

## EFFECT OF SILICA FUME AND STEEL FIBERS ON MECHANICAL AND DURABILITY PROPERTIES OF SELF-COMPACTING CONCRETE

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DOI: <https://doi.org/10.5281/zenodo.18604431>

### Keywords

Self-compacting concrete, silica fume, steel fibers, workability, J-ring, L-box, V-funnel, mechanical properties, compressive strength, tensile strength, flexural performance.

### Article History

Received: 18 November 2025

Accepted: 25 December 2025

Published: 27 January 2026

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### Abstract

Self-Compacting Concrete (SCC) has a great potential as a long-awaited building material that allows easy placement without the use of mechanical vibration. This experimental study seeks to evaluate the synergistic impact of silica fume and Steel fiber on the fresh and hardened Properties of SCC. The study was divided into two parts: Part I evaluated SCC mixtures with partial cement replacement with silica fume at 0%, 5%, 10%, and 15% levels and Part II added 1% volume fraction of straight steel fibers into the same percentages of silica fume. Standard workability tests J-ring, L-box, and V-funnel were carried out in fresh properties, whereas in hardened properties, compressive strength, split tensile strength, and flexural strength tests (28 days) were performed. The results indicate that efficient mechanical performance improvement (~20–25% increase in compressive strength) is achieved when using 10% silica fume replacement with respect to total cement weight under flow capacity of workability acceptance defined by EFNARC. Addition of 1% steel fibers has greatly effects on tensile and flexural properties (enhancement of around 15-20%) while workability characteristics remains almost the same. A composite material manifests high durability and ductility due to the pozzolanic reaction of silica fume and the mechanism of crack-bridging action of steel fibers. This work offers useful guidelines for the effective design of SCC mix for high performance structural applications, such as precast elements, bridges and heavily reinforced structural members.

### INTRODUCTION

Standard vibrated concrete has limitations especially when it comes to elements with confined reinforcement and complicated formwork such as in foundations where sufficient and uniform compaction may be impossible, thus SCC was developed to help address and overcome these deficiencies wherein the quality of the concrete as a whole can be heavily dependent on the workability of the concrete mix [1-3]. Self-Compacting Concrete

(SCC) is a paste-like concrete that can flow under its own weight, fill formwork, and pass through congested reinforcement without segregation and bleeding; thus, eliminating the need for external vibration, reducing labor, noise, and compaction related defects (honey combing and voids). To achieve such behavior SCC generally includes a high paste content, well graded coarse aggregate and use of high-range water-reducing admixtures that

collectively provide viscosity, yield stress and segregation stability while maintaining sufficient flowability.

In the last 20 years, many studies and experimental works have been done on the use of supplementary cementitious materials (SCMs) in SCC focusing not only on performance but also on sustainability aspects, where silica fume has been shown to be one of the most efficient SCMs to add to SCC considering both the ultrafine particle size and extremely high pozzolanic activity [4-7]. The silica fume reacts with calcium hydroxide in the packing space C-S-H, which will refine the pore structure, increase the strength of interfacial transition zone, and reduce the permeability, provide compressive strength, chloride resistance and long term durability [3,8]. Literature reports that the inclusion of silica fume between 5-15% as a cement replacement, results in up to twice as much increase in compressive and flexural strength with a concurrent decrease in sorptivity and capillary water absorption in SCC, although higher replacement levels increase water demand, which may negatively impact workability unless properly compensated with superplasticizer [4-7,9]. Earlier experimental studies also showed that incorporation of silica fume with other SCMs or fine powders (like glass powder or rice husk ash) can further pack the matrix more closely and improve freeze-thaw resistance and overall durability in harsh environments although such a contribution can reduce the embodied carbon in concrete.

Similar to mineral admixtures, the incorporation of fiber reinforcement has also been extensively investigated to assist with the inherent brittleness of concrete and to improve the concrete post-cracking behavior, toughness abrasion and impact resistance [10-12]. In particular, the effective crack-bridging action of fibers in SFRC restricts the crack opening and redistributes stresses in the tensile zone, providing a considerable increase in split tensile strength, flexural strength and energy absorption. Thus, in SCC, incorporation of steel fibers, known as fiber-reinforced self-compacting concrete (FRSCC or SFRSCC), can enable quasi-homogeneous dispersion of the steel fiber and complete encapsulation without vibration by the self-compacting matrix and the inherent contribution of

the fiber which can increase the ductility, and residual load-carrying capacity after cracking. Studies in the literature have shown that the flexural strength of SCC can be suitably enhanced by 50-100% in relation to the aspect ratio and content of the volume of steel fibers added, and also that SCC containing steel fibers can provide a certain extent of enhancement of its tensile strength (30-70%); nevertheless, it is essential that excessive fiber usefulness care as it may lead to a reduction in the flowability of SCC and a higher blocking risk in terms of congested reinforcement and adjustment of the mix design and the amount of the admixture usage (Adesola et al.

