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THE SYNERGISTIC EFFECTS OF STEEL FIBERS AND SILICA FUME ON THE MECHANICAL PROPERTIES OF HIGH-STRENGTH CONCRETE

AUTHORS:
D. N. Kakade[1], A. P. Lanjewar[1], S. K. Undirwade[2], *S. D. Shelare[3, 4]

AFFILIATIONS:
[1]Department of Civil Engineering, P. E. S. College of Engineering, Chh. Sambhajinagar, Maharashtra, INDIA.
[2]Department of Mechanical Engineering, P. E. S. College of Engineering, Chh. Sambhajinagar, Maharashtra, INDIA.
[3]Department of Mechanical Engineering, Priyadarshini College of Engineering, Nagpur- 440019, Maharashtra, INDIA.
[4]Chitkara School of Planning and Architecture, Chitkara University, Punjab, INDIA.

***CORRESPONDING AUTHOR:**
Email: sagmech24@gmail.com

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Abstract

Compressive strength, durability, and environmental resistance make high-strength concrete (HSC) essential in modern construction. With increasing urbanization, the demand for resilient infrastructure necessitates advancements in concrete performance. Despite its numerous advantages, high-strength concrete (HSC) faces challenges such as brittleness, susceptibility to chemical attacks, and shrinkage cracking, especially in extreme environmental conditions. This study analyzed how steel fibers and silica fume improve HSC mechanical properties. To optimize durable high-strength concrete, this paper evaluates the enhancement of compressive, tensile, flexural, bonding, and shear strength by various compounds. Researchers tested six concrete mix designs containing 7.5% silica fume and 0.5% to 5% steel fiber by cement weight, measuring strengths at 7 and 28 days using a Universal Testing Machine. Results indicate that steel fibers notably improve mechanical properties, with a 2.0% fiber content yielding a 13.06% increase in compressive strength at 7 days and 19.69% at 28 days. Maximum improvements in tensile and flexural strengths also occur at this fiber content, while shear and bond strength enhancements plateau beyond 2.0%. Additionally, silica fume reduces porosity, further increasing strength. The study concludes that optimal use of steel fibers (up to 2.5%) and silica fume enhances the durability and stability of high-strength concrete, though excessive fiber may impair workability and ultimate strength, necessitating careful mix design.

1.0 INTRODUCTION

High-Strength Concrete (HSC) has a compressive strength exceeding 40MPa, and can reach up to 100MPa [1], which allows it to be used in many of today's demanding construction projects due to its ability to handle large volumes of load and pressure, as well as extreme environmental conditions. As urbanization grows, so does the need for long-lasting, environmentally friendly structures [2] that engineers and builders will rely on HSC for future development. High-strength concrete is made from the use of low water/cement ratios, quality raw materials, and chemically or mineral- added

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materials that improve the performance of the concrete. The high strength and durability of HSC makes it ideal for high performance buildings [3]. The primary advantage of High-Strength Concrete (HSC), is its potential to provide improved durability, reduced size of structural elements [4], [5]. Furthermore, HSC can resist damage from both chemical attack and physical damage such as water infiltration and freezing/thawing in marine and dam applications [6]. Due to its high strength and durability, HSC is well-suited for heavy-duty offshore and industrial construction where the HSC will be subjected to mechanical abrasion and chemical exposure. While the benefits of HSC are primarily related to its structural performance, the increased load bearing capabilities of HSC will protect taller buildings and bridges from damage and collapse [7]. In addition, the increased durability of HSC provides additional protection against chemical degradation, shrinkage and cracking which will extend the serviceable life of the structure [8].

Although HSC presents numerous benefits, it still faces significant challenges prior to being able to optimize its performance [9], [10]. One of the major problems with HSC is that it is easy to attack by chemicals [11]. Chloride and sulfate ions commonly found in marine and industrial environments, can cause additional damage to steel reinforcement either through corrosive action or chemical reaction on the concrete [12]. Although HSC has a higher degree of water resistance due to its lower porosity, it has decreased water permeability [13]. Due to its lower water-cement ratio, HSC suffers from shrinkage cracking during curing. In large concrete pours or constructions with limited mobility, such as rigid slabs or beams, shrinkage may negatively impact the long-term performance of the concrete. The thermal cracking (cracking from heat) also presents a problem as larger sections of concrete were cast [14]. Furthermore, crack propagation is more noticeable in HSC [15]. Cracks in high-strength concrete can expand into wider because it cannot self-heal [16]. These cracks can degrade the structure, especially if they expose reinforcement to water or chemicals [16].

Achieving uniformity in concrete strength over large quantities is difficult [17]. When subjected to extremely heavy weights or impact, HSC may experience catastrophic failure [18]. Repeatedly applying or cyclically subjecting brittle concrete to stress will cause cracking. Additionally, low porosity combined with high strength reduces the impact resistance of HSC [19]. These problems may be solved by proposing a number of alternatives. The addition of admixtures and additives (such as silica fume, fly ash and slag) to HSC can enhance the micro-structural characteristics of HSC [20].

In high-strength concrete, steel fibers and silica fume enhance the performance [21]. Concrete reinforced with short steel fibers exhibits enhanced mechanical properties. The length and diameter of these fibers depend on the reinforcement and are made from cold-drawn wire or steel sheets [22]. Steel fibers make concrete harder and crack-resistant under tensile stress. Steel fibers provide a matrix network that inhibits fracture growth and improves concrete stress performance [23]. Silica fume, or microsilica, is a byproduct of silicon metal or ferrosilicon alloy manufacture. It consists of extremely small particles of silicon dioxide (SiO_2), often less than 1 micron in diameter. Pozzolanic properties make it ideal for concrete improvement [24]. The pozzolanic reaction reduces concrete permeability, making it more resistant to water, chlorides, and other hazards, reducing shrinkage and boosting durability, especially in hard conditions [25]. Silica fume makes concrete stronger and cohesive, reducing cracking. High-strength concrete with silica fume has better early-age strength and less shrinkage cracking [26].

