Strength and Durability of characteristics of Fiber Reinforced self-Compaction Concrete

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Abstract

Self-Compacting Concrete (SCC) addresses the challenges of poor compaction in traditional concrete, offering superior flowability without mechanical vibration. However, SCC's higher cost, due to superplasticizers and high cement content, can be mitigated using Supplementary Cementitious Materials (SCMs) like fly ash and silica fume. SCMs improve the mechanical strength and durability of concrete by refining its pore structure. Ternary blended concrete (TBC), combining two SCMs as partial cement replacements, optimizes these benefits while addressing individual SCM limitations.

Despite its advantages, SCC has poor tensile strength, impact resistance, and brittleness. Adding glass fibers, which enhance mechanical properties and reduce shrinkage cracks, mitigates these issues. This study evaluated the fresh, mechanical, and durability properties of TBC blends and glass fiber-reinforced SCC. Among the tested blends, TBC9, comprising 70% Ordinary Portland Cement, 20% fly ash, and 10% silica fume, demonstrated superior mechanical and durability properties.

Introducing alkali-resistant glass fibres to TBC9 improved splitting tensile strength by 17% and increased energy absorption, though higher fiber content reduced compressive strength. Overall, the optimal TBC9 blend with glass fibers enhanced SCC's tensile and impact strengths while maintaining workability and durability. These findings highlight the potential of TBC and fiber reinforcement to advance SCC applications in construction.

Key Words: *Self-Compacting Concrete (SCC), Ternary Blended Concrete (TBC), Supplementary Cementitious Materials (SCMs), Glass Fiber, Durability, Mechanical Properties, Workability.*

1.INTRODUCTION

Self-Compacting Concrete (SCC) is an innovative type of concrete that flows under its own weight without requiring mechanical vibration, ensuring uniform compaction even in heavily reinforced or complex structural elements. Introduced in Japan during the late 1980s to address challenges such as poor compaction and labor shortages, SCC has gained prominence worldwide due to its ease of placement and enhanced durability. SCC's ability to flow through congested reinforcement zones without segregation is attributed to its unique mix design, which incorporates a higher percentage of fine aggregate relative to coarse aggregate [1]. The mix design is further optimized using superplasticizers and viscosity-modifying agents to achieve filling ability, passing ability, and segregation resistance [2].

Although SCC offers several advantages, such as reduced noise pollution during placement and suitability for intricate architectural structures, its high cementitious content contributes to increased costs [3]. Supplementary Cementitious Materials (SCMs) like fly ash and silica fume are often used to partially replace cement, reducing costs and improving durability. Fly ash, a by-product of coal combustion, and silica fume, derived from the silicon industry, contribute to pore refinement, strength enhancement, and environmental sustainability [4, 5,6].

Additionally, the inclusion of fibers, such as alkali-resistant glass fibers, addresses SCC's inherent brittleness, low tensile strength, and poor impact resistance. These fibers improve mechanical properties and restrict crack propagation but must be optimally dosed to maintain SCC's workability [6,7,8]. This study investigates the formulation of ternary blended SCC incorporating SCMs and fibers to improve the material's mechanical and durability properties while minimizing costs and addressing environmental concerns [9,10].

1.1SCOPE OF THE WORK

The development of ternary blended self-compacting concrete (SCC) with additional cementitious elements is the main goal of this work. The goal is to decrease carbon dioxide emissions and improve the durability of concrete by substituting some of these components for cement. In addition to reducing maintenance expenses, ternary mixed SCC increases the longevity of structures. Fibers are incorporated into the ternary mixed SCC to mitigate the natural brittleness of concrete. Glass fibers are added to increase impact and tensile strength. Research on the new, mechanical, durability, micro structural, and flexural properties of fiber-reinforced ternary blended SCC is, however, lacking. Thus,it is imperative to investigate the mechanical and durability properties of such concrete.

1.2 OBJECTIVES OF THE WORK

1. To obtain the suitable mix proportion for the self-compacting concrete with proper selection of materials.

2. To study the fresh properties of ternary blended self-compacting concrete and glass fiber reinforced ternary blended self-compacting concrete.

3. To carry out an experimental investigation to determine the compressive strength, flexural strength, split tensile strength modulus of elasticity and impact strength of ternary blended SCC specimens.

4. To perform the water absorption test, porosity, Rapid Chloride Permeability Test (RCPT) to study the durability properties of the ternary blended SCC mixes. strength, flexural strength, split tensile strength modulus of elasticity and impact strengthof ternary blended SCC specimens.