There are some experimental and reviewed works on the combination effect of silica fume and steel fibers in ordinary concrete and SCC, concluded that silica fume improved the bond at the fiber-matrix interface and both of these modifications together provided higher compressive, tensile, and impact resistance compared to their individual use [10,13,14]. Similar studies on the SFRC with silica fume have shown improved compressive strength, flexural toughness, and modulus of elasticity, as well as rheological property enhancements when silica fume replaces a portion of the binder (usually about 8-15%) to refine the matrix and facilitate improved fiber dispersion [1,4,15]. However, the literature also reports that both silica fume and fibers reduce workability, due to viscosity and internal friction increase, and that the quest of workability mix design, simultaneously maximizing mechanical performance whilst ensuring adequate filling ability, passing ability, and segregation resistance are interrelated among the greatest challenges faced in modern-day architecture. A recent review papers [1,3,4,16], indicate that, even though a considerable amount of individual studies have investigated either silica fume-modified SCC or fiber-reinforced SCC, much less studies have systematically carried out experimental investigations on both the fresh and hardened behaviour of SCC containing both silica fume and steel fibers over wide ranges for the replacement of silica fume and the dosage of fibers, using standard SCC test methods (slump flow, V-funnel, L-box, J-ring) in parallel to the mechanical tests.

These findings indicate that there remains a gap in the existing literature that necessitates that coordinated experimental programs that relate changes in fresh properties to subsequent mechanical performance be performed to ascertain the overall performance benefits for mixes incorporating both silica fume and steel fibers in SCC when the mix is designated for either structural or non-structural applications for which both self-compatibility and high mechanical performance are paramount. Specifically, the ideal silica fume content that provides the highest strength and durability without reducing SCC workability, and the effect of constant steel fiber volume fraction (e.g. 1%) towards enhancing tensile and flexural behavior while retaining an adequate filling and passing ability, are still un-optimized for realistic strength ranges and common structural mix proportions [6,17]. Furthermore, despite the positive trends found in each individual investigation, there is a dearth of comparative data, taking multiple silica fume replacement contents into consideration in a single testing program, with and without steel fibers and cured under the same regime and tested under the same conditions, so that design recommendations for real field use cannot be easily extrapolated.

Thus, the objective of the current study is to systematically assess the fresh and mechanical properties of SCC mixes containing silica fume and steel fibers by a two-phase experimental program in which first SCC mixes are produced by replacing different proportions of silica fume (0-15% by weight of cement) and then the same mixes are incorporated with a constant volume fraction of steel fibers. The study deals with fresh properties of SCC their workability, passing ability, and segregation resistance and hardened behavior with compressive, split tensile, and flexural strength tests at an appropriate age to demonstrate the individual and combined effects of silica fume and steel fibers on the mentioned fresh and hardened behaviour of SCC using standard tests (V-funnel, L-box, J-ring) to quantify the fresh properties. The work aims to find out a best combination capable of providing a sufficient degree of self-compatibility while

maintaining the desired mechanical properties for structural applications, by comparing the behaviour of plain SCC, SCC modified with silica fume, SCC reinforced with fiber and (silica fume-steel fiber) SCC, at constant conditions.

## Experimental Program

### 2.1 Materials and Properties

**Cement:** All concrete mix formulations used 53-grade Ordinary Portland Cement (OPC) word-compliant with ASTM C150 standards. The role of the cement by definition is a chief binder and cementitious ingredient in all the mix designs.

**Silica Fume:** The research omitted using silica fume as part of its partial substitute for Portland cement at three different substitution levels: 5%, 10% and 15%.

**Aggregates:** Sand from the Sutlej River in northern Pakistan's natural river was chosen as the fine aggregate, while crushed limestone taken from quarries near Sargodha is the preferred coarse aggregate. Both aggregates were well-sourced from established suppliers and met the requirements of ASTM C33 in terms of particle size and gradation

**Steel Fibers:** In reinforced mixes straight steel fibers were incorporated at a constant volume fraction of 1.0%. A ratio of 80 was found to be the best aspect ratio based on published research.

### 2.2 Concrete Mix Design and Proportioning

The study carried out eight particular mixtures of concrete in accordance with EFNARC guidelines for self-compacting concrete [18]. ACI recommendations, slightly modified to allow for silica fume, mineral fibers as well as water reducers in this filling material were used in the design of mixture proportions. All mixtures retained a constant water-to-binder ratio of 0.45 at all times ensuring that both an equivalent hydration rate would result and that strength kinetics for the materials would be compared. Details of the concrete mixtures are given in Table 1.

Table 1: Concrete Mix Proportions (kg/m<sup>3</sup>)

Cement	Silica fume (%)	Fiber	Sand	C.A	Water (Litre)	Super-Plasticizer (Litre)
1	%	%	1.67	1.31	0.435	0.015
100 kg	0	0	167 Kg	131 kg	43.5	1.5
95 kg	5 kg	0	167 Kg	131 kg	43.5	1.5
90 kg	10 kg	0	167 Kg	131 kg	43.5	1.5
85 kg	15 kg	0	167 Kg	131 kg	43.5	1.5
100 kg	0	1%	167 Kg	131 kg	43.5	1.5
95 kg	5 kg	1%	167 Kg	131 kg	43.5	1.5
90 kg	10 kg	1%	167 Kg	131 kg	43.5	1.5
85 kg	15 kg	1%	167 Kg	131 kg	43.5	1.5

2.3 Specimen Preparation and Curing

A forced-action mixer with the capability of continuous rotation was used for concrete batching. Cement, fine aggregate, and coarse aggregate were dry blended for 60 seconds to ensure that the constituents were homogeneously mixed. After the initial mixing step, silica fume and steel fibers were added to the dry blend and mixed for another 120 seconds mixing, while a maximum care for fibers dispersion avoiding balling/clumping occurred. A constant speed was maintained in the mixer and continuous addition of water and superplasticizer took place over a period of 180 s. Total mixing time remained 420 seconds (≈7 min) in order to provide material homogeneity but also to avoid heating or loss of water by evaporation. After mixing, fresh concrete was immediately put in standard test molds and prepared to be tested for workability.