Several studies have revealed that steel fibers and silica fume alter concrete's mechanical properties and durability. Liu et al. [27] examined how steel fibers and silica fume affect ultra-high performance geopolymer concrete's mechanical and fracture qualities. Saba et al. [28] investigated the fresh and hardened properties of self-compacting concrete (SCC) mixes with four steel fiber percentages. Xie et al. [29] evaluated the impact of silica fume and steel fibers to the recycled aggregate concrete (RAC) compressive strength under high temperatures. Two modification approaches were employed by Pi et al. [30], to improve the interfacial characteristics between the fiber and matrix and the macro-mechanical behavior of the steel fiber reinforced cement-based composite (SFRCC). Singh [31] examined the strength and durability of concrete improved by partially substituting cement with Silica Fume. Waste tire steel fibers were utilized by Quadri et al. [32] to provide environmentally sustainable practices, cost-effective solutions, efficient materials, and aesthetically pleasing finishes that meet the objectives of Sustainable Development Goals (SDGs). Dalvand et al. [33] examined the influence of partially substituting Portland cement with a

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pozzolanic material on high-strength self-compacting cement composites reinforced with wavy steel fibers.

The present article addresses several research gaps in steel-fiber and silica fume-reinforced high-strength concrete. This study investigates the mechanical characteristics of high-strength concrete to evaluate how the use of this type of material affects the mechanical strengths (compressive strength; tensile strength; flexural strength; bond strength; and shear strength) of the material. The overall objective is to identify the best possible composition of high-strength concrete to enhance its performance as a building material for critical structures.

2.0 MATERIALS AND METHODS

The main aim of this experimental research was to study the effect of crimped steel fibers and silica fume on the compressive, tensile and flexural strengths of concrete in addition to bonding and shearing. In addition to studying the effects of steel fibers, this study also compared the studied properties with those of silica fume concrete.

2.1 Materials

The fine and coarse aggregates were confirmed to IS 383 [34], and ordinary Portland cement with a 7-day compressive strength of 45.20 MPa and conforming to IS 12269 [35] was employed. The fineness modulus of the sand used was 2.803, while for the 10mm and 20mm coarse aggregates, it was 7.52. The M-50 grade of concrete was prepared with a mix proportion of 1 : 0.80 : 2.4 : 0.35. The fine aggregate and coarse aggregates (10mm and 20mm) were combined with a water-cement ratio of 0.35 for the experimental study. To facilitate testing, several molds and specimens were prepared: 150 mm cubes for compressive and bond strength, 150 mm x 150 mm x 700 mm beams for flexural strength, and 150 mm x 150 mm x 450 mm push-off specimens for shear strength. Pull-out cubes with 16 mm ribbed Fe-500 bars were also utilized. For the Modified Compression Test, a 150 mm x 150 mm x 150 mm section of the beam was used, and the remaining one-third portion was employed for the Modified Split Tensile Test.

2.2 Mix Design of Concrete

Concrete mix design for M-50 grade concrete was made using the Erntroy and Shacklock method [36] and the ingredients' quantities are illustrated in Table 1, as well as their combined proportions as specified by the design.

Table 1: Material quantities per concrete cubic meter

Material	**Weight in kg**	**Proportion by weight**
F.A.	413.6	0.80
Cement	517	1
CA II (10mm) 40% CAI (25mm) 60%	1241	2.40
W/c ratio	181	0.35

2.3 Preparation of Test Specimens

For this research, six concrete samples were produced with a range of percentages of added steel filaments (from 0 to 5% by weight of cement) and a fixed amount of 7.5% silica fume that remained constant regardless of the percentage of steel filament used. All six concrete samples were made in two conditions; with and without the use of fibers. This ensured that the six concrete samples for all test conditions had an equivalent of 5% silica fume in their composition. The compaction of the mixtures was completed using a table vibrator to prevent clumping of the fibers. All fiber-reinforced concrete specimens incorporating silica fume underwent wet curing for periods of 7 and 28 days at room temperature, and were subsequently tested using a 1000 kN Universal Testing Machine, while conventional concrete specimens received water curing. The properties evaluated included compressive, flexural, shear, bond, and split tensile strength. The strength performance of the hardened concrete was analyzed according to standard testing procedures, with results derived as the average of three test samples for each measurement in this research.

2.4 Steel Fibers Physical Properties

Experimental work was conducted with Novocon (Xorex) steel fibers that adhere to ASTM A 820 type-I. Specially engineered for concrete use, fibers are high-tensile steel cold-drawn wire. NINA Concrete Industries and Company, Mumbai, provides fibers. Table 2 presents the physical properties of steel fibers. The fibers are high-strength cold drawn wire that is 50mm long and has an aspect ratio of 50. The tensile strength of the fibers is 1000 MPa, the modulus of elasticity for these fibers is 200 GPa, and the specific gravity is 7.8. These fibers are bright, they are circular cross-sections that deform continuously as well as having circular segments. The fibers were added into the

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concrete at a dosage range of 0.5% to 5.0% by cement weight.

Table 2: Steel fiber physical properties

Sr.No.	**Property**	**Value**
1	Fiber Length	50.0 mm (Flat)
2.	Aspect ratio (Avg)	50
3.	Appearance	Bright in clean wire
4.	Deformation	Continuously deformed circular segment
5.	Modulus of Elasticity	200 GPa
6.	Tensile strength of Fiber	1000 MPa
7.	Specific Gravity	7.8

2.5 Silica Fume Properties

The dry powder form of micro silica grade 920-D is available and was obtained from Elkem India Private Limited in Mumbai. In a densified form with a smoke gray color, it was available in 25 kg sacks. Table 3 illustrates Properties of Silica Fume used

Table 3: Silica fume Properties

Parameter	**Analysis**	**Specification**
SiO_2	91.0	Min. 85%
Loss of Ignition@975C	1.4	Max 6%
Moisture Content	0.7	Max 3%
>45 micron	0.4	Max 10%
Carbon	0.8	Max 2.5%
Bulk density	640	500-700 kg/m^3

2.6 Experimental Procedure

The Universal Testing Machine (UTM) was utilized to perform a comprehensive series of experiments on hardened concrete, focusing on various strength properties such as compressive, flexural, split tensile, bond, and shear strengths. Specific attention was given to the shear properties of push-off type specimens, which were designed to fail in shear at a predetermined plane. To avoid failure due to flexural, compressive or bearing capacity of the concrete between the reinforcement, the reinforcement was strategically located on either side of the shear zone so that if there was a failure, the failure would be confined to the shear zone.