5. To perform the water absorption test, porosity, Rapid Chloride Permeability Test (RCPT) to study the durability properties of the ternary blended SCC mixes.

2.THEORY AND METHODOLOGY

The methodology of the present study is illustrated in Figure 1.1. Initially, an extensive literature review was conducted, followed by the collection and evaluation of material properties. The mix proportions for ternary blended self-compacting concrete (SCC) were developed after determining the SCC mix design using IS: 10262-2019 standards. Through mechanical and durability analyses, the optimal mixture for ternary blended SCC was identified. Subsequently, glass fibers were incorporated into the optimized ternary blended SCC mix. Finally, experimental research was conducted to examine the microstructural and flexural properties of the glass fiber-reinforced ternary blended SCC.

Selection of Supplementary Cementitious Materials

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Determination of the materials properties

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Mix Design

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Fresh, mechanical and durability properties of TBC mixes

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Identification of optimized ternary blended SCC mix

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Determination of the effects of glass fiber on the optimized ternary blended SCC

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Mix by various fractions.

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Conclusion

Fig 1.1 Research methodology

3. Materials Used in Mix Proportions

Cement: For this study, 53-grade Ordinary Portland Cement (OPC) was utilized, meeting the specifications outlined in IS: 12269-2013. The cement exhibited a specific gravity of 3.12 and a consistency of 31%. Its initial and final setting times were recorded at 42 minutes and 220 minutes, respectively, conforming to IS standards. The OPC's fineness was determined using a Blaine-type air permeability apparatus, ensuring compliance with IS: 4031 (Part 2)–1999. Its chemical composition includes 20.56% SiO_2 and 62.54% CaO, among other components, which are critical for achieving. desired mechanical properties in concrete.

Fine Aggregate: River sand with a specific gravity of 2.62 and a fineness modulus of 2.6 was used as fine aggregate, adhering to the IS: 383-2016 Zone II grading requirements. Its bulk density was 1698 kg/m^3. A sieve analysis confirmed compliance with the grading limits for Zone II, ensuring suitability for SCC by enabling proper flow and compaction without segregation.

Coarse Aggregate: Crushed granite with a maximum particle size of 12.5 mm served as the coarse aggregate, following IS: 383-2016 guidelines. Its specific gravity was measured at 2.67, with a bulk density of 1724 kg/m^3. The aggregate impact and crushing values were determined as 12.2% and 21.6%, respectively, indicating its suitability for producing durable SCC.

Water: Portable drinking water was used for mixing, meeting the quality requirements specified in IS: 456-2000. It had a pH value of 7.8, a chloride content of 126 mg/l, and total dissolved solids of 160 mg/l, all well within permissible limits to ensure optimal hydration and minimal adverse effects on the concrete's properties.

Fly Ash: Class F fly ash, a by-product of coal-fired power plants, was incorporated as a supplementary cementitious material. With a specific gravity of 2.12 and a fineness of 517 m^2/kg, the fly ash contributed to pore refinement and durability enhancement. Its chemical composition included 58.23% SiO_2 and 25.35% Al_2O_3, aligning with ASTM C 618-1992 standards.

Silica Fume: Silica fume, a by-product of the silicon industry, was used for its exceptional pozzolanic reactivity and fineness of 20,000 m^2/kg. It had a specific gravity of 2.26 and a chemical composition dominated by 94.4% SiO_2. Silica fume enhances concrete's durability and mechanical properties by refining pore structure and increasing early-age compressive strength.

Chemical Admixture: A Poly carboxylic ether-based superplasticizer was utilized to improve SCC's flow and workability. With a specific gravity of 1.22 and a recommended dosage of 0.6–1.5 liters per 100 kg of cement, this admixture ensured adequate filling and passing abilities, critical for achieving self-compaction without segregation.

Glass Fiber: Alkali-resistant glass fibres with a filament diameter of 14 microns and a length of 12 mm were added to the optimized SCC mix. The fibres had a specific gravity of 2.68 and a modulus of elasticity of 72 GPa, contributing to improved tensile strength, crack resistance, and durability of the final concrete product.

3.1 MIX PROPORTIONS OF SCC

M30-grade SCC was prepared per IS: 10262-2019 and validated against EFNARC-2005 standards for flowability and segregation resistance. Sixteen mixes used varying fly ash and silica fume replacements, keeping water, coarse, and fine aggregates constant. The superplasticizer dosage was optimized at 2.0% of powder content.