2.4 Fresh Property Testing

V-Funnel Test

V-funnel test: V-funnel test which measures the time required for SCC to flow through a V-shaped funnel

The newly mixed concrete was cast into test molds which had previously been lubricated without the use of a mechanical vibrator, allowing the self-compacting characteristics of SCC to perform the required consolidation. Vertical cylindrical samples (100 mm diameter × 200 mm height) for compression testing as well as split tensile specimens (150 mm diameter × 300 mm height) were prepared by casting concrete in molds and allowing them to harden under self-weight for 24 h in a controlled atmosphere at (23 ± 2 °C) and (95 ± 5%) relative moisture. Flexural strength specimens (40 mm × 40 mm × 160 mm) were produced within standard steel molds and were made using a pouring procedure without vibration. The non-vibrated placement was intentional as SCC would not normally be vibrated and therefore the microstructure developed during placement is naturally preserved.

is used to evaluate the filling ability and viscosity of fresh SCC as shown in Figure 1.

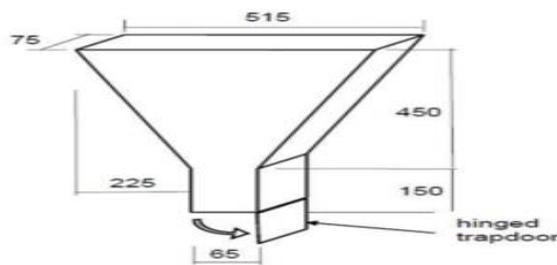


Figure 1: Filling ability testing of SCC using V-funnel method

In the test procedure it was necessary to fill the funnel with about 12 liters of fresh concrete, and immediately open the gate and measure the time to all the concrete to fall under gravity. For most SCC applications, acceptable V-funnel flow times range from 6 to 12 sec. Flow times less than 6 seconds indicate potentially too fluid precluding segregation while times in excess of 12 indicate that the viscosity is too high to be practically playable [18].

#### L-Box Test (EN 12350-10)

The L-box test is a standard measure of the ability of SCC to pass through congested reinforcement, with the principle of the test lying on the ability of fresh

concrete flowing from a vertical form through a horizontal form containing rebar [3] as shown in Figure 2. This test method involved the complete fill of the vertical section with new concrete, followed closely by the opening of a gate to permit new concrete to flow into the horizontal section. The height of concrete in the vertical section ( $H_1$ ) and the distance of flow in the horizontal section ( $H_2$ ) was measured, and the ratio of two was calculated as  $H_2/H_1$ . L-box ratio falling in the range of 0.8 to 1 are considered to be good passing with little segregation and block of passing ability according to EFNARC guidelines.



Figure 2: Filling ability testing of SCC using L-box method

#### J-Ring Test (EN 12350-12)

In this work, the J-ring test is used for evaluation of segregation resistance and block-ability of self-compacting concrete (SCC) based on the fact that the in-situ sectional properties of the structure such as flow would be altered depending on whether or not the mock-reinforcement assembly was included in the test. In this procedure, the J-ring was centered in the slump flow test device and the slump flow diameter with (D<sub>J</sub>-ring) and without (standard slump flow) the ring were measured. Blocking step (BS): The blocking step was calculated as the difference between these two measurements; EFNARC guidelines suggested maximum acceptable blocking steps of  $\leq 50$  mm. If differences are greater than this threshold, they indicate strong blocking

and segregation potential not suitable for use in high-density reinforcements.

#### 2.5 Hardened Property Testing

**Compressive Strength:** Cylindrical specimens (100 mm X 200 mm) were used for compressive strength testing according to ASTM C39/C39M after 28 days of curing [19]. A compression testing machine (minimum capacity 500 kN) was used to test each specimen, by mounting each specimen in a concentric manner on the lower platen and then applying an axial load at a constant rate of  $0.25 \pm 0.05$  MPa/second until failure.

**Split tensile strength test:** The split tensile strength (indirect tensile strength) is a measure of the concrete's ability to resist tensile stresses, and this

was carried out in the laboratory according to the ASTM C496/C496M at 28 days using 150 mm diameter × 300 mm height cylinders. It uses large vertical compressive forces on the diameter of a horizontal specimen, generating tensile stresses perpendicular to the loading direction that result in splitting failure [20].

**Modulus of Rupture:** At 28 days of age, prismatic specimens (40 mm × 40 mm × 160 mm) underwent flexural strength testing, employing the third-point loading method in accordance with ASTM C78/C78M. In this test method, a simply-supported beam is loaded at two equal concentrated loads at the third-points of the span to produce a constant moment region between the load points [21].