Figure 1: (a) Table vibrator arrangement in Laboratory for compaction; (b) Slump measurement; (c) Electrodynamics Test Setup for Longitudinal Frequency; (d) Curing of Specimen; (e) Dry Concrete Mix with Silica fume and Steel Fibers; (f) Shear Specimens; (g) Shear Test Set up After Failure; (h) Pull out Specimen Before Failure; and (i) Broken Specime.

Vertical displacements were carefully measured during the experiment over a 150mm gauge length within the shear zone at regular loading intervals prior to failure. The shear stresses developed in each specimen were determined using the shear force divided by the area of the shear plane. Using the same shear forces and the maximum shear displacement (shear strain) observed during the test,

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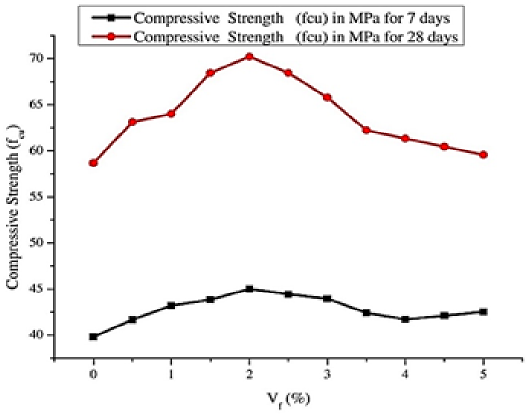
the shear moduli of the specimens were then determined from the ratio of shear stresses to shear strains. It should also be noted that, as opposed to a non-linear shear deformation, the shear strain of the specimens tested here represents the total shear deformation of an elastic lineal element, thus clearly illustrating how the shear properties of this material respond when loaded. These methods provide a means to measure and assess the shear properties of concrete materials, specifically by demonstrating the importance of proper placement of reinforcing elements and careful measurement technique in the laboratory testing of these materials. Figure 1 illustrates various laboratory processes: (a) the table vibrator configuration for compaction, (b) slump measurement, (c) the electrodynamics test apparatus for longitudinal frequency, (d) the specimen curing process, (e) the dry concrete mixture with silica fume and steel fibers, (f) shear specimens, (g) the shear test apparatus post-failure, (h) the pull-out specimen before failure, and (i) the fractured specimen.

3.0 RESULTS AND DISCUSSION

3.1 Compressive Strength Test on Cubes

Figure 2 (a) presents a comparison of the amount of fiber in the concrete mix to the compressive strength at both 7 and 28 days. As illustrated by the Figure, the increase in the amount of steel fiber will result in an increase in compressive strength, with a peak at 2.0 percent for testing at 7 and 28 days.

Compressive strength rises by 13.06% over the control mix (0.0%) at 7 days and 19.69% at 28 days as a result of the incorporation of steel fibers into the concrete mix. The increase in compressive strength of the concrete can be attributed to the fact that steel fibers assist in dispersing the load uniformly throughout the concrete and therefore increase the compressive strength of the concrete. Steel fibers also provide assistance to the cohesion of the concrete matrix and assist in preventing the formation of cracks within the concrete as a result of the compression forces acting on the concrete. Compressive strength shows a significant improvement up to 2.0% fiber content. However, beyond this level, the increase in compressive strength becomes marginal or insignificant. High concentration fiber balling or poor dispersion at higher concentrations can lead to lower compressive strengths of 7 and 28 days of testing at a 2.5% fiber content. The impeding of the compression strength can be due to a disruption in the homogeneity of the concrete mixture strength. In addition to improving the mechanical properties of concrete steel fibers are able to provide structural performance as well as improve the compressive strength of concrete for structural applications that will bear heavy loads. Steel fibers enhance the toughness of concrete, improve the resistance of cracking in concrete and make it stronger.



(a)

Figure 2: (a) Impact of Fiber Content (Vf %) on Compressive Strength;

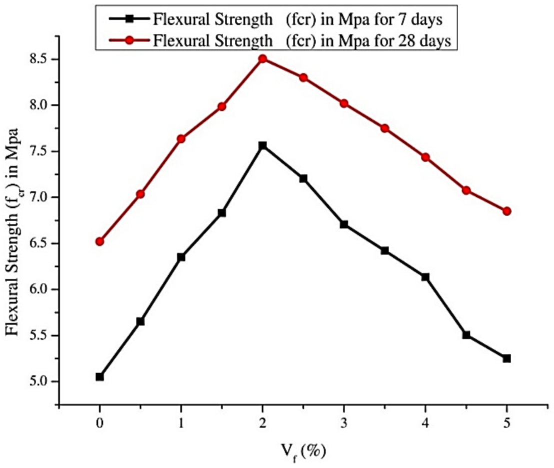


Figure 2; (b) Impact of Fiber Content (Vf %) on Flexural Strength

3.2 Flexural Strength Test on Beams, (f_{cr})

Figure 2 (b) shows how 0% to 5% fiber concentration influences 7- and 28-day concrete beam flexural strength. Fiber concentration above 2% Vf increases flexural strength. Flexural strength peaks at 2% fiber content at 7 days, rising from 5.05 MPa in the control mix (0% fiber) to 7.56 MPa. Strength rises to 8.51 MPa at 2% fiber after 28 days. Two to five percent fiber lowers or plateaus flexural strength.

