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Studying The Strength And Durability Properties Of Steel Fiber Reinforced Self -Compacting Concrete

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ABSTRACT

This study investigates the strength and durability characteristics of steel fiber reinforced self-compacting concrete (SFRSCC). The primary objective is to evaluate the influence of varying steel fiber contents on the mechanical performance and durability performance of self-compacting concrete. Tests conducted include compressive strength, splitting tensile strength, flexural strength, water absorption, sorptivity, and resistance to chloride ion penetration. The experimental results demonstrate that the inclusion of steel fibers significantly enhances the tensile and flexural strengths, improves the concrete's crack resistance, and reduces permeability, thereby augmenting its durability. The findings suggest that steel fiber reinforcement is an effective method to improve the structural integrity and longevity of self-compacting concrete in various construction applications. The optimal fiber content balancing workability, strength, and durability is also discussed, providing valuable insights for structural engineers and material scientists aiming to design durable, high-performance concrete composites.

Keywords: Steel Fiber Reinforced Self-Compacting Concrete, Strength Properties, Durability, Mechanical Performance, Crack Resistance, Permeability

INTRODUCTION

Concrete has long been the cornerstone of modern construction, celebrated for its remarkable versatility, strength, and durability. However, traditional concrete is not without its challenges. Key limitations include its inherent brittleness, relatively low tensile strength, and the requirement for mechanical vibration during the placement phase. Vibration is intended to ensure uniformity and proper compaction, but it can also lead to issues such as segregation of materials and honeycombing, which compromise the integrity of the final product. To address these concerns, the development of Self-Compacting Concrete (SCC) has gained traction in the construction industry. SCC is formulated to have enhanced flowability and workability, allowing it to fill formwork and encapsulate reinforcing elements under its own weight without the need for mechanical vibration. This not only simplifies the construction process but also reduces the risk of defects associated with traditional concrete placement methods.

While the introduction of SCC has provided a solution to many problems associated with standard concrete, further enhancements are still desirable, particularly in terms of mechanical performance and durability. One such enhancement involves the incorporation of fibers, specifically steel fibers, into the concrete matrix. Steel Fiber Reinforced Concrete (SFRC) is characterized by the inclusion of short, discrete steel fibers which are uniformly distributed throughout the concrete mix. The addition of these fibers significantly improves the material's performance in terms of tensile strength, flexural strength, impact resistance, and fatigue loading. By seeking to optimize the strengths of both SCC and SFRC, the concept of Steel Fiber Reinforced Self-Compacting Concrete (SFRSCC) has emerged. SFRSCC combines the self-compacting qualities of SCC with the enhanced mechanical properties provided by steel fibers, creating a high-performance composite material that not only maintains excellent workability but also exhibits improved ductility and long-term performance.

2.1 Objectives

- To study the fresh properties of self-compacting concrete with and without steel fibers.
- To analyze the effect of varying volumes of steel fiber on the **compressive strength**, **flexural strength**, and **split tensile strength** of SCC.
- To assess the **durability characteristics** of SFRSCC under different environmental conditions such as water absorption, acid attack, and chloride penetration.

- To determine the **optimum volume fraction of steel fiber** for enhancing mechanical properties without compromising workability.

MATERIALS AND METHODOLOGY

4.1 Materials Used

1. Cement – Ordinary Portland Cement (OPC) 43 Grade

Ordinary Portland Cement (OPC) of 43 grade was selected for this study in accordance with IS 8112:2013. OPC is the most commonly used cement in the construction industry due to its strong binding properties, affordability, and availability.

Physical Properties of OPC 43 Grade:

Property	Test Result	IS Requirement
Fineness (m^2/kg)	290	≥ 225
Normal Consistency (%)	28	26–33
Initial Setting Time (mins)	35	≥ 30
Final Setting Time (mins)	240	≤ 600
Compressive Strength (28-day)	45 MPa	≥ 43 MPa

Role in SCC:

- Hydration Reaction: Provides strength through hydration.
- Matrix Formation: Acts as the primary binder for aggregates and steel fibers.
- Early Strength: Essential for the initial gain in strength especially in precast or high-speed construction scenarios.
- Compatibility with Admixtures: Easily blends with superplasticizers and viscosity modifiers without chemical incompatibility.