**Results and Discussions**

**Fresh Properties of Concrete**

The V-funnel flow times of all the mixtures were between 9.2s - 11s which is still above EFNARC range(accepted range for under 6 sans top 12 sans) as shown in Figure 3. The control mixture (CC) had the shortest flow time of 9.2 seconds, suggesting a good balance of viscosity. The V-funnel times demonstrated a gradual increase from 5% to 15% silica fume content, ending with a 15SF mixture that required 11 seconds to flow (due to the finer particles of silica fume, which retained more water). Although steel fibers caused slight increases in flow time (0.6–0.5 s) for given silica fume contents, the effect was modest, indicating that 1% v/v fiber volume fraction had a minor disruptive influence on fresh paste rheology.

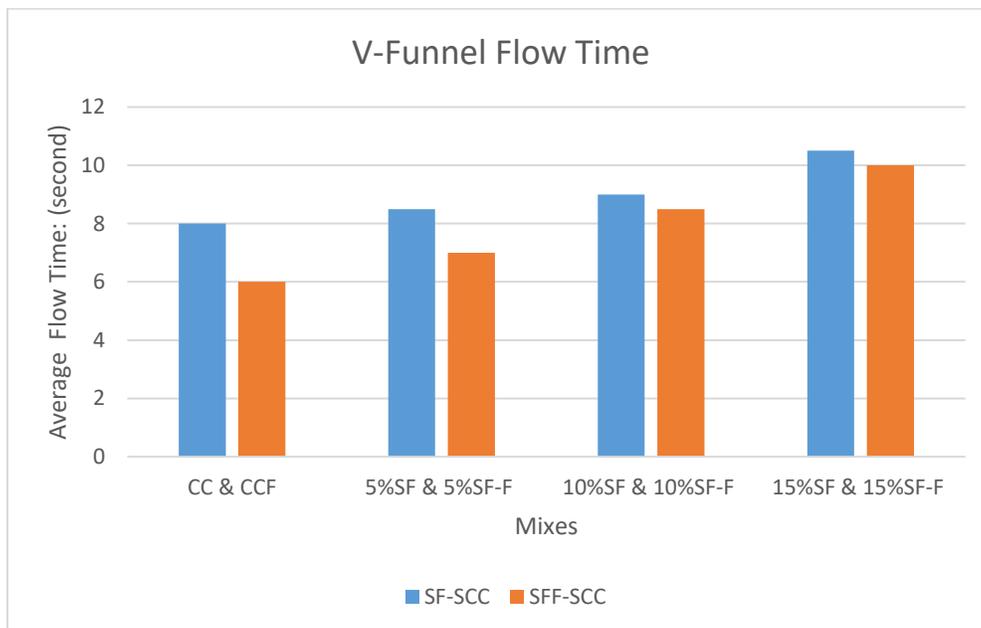


Figure 3: Graphical representation (SF vs SFF SCC) of V-Funnel parameters.

All formulations scored well above passing criteria for the L-box test ( $H_2/H_1 = 0.82$  (15SFF mixture) to  $0.92$  (control)). Minimum EFNARC guidelines required ratios of 0.8 or above were exceeded for all ratios, confirming that the mixes could successfully pass impediments within congested reinforcement without blocking as depicted in Figure 4. The

corresponding decrease in L-box ratio with increasing silica fume content (from  $0.92 \rightarrow 0.84$  for silica fume-only mixtures) reflects the increased viscosity imparted by the ultra-fine silica particles. The introduction of steel fibers also reduced the ratios by another  $0.02-0.04$  units, a minor effect, but stable, due to increased plastic viscosity resulting from fibers.

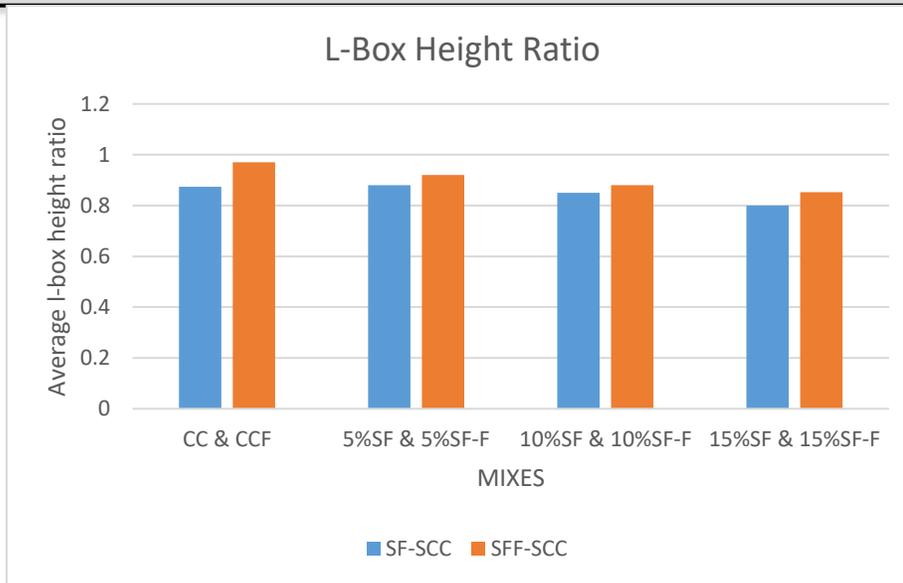


Figure 4: Graphical representation (SF vs SFF SCC) of L-box parameters.