The presence of steel fibers enhances the ductility and strength of concrete, making it more robust and

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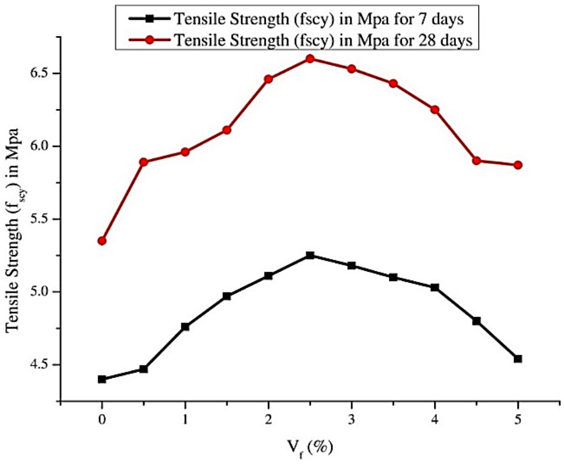
resistant to cracking. Stronger fibers avoid concrete matrix shattering under bending stresses. Fiber concentration above 2.5% to 3% may agglomerate or distribute unevenly in the matrix, lowering flexural strength. Reduced stress transfer by aggregation reduces strength improvement. Fiber reinforcement-concrete matrix cohesiveness balancing is optimum in this trend. Fibers spread well at moderate fiber content, bridging cracks and strengthening bending. Fiber volume above a threshold may influence mix workability or cause stress concentration sites, reducing flexural strength improvement.

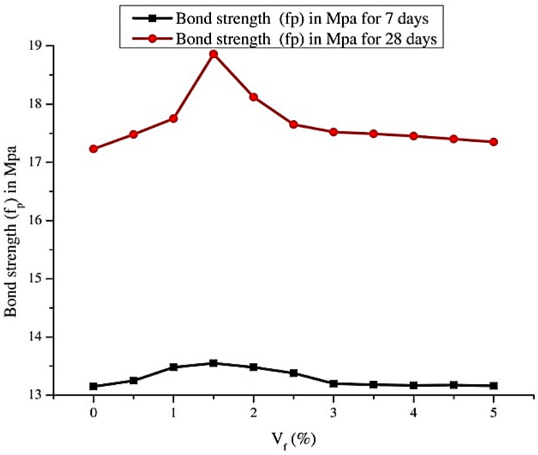
3.3 Split Tensile Test on Cylinder

Figure 3 (a) shows the relationship between steel fiber content (Vf%) and concrete split tensile strength (MPa) at 7 and 28 days curing.



(a)

Figure 3: (a) Impact of Fiber Content (Vf %) on Spilt Tensile Strength;



(b)

Figure 3: (b) Impact of Fiber Content (Vf %) on Bond strength

Tensile strength increases from 4.4 MPa (0% fiber content) to 5.25 MPa (2.5% fiber content) at 7 days and from 5.35 MPa to 6.6 MPa at 28 days during curing. 2.5% fiber concentration enhances tensile strength 19.32% and 23.36% above control concrete at 7 and 28 days. Three to five percent reduces tensile strength at 28 days. Due to steel fibers, concrete has higher tensile strength. Fibers strengthen fissures and prevent micro-cracks, stabilizing concrete under tensile pressures. Fiber concentrations beyond 2.5% may interfere with mix workability or create fiber clumping, resulting in less uniform distribution and poorer strength. Fibers boost split tensile strength, but too much might diminish concrete's mechanical behavior and mixing ease.

3.4 Bond Strength on Cubes

Figure 3 (b) compares high-strength concrete bond strength to fiber content (Vf %) with different steel fiber contents. Fiber incorporation increases bond strength, peaking at 18.86 MPa at 28 days at 1.5% to 2.0% fiber by concrete volume. Fiber content above 2.0% stabilizes or lowers binding strength. At the maximum fiber content (5.0%), the bond strength is 17.35 MPa at 28 days, lower than the peak but equal to concrete without fibers (17.23 MPa). The addition of fibers increases both the hardness of the concrete and mechanical locking between the fiber and the steel for enhanced steel-reinforced concrete (S/R) interfacial bonding. These improvements diminish with increasing fiber volume beyond an optimum volume (i.e., fiber aggregation) in the concrete matrix potentially creating non-uniformities within the concrete matrix, thereby reducing the bond strength of fibers to steel. Additionally, high levels of fibers can reduce hydration rates of cement, or they can alter the workability of the concrete, therefore limiting the bonding of fibers to the surrounding concrete matrix. As shown by the figure, the greatest S/R bond strength will be obtained at low concentrations of fibers; however, at any level of fiber greater than 2.0%, S/R bond strength may also be reduced.

3.5 Shear Strength (τ)

As seen in Figure 4 (a), increasing fiber concentration (Vf%) increases shear strength (τ). Shear strength rises slightly compared to the control mix (0% fiber content) at low fiber volumes (0.5% and 1.0%), from 4.85 MPa to 5.25 MPa in 7 days and 7.48 to 7.56 MPa in 28 days. This benefit peaks at 2.5% fiber content, when shear strength is 6.42 MPa at 7 days and 7.98 MPa at 28 days. Further increases

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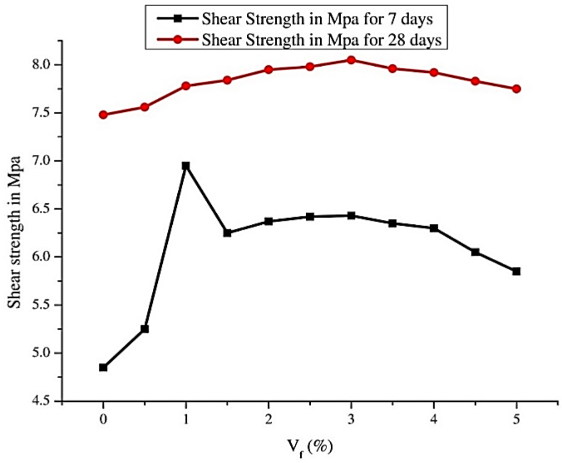
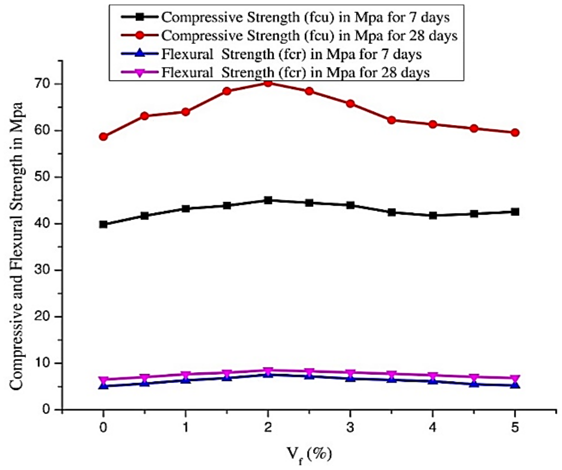
in fiber content plateau or slightly decrease shear strength, especially at 5.0%, which lowers to 5.85 MPa at 7 days and 7.75 in 28 days. This indicates that fibers can boost shear strength, but too much can lower it. Higher doses may make fiber distribution in the concrete mix tougher, resulting in fiber clustering and lower shear force resistance. High-strength concrete fiber content must be tuned based on behavior. 2.5 percent steel fibers seems to be the best compromise between shear strength and fiber content. Fiber reinforcement increases concrete's shear performance, but fiber dose must be regulated to achieve structural benefits.