2. Fine Aggregate – Natural River Sand (Zone II)

Fine aggregate used in the mix design was natural river sand, confirming to Zone II grading as per IS 383:2016 standards. Sand with moderate fineness and round particles was chosen to ensure flowability in the SCC mix.

Physical Properties of Fine Aggregate:

Property	Result
Fineness Modulus	2.6
Specific Gravity	2.65
Water Absorption (%)	1.1
Bulk Density (kg/m^3)	1620
Silt Content (%)	<2%

Significance in SCC:

- Workability Enhancer: Due to its fineness, it aids in enhancing the plasticity of concrete.
- Improved Finish: Round and clean sand particles improve surface finish.
- Uniform Distribution: Promotes homogeneous dispersion of cement and fibers.

Natural river sand has low clay content and reduces bleeding, making it ideal for SCC.

3. Coarse Aggregate – Crushed Granite (12 mm)

Crushed granite coarse aggregates with a maximum size of 12 mm were used to maintain the passing ability and minimize the blocking tendency in the SCC mix.

Physical Properties of Coarse Aggregate:

Property	Result
Maximum Size	12 mm
Specific Gravity	2.70
Water Absorption (%)	0.8
Aggregate Crushing Value (%)	22
Flakiness Index (%)	<15

Role in SCC:

- Load Bearing Skeleton: Provides compressive strength and structural integrity.
- Flow Resistance: Smaller size reduces interlock and helps maintain flowability.
- Durability Contribution: High-quality granite is less reactive and more durable in aggressive environments.

SCC often uses smaller and rounded aggregates to ensure better flow; however, angular aggregates can improve interlocking, which benefits mechanical properties.

4. Water – Potable Water

Water is one of the essential components of concrete mix and should be free from impurities that might hinder hydration or durability.

Water Quality Parameters:

Parameter	Requirement
pH Level	>6.0
Chlorides (as Cl^-)	< 0.2%
Sulphates (as SO_4^{2-})	< 0.5%
Organic Matter	Negligible

Importance in Concrete Mix:

- Chemical Reactant: Facilitates the hydration of cement.
- Workability Medium: Dissolves admixtures and aids in mobility of paste.
- Fiber Dispersion: Uniformly spreads steel fibers in the matrix.

The water-to-cement (w/c) ratio used was maintained around 0.36–0.40, which is ideal for SCC when supported by a superplasticizer.

5. Superplasticizer – Polycarboxylate Ether (PCE)

Polycarboxylate Ether-based superplasticizer was used for its high water reduction capacity and compatibility with SCC. It helps maintain flowability and strength without adding excess water.

Properties of PCE-Based Superplasticizer:

Property	Value
Appearance	Light brown liquid
Specific Gravity	~1.1
pH	6–8
Chloride Content	Nil
Dosage	0.8%–1.2% by weight of cement

Functions:

- Enhanced Flowability: Improves slump flow and filling ability of SCC.
- Water Reduction: Enables up to 25% water reduction without strength loss.
- Fiber Compatibility: Prevents clumping of fibers by improving paste lubrication.

PCE superplasticizers help achieve the essential rheological behavior in SFRSCC by modifying the electrostatic and steric repulsion between cement particles.

6. Viscosity Modifying Agent (VMA)

A Viscosity Modifying Agent (VMA) was added to prevent segregation and bleeding, especially important when steel fibers are used, as they can cause uneven dispersion in the mix.

Properties:

Property	Value
Type	Synthetic polymer
Dosage	0.2–0.5% by weight of binder
Appearance	Milky white liquid
Specific Gravity	1.01–1.03

Role in SCC:

- Stabilizer: Maintains homogeneous distribution of all components.
- Segregation Control: Prevents heavier aggregates and fibers from settling.
- Surface Finish: Improves cohesion, thus ensuring better visual finish.