Blockage steps in a J-ring ranged systematically from 12 mm (control) to 28 mm (15SF) and 32 mm (15SFF) while (50 mm being the EFNARC maximum) as presented in Figure 5. The controlled progression of blocking steps indicates an acceptable level of resistance to the segregation and blocking of

the reinforcement within the experimental range. Steel fiber addition raised blocking steps by 3–4 mm of aggregate towards the corresponding silica fume levels, which is consistent with the medium magnitude of fiber-induced effects on paste viscosity.

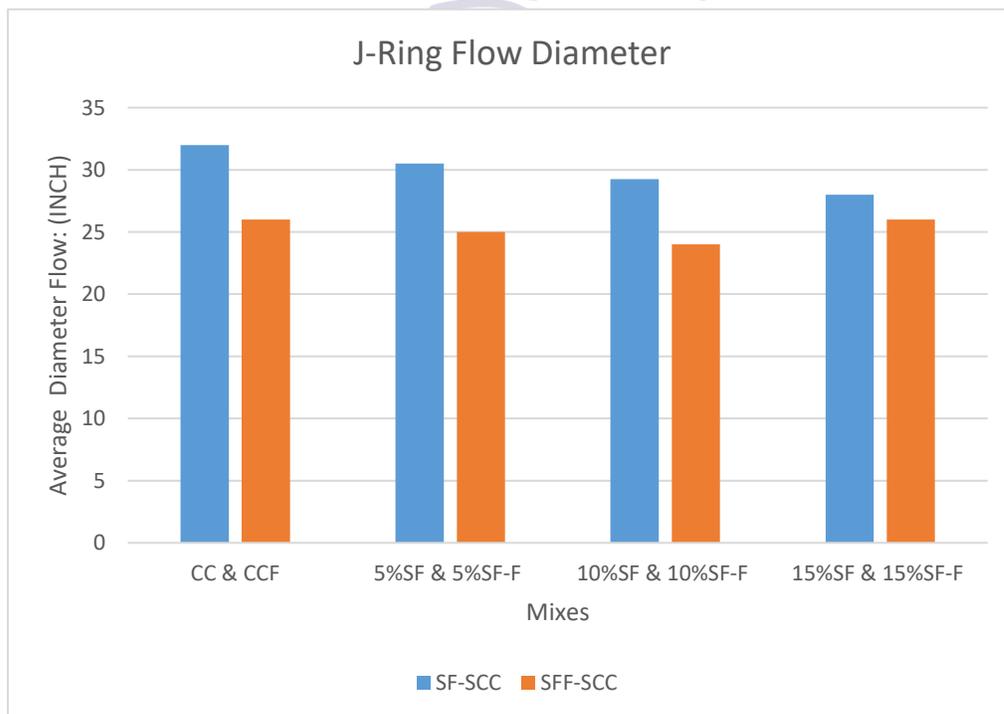


Figure 5: Graphical representation (SF vs SFF SCC) of J-ring parameters.

The slump flow measurements were between 675 and 720 mm, all lying comfortably within the EFNARC SF2 classification range of 660–750 mm suitable for most reinforced concrete applications. Results demonstrate that the control mixture achieved maximum flow of 720 mm, while the incorporation of silica fume progressively reduced flow diameter to 675 mm at 15% replacement, a reduction of 45 mm reflecting the increased yield stress due to the higher fine fraction content.

**Hardened Properties of Concrete**

**Compressive Strength:** Figure 6 highlights a graphical comparison of compressive strength, while table 2 and 3 show the average compressive strength (MPa) among the various concrete design mixes examined. It includes the control concrete (CC) mix design vs Control concrete with fiber, and silica fume concrete (SFC) vs combined silica fume + fiber concrete (SFFC) mix design for SCC.

**Table 2: Average Compressive Strength Measurements (SFSCC).**

S. No	Specimen Type (Cylinder 100 mm x 200 mm)	Compressive Strength (MPa)
1	Control Concrete (CC) SCC	24.4
2	5% Silica Fume SCC	28.56
3	10% Silica Fume SCC	31.33
4	15% Silica Fume SCC	27.76

**Table 3: Average Compressive Strength Measurements (SFFRSCC).**

S. No	Specimen Type (Cylinder 100 mm x 200 mm)	Compressive Strength (MPa)
1	Control Concrete (CC) with Fiber SCC	32.24
2	5% Silica Fume & 1% Fiber SCC	33.7
3	10% Silica Fume & 1% Fiber SCC	34.54
4	15% Silica Fume & 1% Fiber SCC	33.3