Table .1 Mix proportions

	Cement	Fine aggregate	Coarse aggregate	Water
Weight (kg/m^3)	514	908	785	204
Mix Proportion	1	1.76	1.52	0.4

NM: Normal SCC mix (OPC 100%).
TBC1: 85% OPC + 10% Fly Ash (F) + 5% Silica Fume (SF).
TBC2: 82.5% OPC + 10% F + 7.5% SF.
TBC3: 80% OPC + 10% F + 10% SF.
TBC4: 80% OPC + 15% F + 5% SF.
TBC5: 77.5% OPC + 15% F + 7.5% SF.
TBC6: 75% OPC + 15% F + 10% SF.
TBC7: 75% OPC + 20% F + 5% SF.
TBC8: 72.5% OPC + 20% F + 7.5% SF.
TBC9: 70% OPC + 20% F + 10% SF.
TBC10: 70% OPC + 25% F + 5% SF.
TBC11: 67.5% OPC + 25% F + 7.5% SF.
TBC12: 65% OPC + 25% F + 10% SF.
TBC13: 65% OPC + 30% F + 5% SF.
TBC14: 62.5% OPC + 30% F + 7.5% SF.
TBC15: 60% OPC + 30% F + 10% SF. **GFTBC1**: TBC9 + 0.2% Glass Fiber (GF).**GFTBC2**: TBC9 + 0.4% GF.
GFTBC3: TBC9 + 0.6% GF.
GFTBC4: TBC9 + 0.8% GF.

4. Result analysis

4.1 slump

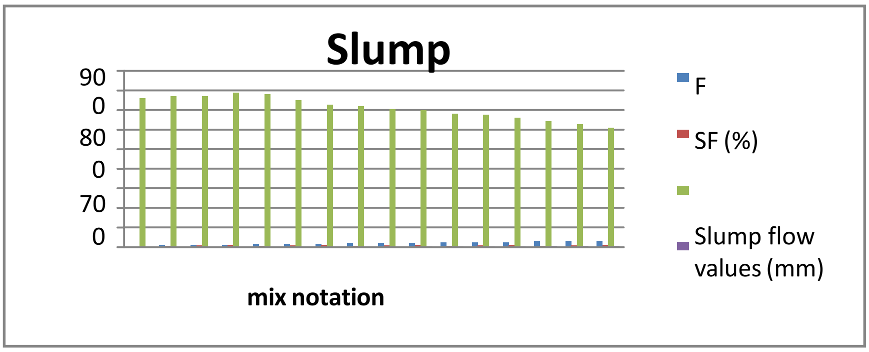

Fig.2 slump cone result

The slump flow of ternary blended SCC mixtures (TBC1-TBC15) ranged from 610–785 mm, meeting EFNARC-2005 standards. TBC3 (F10% + SF10%) achieved the highest flow (788 mm). Optimal blend TBC9, selected for durability and performance, was tested with 0.2–0.8% glass fibers, maintaining workability and enhancing T500 mm durations (2–5 seconds).