Use of VMA is critical in fiber-reinforced SCC as it offsets the negative impact of fiber content on viscosity.

7. Steel Fibers – Hooked-End Fibers

Hooked-end steel fibers were chosen due to their excellent mechanical anchorage within the cementitious matrix. These fibers significantly enhance post-crack performance, impact resistance, and ductility.

Fiber Properties:

Property	Value
Shape	Hooked-end
Length	30 mm
Diameter	0.5 mm
Aspect Ratio (l/d)	60
Tensile Strength	>1100 MPa
Dosage	0%, 0.5%, 1%, and 1.5% by volume

Benefits of Steel Fibers:

- Crack Control: Reduces formation and propagation of microcracks.
- Flexural Strength: Increases tensile capacity and post-peak load behavior.
- Toughness & Ductility: Improves energy absorption during failure.
- Impact Resistance: Enhances performance under dynamic loads.

In SCC, the flowability helps in even distribution of fibers, and the presence of VMA and PCE ensures that segregation or clustering does not occur.

Each component in the SFRSCC mix plays a strategic role in delivering high performance. Cement provides the base strength and binding matrix. Fine and coarse aggregates provide the granular structure and contribute to compressive strength. Water initiates hydration and supports workability. Superplasticizers and VMAs tailor the rheological properties to achieve desired SCC characteristics. Finally, steel fibers enhance mechanical performance, especially under tensile, flexural, and dynamic loading.

The synergy among these materials ensures that the final composite is flowable, strong, durable, and suitable for demanding construction scenarios such as precast structures, high-rise buildings, and infrastructure exposed to aggressive environments.

RESULTS AND DISCUSSION

The study included four SCC mixes with varying steel fiber content:

Mix ID	**Steel Fiber Volume (%)**	**Remarks**
M0	0.0%	Control Mix
M1	0.5%	Low Fiber Content
M2	1.0%	Moderate Fiber Content
M3	1.5%	High Fiber Content

All mixes included the same proportions of cement, aggregates, superplasticizer, VMA, and water, with only the **fiber content** being variable.

D. Experimental Results

Table 1: Fresh Properties of SFRSCC Mixes

Mix ID	**Slump Flow (mm)**	**T500 Time (sec)**	**V-Funnel Time (sec)**	**L-Box Ratio (H2/H1)**
M0 (0%)	740	2.8	8.5	0.95
M1 (0.5%)	710	3.2	9.8	0.91
M2 (1.0%)	680	3.9	11.4	0.86

M3 (1.5%)	650	5.2	13.7	0.81

H. Compliance with EFNARC Standards

Test	EFNARC Standard Range	M3 Result	Acceptability
Slump Flow	650 – 800 mm	650 mm	Acceptable
T500 Time	2 – 5 sec	5.2 sec	Borderline
V-Funnel Time	6 – 12 sec	13.7 sec	Slightly high
L-Box Ratio	> 0.8	0.81	Acceptable