(a)

Figure 4: (a) Impact of Fiber Content (Vf %) on Shear Strength (τ)



(b)

Figure 4: (b) Comparison between Compressive Strength and flexural Strength

3.6 Relation Between Flexural Strength And Compressive Strength

Figure 4 (b) shows how steel fiber and silica fume percentages affect concrete compressive and flexural strengths. Fiber improves both strengths, especially in the 28-day test, as shown in the graph.

Even at 0.5% fiber concentration, compressive and flexural strength exceed the fiberless control mix (M0). Compressive strength increases quantitatively from 39.81 MPa at 7 days and 58.67 MPa at 28 days for the control mix to 45.01 and 70.22 MPa for the M4 mix with 2% steel fibers. Flexural strength increases from 5.05 MPa at 7 days and 6.52 MPa at 28 days for M0 to 7.56 and 8.51 for the same 2% fiber mix. Strength peaks at 2% fiber content and plateaus with more fiber. Using steel fibers as crack arresters distributes loads more evenly and increases concrete's compressive and bending strength. The concrete matrix is strengthened by reduced fiber concentrations. Steel fibers up to 2-2.5% and silica fume strengthen concrete, improving structural stability. When fiber content exceeds an optimal level, advantages plateau, underscoring the importance of mix design for high-strength concrete. The significant increase in flexural strength (as shown in figure 4b) from 7 to 28 days is due to the continuing hydration of the cement, as well as the ongoing pozzolanic reaction of the silica fume, that continues to densify the matrix and improve the interface bonding between the fibers and the cement paste. The improved bonding over time results in an increased effectiveness of the fiber's ability to bridge the opening of cracks and resist bending forces, leading to significantly higher strength gains than at earlier ages, based on the observed performance at each age.

3.7 Relation Between Split Tensile Strength Compressive Strength

Figure 5 (a) shows how fiber content (Vf%) affects high-strength concrete's compressive and split tensile strengths.

Steel fibers increase compressive strength up to 2.0% fiber content. Compressive strength at 28 days increases from 58.67 MPa (without fibers) to 70.22 MPa (M4 mix) with 2.0% fibers. Same mix (M4) tensile strength increases to 6.46 MPa after 28 days. When fiber content exceeds 2.5%, strengths plateau or decline. Steel fibers boost concrete strength, however more than 2.5% may produce uneven distribution or balling, restricting its application. Silica fume and steel fiber synergy affect the graph. Silica fume improves concrete cohesiveness and compressive and tensile strengths by reducing porosity. However, steel fibers increase concrete load distribution and prevent cracking under tensile stress, enhancing its strength. Beyond the optimal fiber percentage (2.0-2.5%), fiber aggregation can disturb

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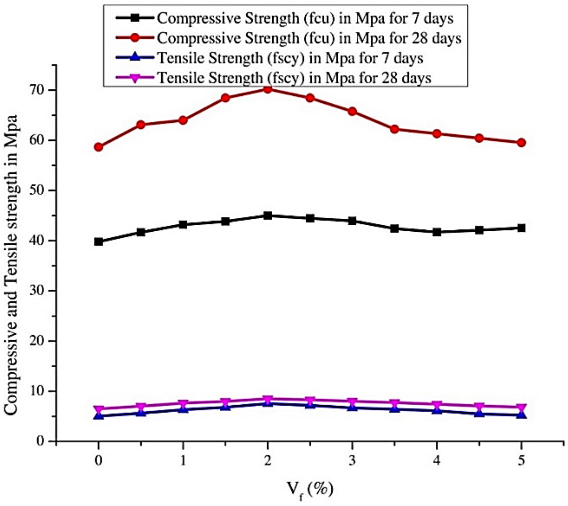
the concrete mix's uniform fiber distribution and reduce fiber reinforcing efficiency. The trend shows how fine-tuning is important with regard to designing mixtures. The best fiber content for best results allows for better dispersion of fibers, which improves the mechanical properties of the concrete.



(a)

Figure 5: (a) Comparison between Compressive Strength and tensile strength;

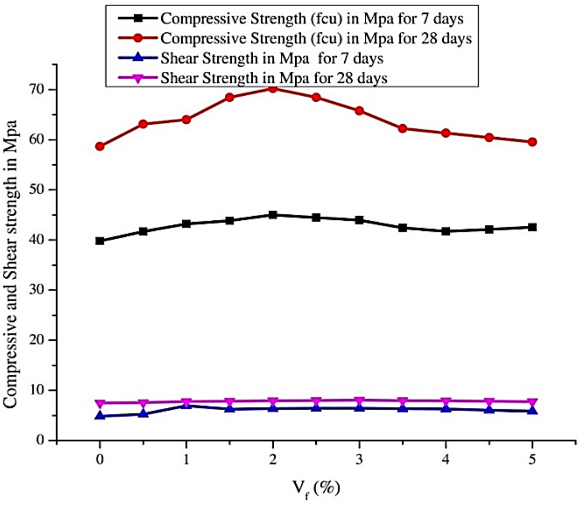


Figure 5: (b) Comparison between Compressive Strength and Shear strength

3.8. Relation Between Shear Strength And Compressive Strength

Compressive and shear strength of high-strength concrete (HSC) vary with fiber content, as seen in Figure 5 (b). Fiber content increases compressive and shear strengths. At 7 days, compressive strength rises from 39.81 to 42.54 MPa and shear strength from 4.85 to 5.85 MPa at 5% fiber content. At 28 days, compressive strength reaches 59.56 MPa and shear strength stabilizes at 7.75 MPa.