This graphical representation shows the comparison the compressive strengths of different SCC design mixes including Control concrete vs Control + fiber and Silica Fume dosage vs combined silica fume + Fiber after the 28 days of curing. Each of design mix is highlighted on the horizontally X-axis, and compressive strength (MPa) is on the vertically Y-axis. The bar chart shows the enhancement as addition of silica fume and fiber content. Research investigation has observed from the tables and figures that compressive strength is improved by increasing the dosages of Silica fume and addition of fiber. As value of control concrete (reference point) 35.24 MPa without incorporation of fibers. And with 1%

fiber content (25 mm in length) 24.4 MPa has been attained. And whereas various dosages of silica fume concrete achieved improve compression strength compare to control concrete due to its pozzolanic effects of silica fume. While due to pozzolanic reaction of specific dosage of silica fume with fiber content as reinforcing effects generally shows the highest compressive strength, that’s supported for structural life for both resistances for cracks and stability [22]. It is resulted the improvement in the compressive strength clearly highlights through particular dosage of silica fume due to pozzolanic reaction and fiber reinforcing with the length of 25 mm and 1% fixed percentage of volume.

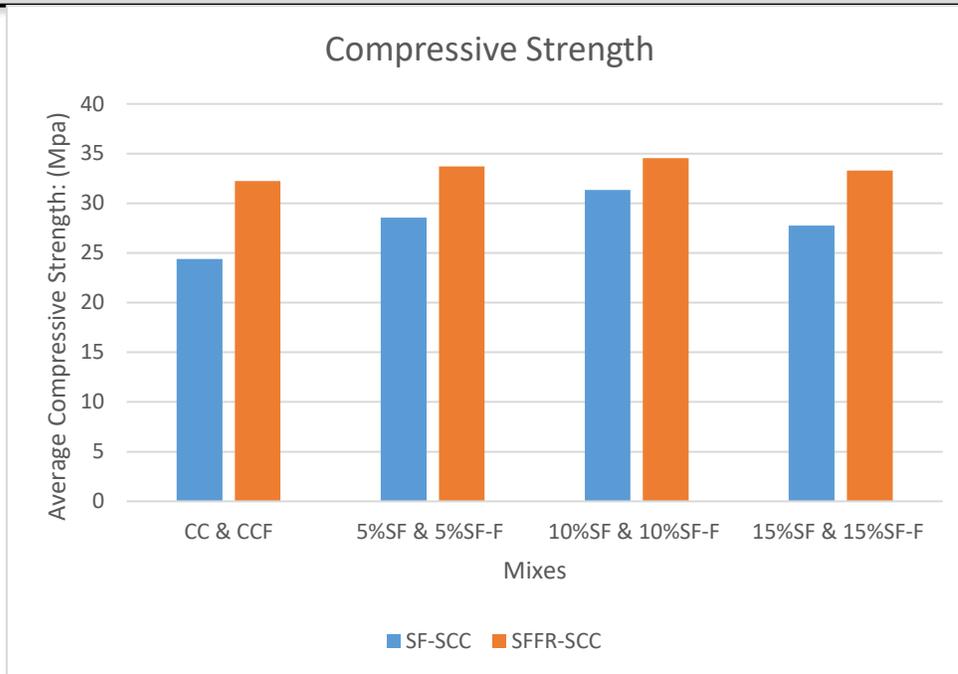


Figure 6: Compressive strength values at 28-days of curing

**Split Tensile Strength:**

This table 4 and 5 shows the average spilt tensile strength (MPa) among the various concrete design mixes examined, while figure 7 shows graphical comparisons of tensile strength of different design mixes. Including the control concrete (CC) mix design vs Control concrete with fiber, and silica fume concrete (SFC) vs combined silica fume + fiber concrete (SFFC) mix design for SCC.

Table 4: Average Spilt Tensile Strength Test Measurements (SFSCC).

S. No	Specimen Type (Cylinder 150 mm x 300 mm)	Spilt Tensile Strength (MPa)
1	Control Concrete (CC) SCC	2.2
2	5% Silica Fume SCC	2.8
3	10% Silica Fume SCC	3.1
4	15% Silica Fume SCC	2.7

Table 5: Average Spilt Tensile Strength Measurements (SFFRSCC).

S. No	Specimen Type (Cylinder 150 mm x 300 mm)	Spilt Tensile Strength (MPa)
1	Control Concrete (CC) with Fiber SCC	3.2
2	5% Silica Fume & 1% Fiber SCC	3.3
3	10% Silica Fume & 1% Fiber SCC	3.6
4	15% Silica Fume & 1% Fiber SCC	3.3

This graphical representation shows the comparison the spilt tensile strengths (MPa) of different SCC design mixes such as Control concrete vs Control +

fiber and Silica Fume dosage vs combined silica fume + Fiber after curing of 28 days period. As control concrete is resulted as lowest value of tensile

strength due to lack of reinforcing materials so it's a reference value for comparisons among the design mixes. Each of design mix is shown on the horizontally X-axis, and tensile strength (MPa) is on the vertically Y-axis. The bar chart shows the enhancement of tensile strength as addition of percentage of fiber content in both silica fume concrete (SFC) and in control concrete (CC).