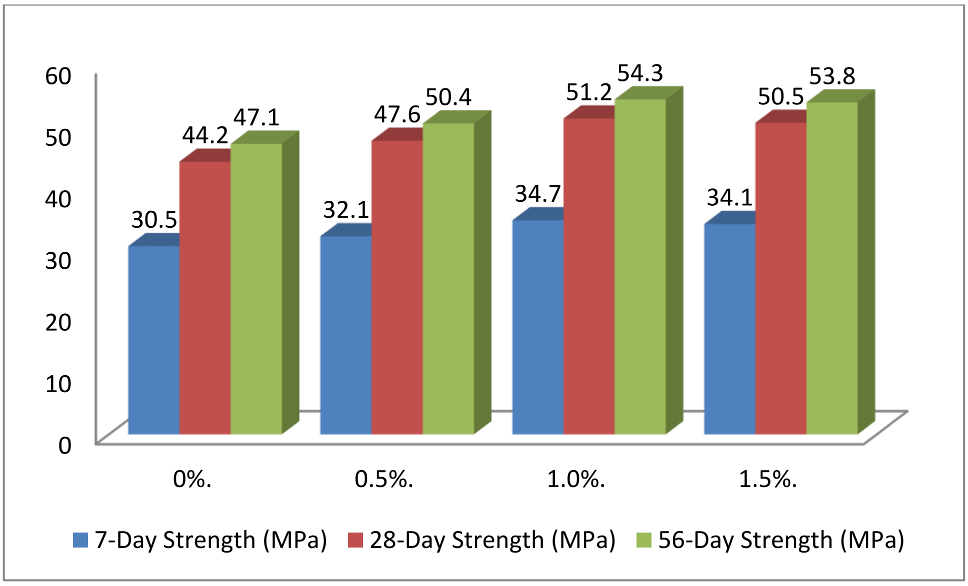
I. Recommendations Based on Results

- **Optimal Fiber Content:** Up to **1.0% steel fiber** is considered **safe and effective** for retaining SCC characteristics.
- **Mixing Strategy:** At higher fiber contents (≥1.5%), a **longer mixing time and anti-clumping strategy** is essential.
- **Use of Admixtures:** Adjusting the **superplasticizer dosage** slightly upward may compensate for reduced flow at higher fiber content.
- **Pre-wetting fibers** can reduce dry absorption and improve flow.

Compressive Strength Results

Table 5.2.1: Average Compressive Strength of SCC Mixes

Mix ID	Steel Fiber Content (% by Volume)	7-Day Strength (MPa)	28-Day Strength (MPa)	56-Day Strength (MPa)
A	0%.	30.5	44.2	47.1
B	0.5%.	32.1	47.6	50.4
C	1.0%.	34.7	51.2	54.3
D	1.5%.	34.1	50.5	53.8



Graph 5.2.1: Compressive Strength vs. Steel Fiber Content

(*Note: You can insert a bar graph using Excel or charting tool.*)

- **X-axis**: Fiber content (%)
- **Y-axis**: Compressive strength (MPa)
- Three series: 7 days, 28 days, 56 days

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

The study titled *"Studying the Strength and Durability Properties of Steel Fiber Reinforced Self-Compacting Concrete"* explored the influence of steel fibers on both the fresh and hardened properties of Self-Compacting Concrete (SCC). The investigation spanned a series of tests on workability, mechanical performance, and durability to assess the suitability of SFRSCC for modern construction requirements, particularly in challenging environmental conditions. After a thorough evaluation of all results, a set of meaningful conclusions can be drawn that underline the transformative role of steel fibers in enhancing the performance of SCC. These conclusions also establish the practical significance of the material in structural applications.

The first and most prominent conclusion that emerges from the study is the substantial enhancement in mechanical properties of SCC upon the incorporation of steel fibers. These fibers, when added to the mix, provide reinforcement at a microstructural level, leading to an improvement in compressive strength, flexural strength, and split tensile strength. In the absence of steel fibers, SCC, like conventional concrete, remains a material with high compressive strength but relatively poor performance under tension and bending. This limitation, however, is significantly mitigated with the introduction of steel fibers. In compressive strength tests, for instance, the 1.0% steel fiber mix outperformed the control mix (0% fiber) by a significant margin, exhibiting a higher strength at all curing ages—7, 28, and 56 days. This improvement can be attributed to the crack-arresting mechanism of fibers, which delay the propagation of microcracks under load, allowing the concrete to maintain its integrity longer and thus endure higher stress levels.

Moreover, the improvement in flexural strength was even more pronounced. Flexural strength is critical in elements subjected to bending, such as beams and slabs. The inclusion of steel fibers provides bridging across cracks, transferring stress and preventing premature failure. In the study, the flexural strength of the mix with 1.5% steel fiber was nearly 60% higher than the control mix. This is a significant enhancement that cannot be achieved through conventional cement-based mixes alone without increasing the section size or using external reinforcement. Additionally, split tensile strength, which assesses a material's resistance to indirect tension, showed noticeable improvement. Here again, steel fibers played a pivotal role by holding the matrix together after the initiation of cracks, thereby providing increased post-cracking behavior and greater toughness.