Behavior is attributed to steel fibers. With more fiber, the concrete matrix resists breaking and deformation under compressive and shear forces. Steel fibers strengthen by bridging cracks and preventing propagation. Low-porosity, brittle high-strength concrete has poor crack resistance, highlighting this effect. But shear strength rises slower than compressive. Different mechanisms govern these two strengths, explaining the difference. Compressive strength resists direct axial loads, while shear strength resists internal plane sliding. Fibers resist shear failure less than compressive load-bearing capacity, hence shear strength improves slower. In conclusion, steel fibers in high-strength concrete increase compressive and shear strength. Fibers' ability to resist internal fracture propagation under axial loading enhances compressive strength, but shear stress resistance increases shear strength less.

3.9 Relation Between Bond Strength And Compressive Strength

Figure 6 shows how silica fume and steel fibers affect concrete's compressive and bond strengths. Silica fume with steel fibers increase compressive and bond strength at low fiber content.

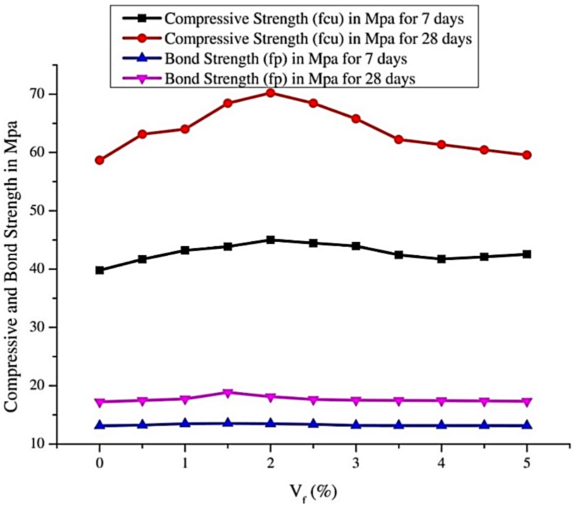


Figure 6: Comparison between Compressive Strength and Bond Strength

At 2.0% fiber concentration, compressive strength peaks at 70.22 MPa. Microstructure, porosity, and concrete density improve with silica fume. Steel fibers increase concrete matrix mechanical interlock and compressive strength. Fibers, especially up to 2.0%, boost bond strength. Bond strength peaks at 18.86 MPa at 28 days. Fiber dosages over this amount do not strengthen bonds.

The differences in strength observed between 7 and 28 days of curing may be attributed to the continuing

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hydration process occurring as a function of time. Concrete has a high degree of strength development early in the curing stage because the cement reacts with the water added to form hydrated products that will ultimately provide the strength. In the case of non-fiber reinforced plain concrete, there is considerable growth in strength from 7 to 28 days due to the hydration reactions occurring during the curing period. For fiber-reinforced concrete however, the introduction of the steel fibers acts to support load distribution and to minimize internal cracking thus providing a slightly increased strength in the 7-28 day curing period. Although the primary function of steel fibers is to enhance the toughness, crack resistance and cohesion of the concrete they also provide an increase in the mechanical properties of the concrete. This increase in the mechanical properties is greater than would occur in non-fiber reinforced concrete as the hydration of the cement and the pozzolanic reaction of the silica fume continue to densify the matrix and improve the bonding of the fibers to the cement paste.

By 28 days, the fibers act to bridge micro-cracks and provide a considerable increase in strength, although it may not be as great as that provided by the hydration reactions in the first few days; nevertheless, the increase in strength at 28 days represents a considerable improvement in the durability and toughness of the concrete when subjected to tension and bending stresses. Thus, while the curing age is certainly a major factor influencing the development of the strength of concrete, the inclusion of fibers results in sustained improvements that become more evident over longer curing ages particularly in regard to resistance to cracking and the total structural integrity of the concrete.

Numerous studies have been conducted in relation to varying levels of fiber (in this case steel) and their resultant impacts upon concrete's mechanical properties, as well as strength. For example, studies such as those completed by Liu et al. [27] have demonstrated that the incorporation of higher amounts of steel fibers into the matrix of concrete results in improved mechanical properties until a point where no further improvement occurs. Additionally, similar work by Saba et al. [28], demonstrated an improvement in toughness of concrete due to inclusion of steel fibers; however, they also noted that a level of fiber (specifically above 2%) will result in a plateau of benefit from the addition of steel fibers. In conclusion, our data supports other studies indicating that the use of steel fibers in concrete results in increased concrete strength, yet it also illustrates that proper consideration to the amount of steel fibers added into the mix is important to achieve maximum concrete strength.

4.0 CONCLUSION

The research found a synergistic effect from combining silica fume and steel fiber to improve mechanical properties of high-strength concrete. The data indicate an increase in mechanical performance of HSC in terms of compressive, flexural, tensile, shear, and bond strength through the addition of steel fibers. The key conclusions are:

- Optimal fiber content is determined to be 2.0%, which enhances compressive strength at 7 and 28 days, showing increases of 13.06% and 19.69% respectively compared to control mix.
- Adding more than 2.0% fiber leads to diminishing returns due to fiber balling and poor distribution, negatively affecting concrete strength and workability.
- Silica fume reduces voids in the concrete matrix via its pozzolanic reaction, enhancing cohesion, durability, and mechanical properties. A 7.5% substitution of silica fume improves compressive strength and decreases permeability.
- The combination of silica fume and steel fibers enhances concrete's resistance to cracking, impacts, and chemical degradation, making it suitable for high-performance applications like industrial flooring, high-rise buildings, bridges, and marine construction.
- Precise mix design is crucial; excessive fiber (beyond 2.5%) can lead to reduced mechanical properties, including bond strength and workability.