Study has observed from the tables 4., 5 and figure 7 that tensile strength is improved with addition of fiber percentage. As value of control concrete It is noted that the highest improvement in the tensile strength clearly recorded through the fiber content as reinforcing the concrete with the length

(reference point) 2.7 MPa without incorporation of fibers. And with 1% fiber content (25 mm in length) 3.2 MPa has been attained. And whereas various dosages of silica fume concrete achieved slightly improve tensile strength and improved the concrete matrix compare to control concrete due to increase in densification. While with fiber content as reinforcing effects generally highlights the highest tensile strength. Which is supported for structural durability for both resistance for cracks and life of structure [22].

of 25 mm improving crack resistance and silica fume improving the matrix.

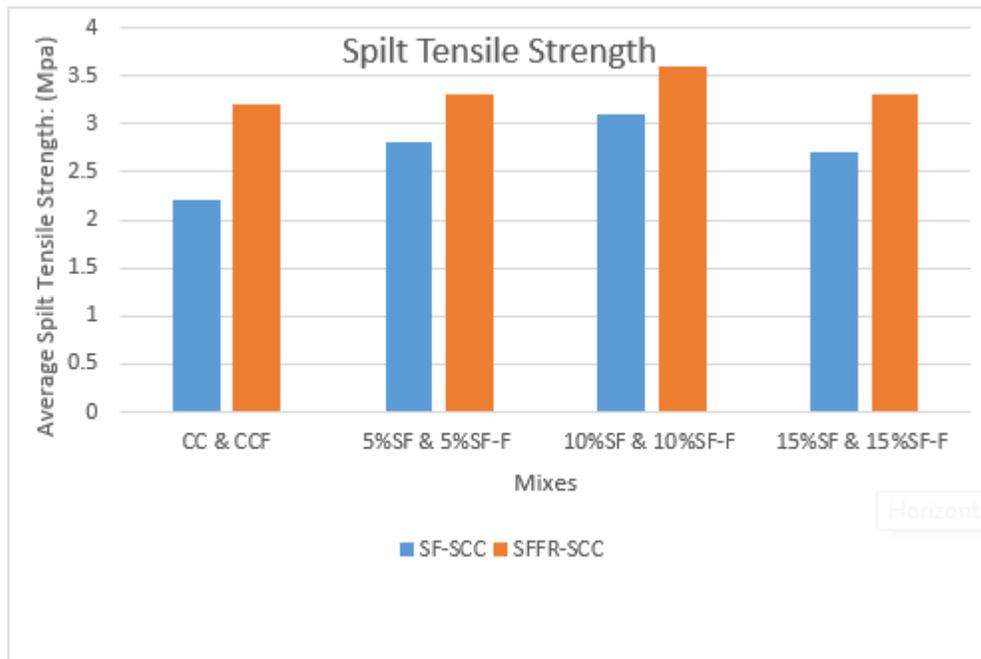


Figure 7: Graphical representation (SF vs SFRRSCC) of Tensile Strength.

**Flexural Strength Tests:** This tests for flexural strength performed after 28 days of curing. Which show that silica fume with stand the stress and bending moment due to its cement matrix.

Although, fibers improve the structural load bearing capacity of concrete. The outcomes of tests are shown in following Table no 6, 7 and comparisons in figure 8.

Table 6: Flexural Strength Test Outcomes (SFSCC).

S.No	Specimen Type (Prisms 4 mm x 4 mm x 160 mm)	Flexural Strength (MPa)
1	Control Concrete (CC) SCC	3.66
2	5% Silica Fume SCC	4.28
3	10% Silica Fume SCC	4.69
4	15% Silica Fume SCC	4.15

Table 7: Flexural Strength Test Outcomes (SFFRSCC).

s	Specimen Type (Prisms 4 mm x 4 mm x 160 mm)	Flexural Strength (MPa)
1	Control Concrete (CC) SCC	4.83
2	5% Silica Fume SCC	5.05
3	10% Silica Fume SCC	5.18
4	15% Silica Fume SCC	4.99

In order to examine the hardened properties of SFSCC and SFFRSCC flexural strength (MPa) of specimen of standardize size in laboratory after curing of 28 days period. The flexural strength test were also conducted in machine (UTM). The flexural molds were procured in the beams molds and molds were performed to examine the flexural strength of different concrete mixes and results compare with CC design mix to evaluate the difference. For study the resistance to cracking and resistance to bending and improve load bearing capacity the flexural strength play an important role. The figure 4.10 compares the flexural strength of the different SCC design mixes after curing of 28 days period.

This table 4.8 and 4.9 shows the average flexural strength (MPa) among the various concrete design mixes examined, while figure 4.10 shows graphical comparisons of flexural strength of different design mixes. Including the control concrete (CC) mix design vs Control concrete with fiber, and silica fume concrete (SFC) vs combined silica fume + fiber concrete (SFFC) mix design for SCC. This graphical representation shows the comparison the flexural strengths (MPa) of different SCC design mixes such as Control concrete vs Control + fiber and Silica Fume dosage vs combined silica fume + Fiber after curing of 28 days period. As control concrete (CC) is resulted as a reference value for comparisons among the design mixes. Each of design mix is shown on the horizontally X-axis, and flexural strength (MPa) is on

the vertically Y-axis. The bar chart shows the enhancement of load bearing capacity as addition of percentage of fiber content in both silica fume concrete (SFC) and in control concrete (CC).