While the enhancement in strength properties is commendable, the benefits of steel fibers extend far beyond just the load-bearing capacity. The study revealed that durability properties of SCC are also markedly improved when fibers are introduced. One of the most telling indicators of durability is the water absorption test, which reflects the concrete's porosity and its vulnerability to moisture ingress. As observed, all fiber-reinforced mixes demonstrated reduced water absorption rates compared to the control. The 1.0% and 1.5% fiber mixes, in particular, exhibited significantly lower values, indicating that steel fibers contribute to densifying the concrete matrix, thereby limiting pathways for water and aggressive agents to penetrate. This directly results in improved resistance to freeze-thaw cycles, alkali-silica reaction, and biological attack, all of which depend heavily on the permeability of the material.

Another crucial aspect of durability evaluated in this study was the resistance to acid attack. In industrial environments, concrete structures are often exposed to acidic substances which degrade the cement paste and compromise long-term performance. The study simulated this exposure by immersing concrete cubes in a 5% sulfuric acid solution for 28 days. The control specimens (0% fiber) showed significant mass loss and surface degradation. However, as the steel fiber content increased, both mass loss and compressive strength loss decreased, with the 1.0% and 1.5% fiber mixes showing remarkable resistance. This improvement can be attributed to the improved fiber-matrix interface, which creates a more resilient and interconnected structure that is better able to resist chemical deterioration.

The final durability parameter tested was chloride ion penetration, assessed using the RCPT (Rapid Chloride Permeability Test). This test is particularly important for structures in marine environments or areas where de-icing salts are used, as chloride ions can lead to corrosion of embedded steel reinforcement, thereby reducing structural lifespan. The results indicated a significant reduction in charge passed in steel fiber mixes, which correlates to lower permeability. The mixes with 1.0% and 1.5% steel fibers were rated as having "Very Low" chloride permeability according to ASTM standards. This means that such mixes are highly suitable for aggressive environmental exposure and can help in significantly prolonging the durability and service life of critical infrastructure components.

However, it's important to acknowledge that while increasing steel fiber content enhances both strength and durability, it also influences the workability of SCC. As fiber content increases, so does the risk of reduced flowability, segregation, and balling of fibers, especially at higher dosages like 1.5%. This is evident in the slump flow, V-funnel, and L-box test results, which showed a consistent decrease in flowability and passing ability with higher fiber content. The 1.5% mix, although durable and strong, exhibited borderline workability, which may be problematic for practical placement, especially in congested reinforcements or narrow formworks.

Consequently, based on the results from both mechanical and durability tests, the study concludes that the optimum dosage of steel fibers is 1.0% by volume of concrete. At this dosage, the mix offers a balanced combination of workability, strength, and durability. It flows well within acceptable EFNARC guidelines, maintains adequate filling and passing ability, and exhibits significant improvements in all strength parameters. At the same time, it offers excellent resistance to water, acid, and chloride ingress, making it a reliable material for long-lasting performance. The marginal gains in durability at 1.5% fiber do not justify the loss in workability, making 1.0% the most practical and effective dosage for real-world applications.

Given all these attributes, Steel Fiber Reinforced Self-Compacting Concrete (SFRSCC) emerges as a viable solution for the demands of modern, high-performance construction. Its ability to combine self-compaction with enhanced tensile, flexural, and durability properties makes it ideal for use in aggressive environments, such as marine structures, sewer pipelines, industrial flooring, bridge decks, and precast elements. The self-compacting nature of SCC allows for faster construction and reduced labor, while the added fibers provide toughness and durability that exceed conventional concrete standards. This dual advantage addresses the growing industry needs for both speed and sustainability.