REFERENCES

[1] Shah, S. Akashah, F. and Shafigh, P. “Performance of High Strength Concrete Subjected to Elevated Temperatures: A Review,” *Fire Technology*, 55 (5), p. 1571–1597, 2019. doi: 10.1007/s10694-018-0791-2.

[2] Sharma, R. Jang, J. and Hu, J. “Phase-Change Materials in Concrete: Opportunities and Challenges for Sustainable Construction and Building Materials,” *Materials*, 15 (1), p. 1-28, 2022. doi: 10.3390/ma15010335.

[3] Olofintuyi, I. Arum, C. Akingbonmire, S. and Ojokoh, B. “Development And

https://doi.org/10.4314/njt.2026.5752

Application of Concrete Sensor to Measure Onsite Strength of Concrete," *Nigerian Journal of Technology*, 43 (3), p. 436-443, 2024, doi: 10.4314/njt.v43i3.5.

[4] Oke, A. Ojo, O. Olabanji, T. Akinmusere, O. and Akande, S. "Mechanical Properties of Laundry Wastewater Concrete Incorporating Polyethylene 2 Terephthalate (Pet) as Partial Replacement for Sand," *Nigerian Journal of Technology*, 43 (4), p. 618–627, 2025. doi: 10.4314/njt.v43i4.2.

[5] Nguyen, W. Trono, W. Panagiotou, M. and Ostertag, C. "Seismic response of a rocking bridge column using a precast hybrid fiber-reinforced concrete (HyFRC) tube," *Composite Structures*, 174 (1), p. 252–262, 2017. doi: 10.1016/j.compstruct.2017.04.058.

[6] Korol', E. and Kustikova, Y. "Constructive systems, load-bearing and enclosing structures of high-rise buildings," *E3S Web of Conferences*, 33, p. 1-9, 2018. doi: 10.1051/e3sconf/20183301043.

[7] Idagu, F. Onwuka, D. Okere, C. and Onwuka, U. "Comparison of Split Tensile Strength of Concrete Using Basalt and Granite as Coarse Aggregates," *Nigerian Journal of Technology*, SE-Building, Civil & Geotechnical Engineering, 43 (2), p. 247-252, 2024. doi: 10.4314/njt.v43i2.7.

[8] Tekwani, B. and Gupta, A. "Machine Learning Classification Techniques to Predict In Situ Compressive Strength of Reinforced Concrete Using Ndt Data," *Nigerian Journal of Technology*, 44 (4), p. 1–13, 2025. doi: 10.4314/njt.2025.5155.

[9] Ezemenike, C. and Ikumawoyi, R. "Investigating the chemical properties, thermal and microstructural characterizations of industrial waste based asphalt concrete for enhanced performance," *Nigerian Journal of Technology*, 44 (3), p. 367–377, 2025. doi: 10.4314/njt.v44i3.1.

[10] Babalola, H. "Principal component analysis of factors contributing to incomplete construction project contracts in Lagos, Nigeria," *Nigerian Journal of Technology*, 44 (3), p. 390–400, Nov. 2025. doi: 10.4314/njt.v44i3.3.

[11] Jaswal, A. Singh, P. and Mondal, T. "Furfural – a versatile, biomass-derived platform chemical for the production of renewable chemicals," *Green Chemistry*, 24 (2), p. 510–551, 2022. doi: 10.1039/D1GC03278J.

[12] Dalmora, G. Filho, E. P. Maraschin Conterato, A. Roso, W. Pereira, C. and Dettmer, A. "Methods of corrosion prevention for steel in marine environments: A review," *Results in Surfaces and Interfaces*, 18 (1), p. 1-9, 2025. doi: https://doi.org/10.1016/j.rsurfi.2025.100430.

[13] Ali, B. Fahad, M. Ullah, S. Ahmed, H. Alyousef, R. and Deifalla, A. "Development of Ductile and Durable High Strength Concrete (HSC) through Interactive Incorporation of Coir Waste and Silica Fume," *Materials*, 15 (7), p. 1-21, 2022. doi: 10.3390/ma15072616.

[14] Le, H. Vu, C. Ho, N. and Luu, V."A method of controlling thermal crack for mass concrete structures: modelling and experimental study," *IOP Conference Series: Materials Science and Engineering*, 869 (7), p. 072054, 2020. doi: 10.1088/1757-899X/869/7/072054.

[15] Rizk, M. Frahat, N. Salama, I. Abd-Elrahman, M. and Agwa, I. "Effect of casting joint position on structural behavior of beams by HSC and SCHSC: experimental and numerical analysis," *Innovative Infrastructure Solutions*, 10 (12), p. 563, 2025. doi: 10.1007/s41062-025-02301-6.

[16] Toghroli, A. Hosseini, S. and Farokhizadeh, F. "Mechanical and durability properties of coal cinder concrete: Experimental study and GPR-based analysis," *Case Studies in Construction Materials*, 22 (1), p. 1-17, 2025. doi: 10.1016/j.cscm.2024.e04093.

[17] Quadri, A. Rufai, M. and Ajayi, J. "Shear Response of Reinforced Concrete Deep Beams Utilizing Waste Fiber-Reinforced Expanded Polystyrene Concrete Under Static Loading," *Nigerian Journal of Technology*, 44 (1), p. 9–16, 2025. doi: 10.4314/njt.v44i1.2.

[18] Quadri, A. Kupolati, W. Ackerman, C. and Ajayi, O. "Investigation Into The Causes And Effects of Cracks in Structural Members of Buildings And Possible Strategies For Repair," *Nigerian Journal of Technology*, 44 (2), p. 202–214, 2025. doi: 10.4314/njt.v44i2.4.

