma, P. (2023). Resilient Urbanization: Civil Engineering Strategies for Sustainable Megacities. SUNSHINE AGRICULTURE E-Newsletter, 3(11), 65–66.
21. Verma, P. (2023). Smart Infrastructure: Civil Engineering's Role in Building Intelligent Cities. SUNSHINE AGRICULTURE E-Newsletter, 3(11), 63–64.
22. Verma, P. (2023). Revolutionizing Urban Mobility: The Role of Civil Engineering in Sustainable Transportation. AGROSPHERES E-Newsletter, 4(12), 38–39.

23. Verma, P. (2023). Digital Twins and the Future of Civil Engineering: Transforming Design, Construction, and Operation. AGROSPHERES E-Newsletter, 4(12), 40–41.
24. Verma, P. (2023). Innovative Materials in Civil Engineering: Paving the Way for Sustainable Infrastructure. AGROSPHERES E-Newsletter, 4(12), 42–43.
25. Verma, P. (2023). Next-Generation Construction Techniques: Robotics and Automation in Civil Engineering. AGROSPHERES E-Newsletter, 4(12), 44–45.
26. Verma, P. (2023). Sustainable Water Management: Civil Engineering Solutions for a Thirsty World. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(12), 29–30.
27. Verma, P. (2023). Earthquake-Resilient Infrastructure: Advancements in Civil Engineering for Seismic Safety. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(12), 31–32.
28. Verma, P. (2023). Bridging the Future: Innovations in Civil Engineering for Sustainable and Resilient Bridges. CURRENT AGRICULTURE TRENDS E-Newsletter, 2(12), 33–34.
29. Verma, P. (2023). Inclusive Megacities: Civil Engineering Strategies for Diverse and Accessible Urban Environments. SUNSHINE AGRICULTURE E-Newsletter, 3(12), 33–34.
30. Verma, P. (2023). Smart Resilience: Civil Engineering Strategies for Adaptable Megacities. SUNSHINE AGRICULTURE E-Newsletter, 3(12), 31–32.
31. Verma, P. (2023). Circular Urbanization: Civil Engineering Strategies for Sustainable Megacities. SUNSHINE AGRICULTURE E-Newsletter, 3(12), 28–30.
32. Verma, P., Dhurvey, P., & Sundramurthy, V. P. (2022). Research Article Structural Behaviour of Metakaolin Geopolymer Concrete Wall-Type Abutments with Connected Wing Walls.
33. Verma, P., Dhurvey, P., & Sundramurthy, V. P. (2022). Research Article Potential Assessment of E-Waste Plastic in Metakaolin Based Geopolymer Using Petrography Image Analysis.
34. Mishra, G. S., Tiwari, M., Verma, P., Hoonka, V., Khare, A., & Sirbaiya, B. (2022). Incorporating Nano-Silica (NS) into Concrete Mixtures. IJMRSET, 5(1), 204–208.
35. Hoonka, V., Tiwari, M., Verma, P., Mishra, G. S., Khare, A., & Sirbaiya, B. (2022). Comprehensive Management and Community Engagement in Biomedical Waste Disposal. IJMRSET, 5(2), 425–427.
36. Hoonka, V., Tiwari, M., Verma, P., Mishra, G. S., Khare, A., & Sirbaiya, B. (2022). Optimizing Energy Efficiency in High-Rise Buildings. IJMRSET, 5(3), 358–360.
37. Verma, P., Tiwari, M., Hoonka, V., Mishra, G. S., & Sirbaiya, B. (2022). Analysis of Layered Beam Behavior with ANSYS. IJMRSET, 5(4), 668–673.
38. Tiwari, M., Verma, P., Hoonka, V., Mishra, G. S., Khare, A., & Sirbaiya, B. (2022). Strength of Steel Fiber Concrete Using Coal Fly Ash and Silica Fume. IJMRSET, 5(5), 932–938.
39. Verma, P., Tiwari, M., Hoonka, V., Mishra, G. S., & Sirbaiya, B. (2022). Comparative Study of Drying Shrinkage in Mortar with Different Cement-To-Fly Ash Ratios. IJMRSET, 5(6), 1903–1907.
40. Tiwari, M., Verma, P., Hoonka, V., Mishra, G. S., Khare, A., & Sirbaiya, B. (2022). Comparative Analysis of Mechanical Properties with Partial Replacement of Cement. IJMRSET, 5(7), 1248–1253.
41. Tiwari, M., Verma, P., Mishra, G. S., Khare, A., & Sirbaiya, B. (2025). Sustainable Urban Development through Circular Urbanization. IJRAR, 12(3), 470–473.
42. Verma, P., Tiwari, M., Mishra, G. S., Khare, A., & Sirbaiya, B. (2025). Strength & Durability of E-Waste Metakaolin Geopolymer Concrete. IJRAR, 12(3), 474–481.
43. Baderia Global Institute of Engineering and Management Jabalpur et al. (2025). DEVICE TO PREDICT SOIL PROPERTIES FROM VOID RATIO & PARTICLE SIZE. IN Patent 221548.
44. Tiwari, M., Verma, P., Mishra, G. S., Sirbaiya, B., Khare, A., & Vyaspat, U. (2025). Metakaolin-Based Alkali-Activated and Hybrid Geopolymer Concrete. IJSIE, 2(12), 1220–1226.
45. Verma, P., Tiwari, M., Mishra, G. S., Sirbaiya, B., Khare, A., & Vyaspat, U. (2025). Fire Resistance of Cement-Based and Geopolymer Concrete. IJSIE, 2(12), 1227–1233.
46. Verma, P. (2026). Use of Recycled Aggregates in Sustainable Concrete Production. EDU Academic Incorporation.