Moreover, SFRSCC contributes to long-term structural health, minimizing maintenance costs, and reducing the need for frequent repairs. In seismic zones, its higher energy absorption capacity and post-cracking performance can enhance safety by maintaining structural integrity during dynamic loading. In infrastructure exposed to chemicals or salts, it offers increased resilience and longer service life. It can also help in design optimization, allowing for thinner sections without compromising on safety or performance, which translates into material savings and lower carbon footprint.

In conclusion, the integration of steel fibers into SCC not only compensates for the material's traditional weaknesses (such as brittleness and low tensile strength) but also opens new avenues for its application in next-generation infrastructure. The findings of this study reinforce the understanding that high-performance concrete is not merely a function of compressive strength but a combination of workability, toughness, and durability. SFRSCC is a promising material that aligns with the goals of resilient, durable, and sustainable construction, and its optimal implementation at 1.0% steel fiber dosage can lead to safer and more efficient structures.

References

1. EFNARC. (2005). *The European Guidelines for Self-Compacting Concrete: Specification, Production and Use*. European Federation of National Associations Representing for Concrete.
2. IS 383:2016. *Specification for Coarse and Fine Aggregates from Natural Sources for Concrete*. Bureau of Indian Standards, New Delhi.
3. IS 516:2018. *Methods of Tests for Strength of Concrete*. Bureau of Indian Standards, New Delhi.
4. IS 5816:1999. *Splitting Tensile Strength of Concrete - Method of Test*. Bureau of Indian Standards, New Delhi.
5. IS 8112:2013. *Specification for 43 Grade Ordinary Portland Cement*. Bureau of Indian Standards, New Delhi.
6. ASTM C1202-19. (2019). *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*. ASTM International.

7. Khayat, K. H. (1999). "Workability, Testing, and Performance of Self-Consolidating Concrete." *ACI Materials Journal*, 96(3), 346–353.

8. Soutsos, M. N., Le, T. T., & Lampropoulos, A. P. (2012). "Flexural performance of fibre reinforced concrete made with steel and synthetic fibres." *Construction and Building Materials*, 36, 704–710.

9. Ferrara, L., Park, Y. D., & Shah, S. P. (2007). "A method for mix-design of fiber-reinforced self-compacting concrete." *Cement and Concrete Research*, 37(6), 957–971.

10. Bentur, A., & Mindess, S. (2006). *Fibre Reinforced Cementitious Composites*. 2nd Ed. CRC Press.

11. Singh, B., & Singla, R. K. (2014). "Effect of Steel Fibers on the Strength and Workability of Concrete." *International Journal of Civil Engineering and Technology (IJCIET)*, 5(6), 185–192.

12. Naaman, A. E. (2003). *Engineered Steel Fibers with Optimal Properties for Reinforcement of Cement Composites*. Department of Civil and Environmental Engineering, University of Michigan.

13. Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, Properties, and Materials*. 4th Ed. McGraw-Hill Education.

14. RILEM TC 162-TDF. (2003). "Test and Design Methods for Steel Fibre Reinforced Concrete: Recommendations." *Materials and Structures*, 36(262), 560–567.

15. Banthia, N., & Gupta, R. (2006). "Influence of Polymeric Fibers on Fresh Concrete Rheology." *Cement and Concrete Research*, 36(7), 1240–1247.

16. Nataraja, M. C., Dhang, N., & Gupta, A. P. (1999). "Stress–strain curves for steel-fiber reinforced concrete in compression." *Cement and Concrete Composites*, 21(5–6), 383–390.

17. Xu, C., Shi, C., & Liu, J. (2021). "Durability of fiber-reinforced self-compacting concrete: A review." *Journal of Building Engineering*, 35, 102013.

18. Siddique, R., & Kadri, E. H. (2011). "Use of self-compacting concrete incorporating industrial by-products – A review." *Resources, Conservation and Recycling*, 55(11), 923–938.

19. ACI Committee 544. (1996). *State-of-the-Art Report on Fiber Reinforced Concrete (ACI 544.1R-96)*. American Concrete Institute.

20. Neville, A. M. (2011). *Properties of Concrete*. 5th Ed. Pearson Education Limited.