[19] Mezzal, S. Al-Azzawi, Z. and Najim, K. "Effect of discarded steel fibers on impact resistance, flexural toughness and fracture energy of high-strength self-compacting concrete exposed to elevated temperatures," *Fire Safety Journal*, 121 (1), p. 1-16, 2021. doi: https://doi.org/10.1016/j.firesaf.2020.103271.

[20] Zhao, Z. Qu, X. Li, F. and Wei, J. "Effects of steel slag and silica fume additions on

https://doi.org/10.4314/njt.2026.5752

compressive strength and thermal properties of lime-fly ash pastes," *Construction and Building Materials*, 183 (1), p. 439–450, 2018. doi: https://doi.org/10.1016/j.conbuildmat.2018.05.220.

[21] Kumar, M. Saikrishnamacharyulu, I. Mohanta, N. Ashutosh, A. Mishra, P. and Samantaray, S. "Mechanical behaviour of high strength concrete modified with triple blend of fly ash, silica fume and steel fibers," *Materials Today: Proceedings*, 65, p. 933–942, 2022, doi: https://doi.org/10.1016/j.matpr.2022.03.528.

[22] Choi, E. Ostadrahimi, A. and Lee, J. "Pullout resistance of crimped reinforcing fibers using cold-drawn NiTi SMA wires," *Construction and Building Materials*, 265 (1), p. 1-14, 2020. doi: https://doi.org/10.1016/j.conbuildmat.2020.120858.

[23] Rashidi, M. Kargar, S. and Roshani, S. "Experimental and numerical investigation of steel fiber concrete fracture energy," *Structures*, 59 (1), p. 1-11, 2024. doi: https://doi.org/10.1016/j.istruc.2023.105792.

[24] Shaban, W. Yang, J. Su, H. Liu, Q. Tsang, D. C. W. Wang, L. Xie, J. and Li, L. "Properties of recycled concrete aggregates strengthened by different types of pozzolan slurry," *Construction and Building Materials*, 216 (1), p. 632–647, 2019. doi: https://doi.org/10.1016/j.conbuildmat.2019.04.231.

[25] Rangrazian, M. Madandoust, R. Mahjoub, R. and Raftari, M. "Experimental investigations on the engineering properties of pozzolanic concrete reinforced with fibers and the reduction of CO_2 emissions: A case study on local mineral pozzolan," *Mater Today Communications*, 34 (1), p. 1-18, 2023. doi: https://doi.org/10.1016/j.mtcomm.2022.105129.

[26] Shen, D. Kang, J. Jiao, Y. Li, M. and Li, C. "Effects of different silica fume dosages on early-age behavior and cracking resistance of high strength concrete under restrained condition," *Construction and Building Materials*, 263 (1), p. 1-12, 2020. doi: https://doi.org/10.1016/j.conbuildmat.2020.120218.

[27] Liu, Y. Shi, C. Zhang, Z. Li, N. and Shi, D. "Mechanical and fracture properties of ultra-high performance geopolymer concrete: Effects of steel fiber and silica fume," Cement and Concrete Composites, 112 (1), p. 1-13, 2020. doi: https://doi.org/10.1016/j.cemconcomp.2020.103665.

[28] Saba, A. Khan, A. Akhtar, M. Khan, N.. Koloor, S. Petrů, M. and Radwan, N. "Strength and flexural behavior of steel fiber and silica fume incorporated self-compacting concrete," *Journal of Materials Research and Technology*, 12 (1), p. 1380–1390, 2021. doi: https://doi.org/10.1016/j.jmrt.2021.03.066.

[29] Xie, J. Zhang, Z. Lu, Z. and Sun, M. "Coupling effects of silica fume and steel-fiber on the compressive behaviour of recycled aggregate concrete after exposure to elevated temperature," *Construction and Building Materials*, 184 (1), p. 752–764, 2018. doi: https://doi.org/10.1016/j.conbuildmat.2018.07.035.

[30] Pi, Z. Xiao, H. Liu, R. and Li, H. "Combination usage of nano-SiO2-coated steel fiber and silica fume and its improvement effect on SFRCC," *Composites Part B: Engineering*, 221 (1), p. 1-12, 2021. doi: https://doi.org/10.1016/j.compositesb.2021.109022.

[31] Singh, G. "Study on collective effect of silica fume and steel fiber on strength and durability properties of concrete," *Materials Today: Proceedings*, 37 (1), p. 2256–2265, 2021. doi: https://doi.org/10.1016/j.matpr.2020.07.701.

[32] Quadri, A. Kupolati, W. Ackerman, C. Snyman, J. and Ndambuki, J. "Assessment of shear capacity of reinforced concrete slender beams using tire steel fiber," *Innovative Infrastructure Solutions*, 10 (3), p. 92, 2025. doi: 10.1007/s41062-025-01879-1.

[33] Dalvand, A. and Ahmadi, M. "Impact failure mechanism and mechanical characteristics of steel fiber reinforced self-compacting cementitious composites containing silica fume," *Engineering Science and Technology, an International Journal*, 24 (3), pp. 736–748, 2021. doi: https://doi.org/10.1016/j.jestch.2020.12.016.

[34] Sharma, R. and Senthil, K. "An investigation on mechanical and microstructural properties of hybrid fiber reinforced concrete with manufactured sand and recycled coarse aggregate," *Journal of Building Engineering*, 69 (1), p. 1-22, 2023. doi: https://doi.org/10.1016/j.jobe.2023.106236.

[35] Shirodkar, V. Patel, R. Verma, M. and Mahate, V. "An investigation into the

https://doi.org/10.4314/njt.2026.5752

durability of concrete using red mud as a substitute in cement," *Materials Today: Proceedings*, 2023. doi: https://doi.org/10.1016/j.matpr.2023.12.010.

[36] Qader, M. Ibrahim, A. Alaidaros, A. Abdulkareem, A. Alwuayl, A. Alsaluli, A. Alwetaishi, M. Alsehli, M. and Alghamdi, S. "Investigating trends and costs associated with designing concrete mixes using different methods by computer programs," *Advances in Civil Engineering*, 2022 (1), p. 1-13, 2022. https://doi.org/10.1155/2022/2526833

https://doi.org/10.4314/njt.2026.5752