Study has observed from the tables 4.8, 4.9 and figure 4.10 that flexural strength is improved with addition of silica fume as cement matrix, while fiber percentage improve the resistance in bending and cracking as its act as reinforcing. As value of control concrete (reference point) 6.5 MPa without incorporation of fibers. And with 1% fiber content (25 mm in length) 8.36 MPa has been attained. And whereas various dosages of silica fume concrete achieved improve flexural strength and improved the bending and stress resistance compare to control concrete. While with fiber content as reinforcing effects generally heighlights the highest flexural strength by improving in load bearing capacity. Which is supported to resist the bending and induced cracking [23].

It is recorded that the highly resistance in the flexural strength clearly noted through the fiber content as reinforcing the concrete with the length of 25 mm improving crack, bending resistance, load bearing capacity and silica fume resisting the bending and stress because of the cement matrix.

Flexural strength tests outcomes determine the cooperative effects of silica fume and fibers in SCC, with improved formation of cement matrix and improving in structural load bearing capacity.

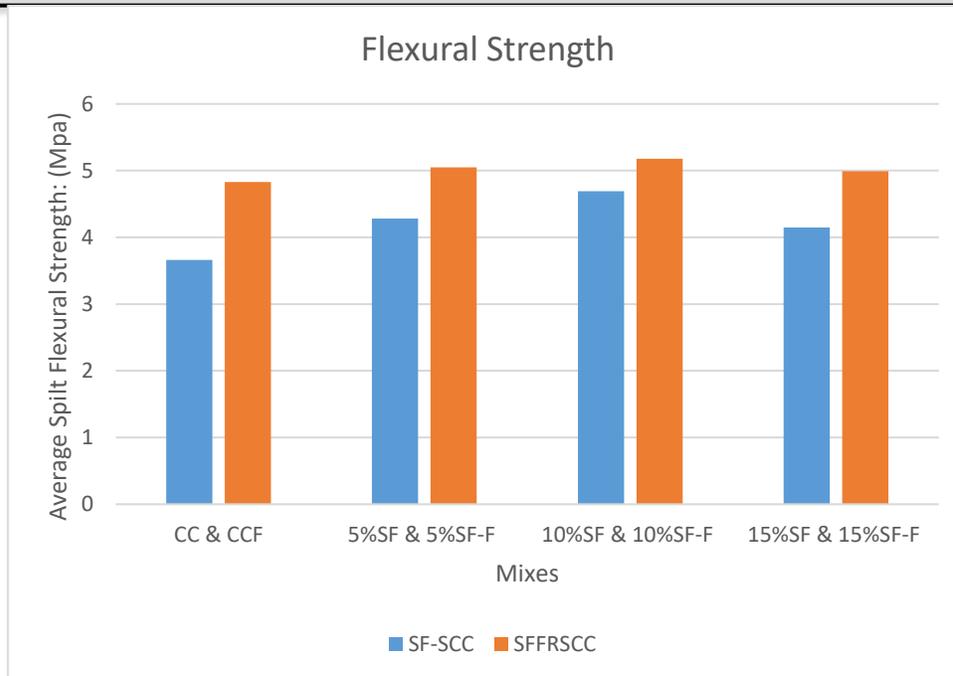


Figure 8: Graphical representation (SF vs SFFRSCC) of Flexural Strength.

### Conclusions

The present study was an experimental programme to find out the simultaneous effects of silica fume and steel fiber on fresh and hardened properties of SCC. On the basis of the test results, the following inferences are made:

**SCC Workability:** All silica fume-modified mixtures met the requirements for workability in EFNARC (V-funnel 6–12 s and L-box  $\geq 0.8$ ). While increasing amounts of silica fume caused a decline in workability, acceptable flow was retained with moderate increases in superplasticizer dosage, indicating the practical viability of SCC with silica fume.

**Application of silica fume:** 10% replacement of cement with silica fume gave the best overall performance. This was found to increase the compressive strength by 25.0%, the split tensile strength by 28.1% and the flexural strength by 21.6% at this level as compared to the control mix with adequate workability and segregation resistance. Higher silica fume content (15%) achieved a plateau in terms of strength increase. This phenomenon would indicate that the saturation of calcium hydroxide, which maybe had been induced by more

silica fume, actually started to consume larger amounts of water.

**Steel Fibers** alone had a marginal effect on the improvement in compressive strength, but were much more effective in enhancing tensile and flexural properties. Results indicated an increase in tensile strength of 50–84%, and in flexural strength of 41–72.5%, overall, because of efficient crack-bridging mechanisms.

**Strength Increase:** 10% Silica Fume + 1% Steel Fibers (Synergist effect): The combined system (10% silica fume + 1% steel fibers) displayed significant synergistic behavior, as indicated by strength gains of 29.2% in compression, 84.4% in tension and 72.5% in flexure. The among improvements in performance is attributed to better fiber-matrix bonding due to the improved microstructure facilitated by silica fume.

**Sustainability Aspects:** By replacing 8–12 percent of cement with silica fume, cement usage and the related CO<sub>2</sub> emissions were lowered at a rate of 8–12 percent, promoting sustainable and ecofriendly concrete manufacturing.

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