4.2 Compressive strength result:

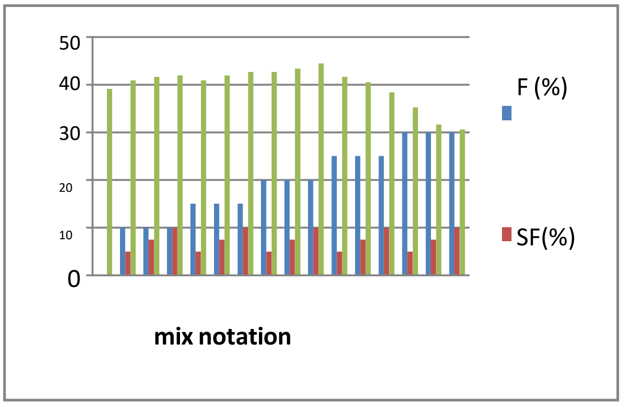

Fig.3 compressive strength for 28 days

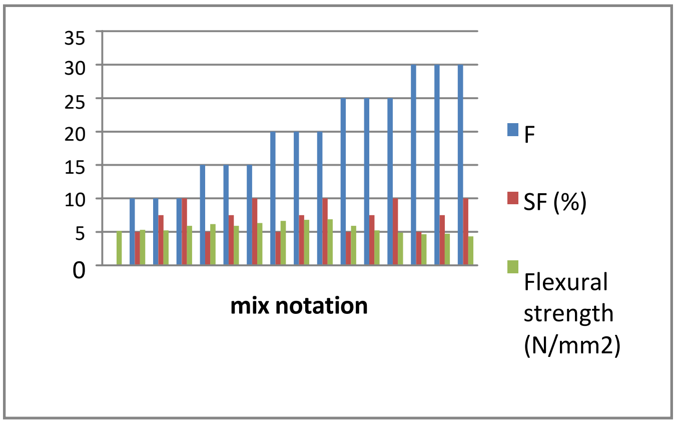

Fig.4 Flexural strength for 28 days

TBC8 and TBC9 demonstrated the highest flexural strength among blends, outperforming the standard SCC mix (NM). A strong correlation was observed between compressive and flexural strength, with TBC blends exhibiting a higher flexural strength increase. TBC9 exceeded NM by 34.38% in flexural strength, compared to a 13.64% improvement in compressive strength.

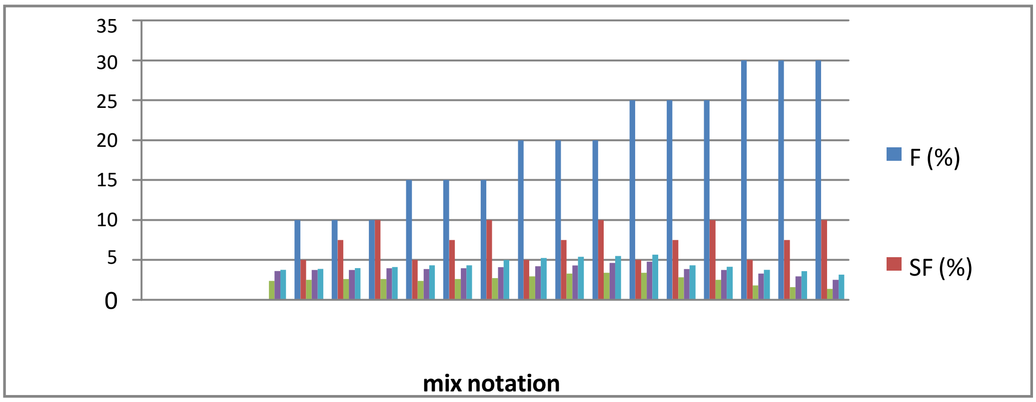

Fig.5. Split tensile strength

At 28 days, adding glass fiber to the optimal ternary blended SCC mix (TBC9) consistently enhanced splitting tensile strength. GFTBC4 showed an 11% increase over TBC9 and a 17% increase over GFTBC1. These findings align with prior research documenting similar strength improvements with glass fiber reinforcement in concrete.

5. Durability properties:

RCPT: The chloride ion penetration test revealed that all ternary blended SCC mixes (TBC1–TBC15) exhibited "very low" chloride permeability, with total charge passed ranging from 422 to 787 coulombs. TBC9 showed significantly reduced permeability (539 coulombs) compared to the standard SCC mix (NM), which recorded "low" permeability at 1121 coulombs.

Water absorption: Water absorption tests indicated minimal variation in initial and saturated water absorption across mixes. The optimal blend, TBC9, showed initial and saturated water absorption of 2.93% and 3.9%, respectively. Adding glass fibers slightly increased values, with GFTBC1 (0.2% GF) recording the highest saturated absorption at 3.98%. All results were within acceptable limits.

6.CONCLUSION

The study demonstrated that ternary blended SCC mixes (TBC1–TBC15) achieve superior performance in workability, strength, and durability compared to normal SCC (NM). TBC9 (20% fly ash, 10% silica fume) emerged as the optimal mix, meeting EFNARC-2005 workability standards and displaying the highest durability with minimal chloride ion permeability (539 coulombs) and acceptable water absorption. Adding glass fibers (0.2–0.8%) further enhanced splitting tensile strength, with GFTBC4 (0.8% GF) showing a significant 17% improvement over GFTBC1 (0.2% GF).

Strength analysis revealed a strong correlation between compressive and flexural strength, with TBC9 outperforming NM in flexural strength by 34.38% and compressive strength by 13.64%. Durability properties, including reduced permeability and low water absorption, validate TBC9's suitability for long-term applications. These results emphasize the effectiveness of combining supplementary cementitious materials and glass fibers for enhancing SCC properties, offering sustainable and durable concrete solutions for modern construction.

6.1 FUTURE OF WORK

Future work can focus on evaluating long-term durability of ternary blended SCC under harsh conditions, exploring microstructural behavior using SEM/XRD, and optimizing glass fiber proportions for dynamic properties like fatigue strength. Life cycle assessments, cost analysis, and testing alternative materials like GGBS or nano-silica could further enhance SCC's performance and sustainability.

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