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# ENHANCING TENSILE PERFORMANCE OF CONCRETE USING STEEL FIBER REINFORCEMENT: AN EXPERIMENTAL STUDY

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***Abstract-*** Conventional concrete, despite its widespread use, exhibits low tensile and shear strength, often leading to brittle failure under stress if not adequately reinforced. To address this limitation, steel fibers are increasingly employed to enhance mechanical performance. The effectiveness of Steel Fiber Reinforced Concrete (SFRC) largely depends on the bond between the fibers and the surrounding concrete matrix. This bond influences critical factors such as fracture initiation, crack spacing, and crack width. A comprehensive understanding of these bond mechanisms is essential for optimizing SFRC performance. This study investigates the role of steel fiber reinforcement in improving tensile behavior, highlighting that incorporating up to 5% steel fibers significantly increases the tensile strength of concrete. Furthermore, the inclusion of fibers enhances the pull-out resistance, contributing to improved crack control and overall structural integrity. The findings support the practical application of SFRC in structures requiring enhanced toughness and durability.

***Keywords-*** Bond Behavior, Crack Control, Steel Fiber Reinforced Concrete (SFRC), Tensile Strength Enhancement.

## 1 Introduction

Concrete is susceptible to cracking due to various internal and external factors. In modern construction, applications such as bridge decks, highway pavements, and industrial floors demand materials with greater ductility and higher energy absorption capacity [1]. However, conventional concrete exhibits low tensile strength, limited ductility, poor crack resistance, and minimal energy absorption. These weaknesses are primarily due to the presence of internal microcracks, which are inherent in the material and often lead to brittle failure under stress [2]. To enhance concrete performance in such demanding applications, it is essential to address these deficiencies by improving its toughness and minimizing inherent flaws [3].

Concrete is inherently brittle and exhibits low post-cracking strength and limited ductility [4]. Cracks in plain concrete typically appear when applied tensile stresses exceed its tensile capacity [5]. To address this issue, the incorporation of short, discrete fibers into the concrete matrix has proven effective in reducing microcracking and controlling the spread of localized macrocracks. This also enhances post-cracking strength and improves ductile behavior under load [6]. However, it is important to note that fibers have minimal influence on the material’s performance prior to the initiation of cracking [7]. The use of short reinforcing fibers dates back thousands of years and has been applied in various materials throughout history. In modern concrete applications, this concept has evolved significantly. Today, a wide range of fibers including steel, other metallic types, and polymeric materials are used to enhance the mechanical properties of concrete [8].

When fiber reinforcement takes the form of short, discrete fibers, it functions well as stiff inclusions in the concrete matrix [9]. Steel fiber reinforcement cannot be regarded as a direct replacement for longitudinal reinforcement in reinforced and prestressed structural components due to their physical resemblance to aggregate inclusions [10]. However, it is expected that adding fibers to the concrete's body or creating a tensile skin will improve the structural components' resistance to deformation, cracking, and other serviceability conditions because of the material qualities of fiber concrete [11].

Fiber reinforcement can be applied in various forms to meet different structural needs. In one approach, the fibers are randomly and uniformly dispersed in three dimensions throughout the concrete, enhancing both shear resistance and tensile performance [12]. Alternatively, fibers can be aligned in a two-dimensional arrangement to act as a tensile skin over conventional steel reinforcement. This method provides additional control over cracking and further strengthens the structure [13]. Although steel fibers are known to improve concrete performance, a clearer understanding of their effect on tensile strength, particularly under split tensile conditions, is still needed. This study addresses that by experimentally evaluating the tensile behavior and crack resistance of SFRC using a 5% steel fiber dosage. The novelty lies in examining the bond mechanisms and pull-out resistance of the fibers, providing practical insights into optimizing SFRC for applications requiring improved ductility and toughness.

# 2 Research Methodology

## *2.1 Raw Materials*

Plain concrete was prepared using ordinary Portland cement, clean drinking water, locally sourced sand, and aggregates with mixed sizes of 12 mm and 6 mm (maximum size ≤12 mm). To produce Steel Fiber Reinforced Concrete (SFRC), 50 mm long steel fiber strands were incorporated into the same mix. Prior to mixing, the steel fibers were thoroughly cleaned to remove surface dust and allowed to dry. After cleaning, the fibers were manually cut to a uniform length of 50 mm to ensure consistency in the mix.

## *2.2 Mix Proportions and Casting*

For plain concrete (PC), a mix ratio of 1:2:4 (cement, sand, and aggregate) was used, maintaining a constant water-to-cement (w/c) ratio of 0.5. All dry materials were added to a drum-type mixer and mixed for one minute. The required amount of water was then added, and mixing continued for an additional five minutes to achieve a homogenous mixture.

For Steel Fiber Reinforced Concrete (SFRC), steel fibers were incorporated at 5 percent of the cement's weight. The dry components, including cement, sand, aggregate, and steel fibers, were added in three stages. Two-thirds of the water was introduced initially, followed by four minutes of mixing. After the remaining one-third of the water was added, mixing continued for another two minutes to ensure uniformity. The SFRC mix was then poured into molds in three layers. Each layer was compacted using a tamping rod with 25 blows to ensure proper consolidation.

## *2.3 Testing Methods and Key Parameters*

Slump tests for both plain concrete (PC) and steel fiber reinforced concrete (SFRC) were conducted in accordance with ASTM C143 [14]. The tensile strength of concrete was evaluated using the split tensile test, following ASTM C496 [15]. The slump values recorded were 125 mm for PC and 12.5 mm for SFRC, as shown in Table 1. This significant reduction in slump for SFRC indicates lower workability compared to PC. Although both mixes maintained a constant water-to-cement ratio of 0.5, SFRC exhibited reduced workability. This is because steel fibers absorb some water from the mix, reducing overall fluidity. Additionally, the relatively long steel fibers caused congestion within the mix, further contributing to the lower slump value.

*Table 1 Slump Values for PCC and SFRC Mixes*

| Sr. | Concrete | W/C | Slump (mm) |
|---|---|---|---|
| 1 | PC | 0.5 | 125 |
| 2 | SFRC | 0.5 | 12.5 |

# 3 Results and Analysis

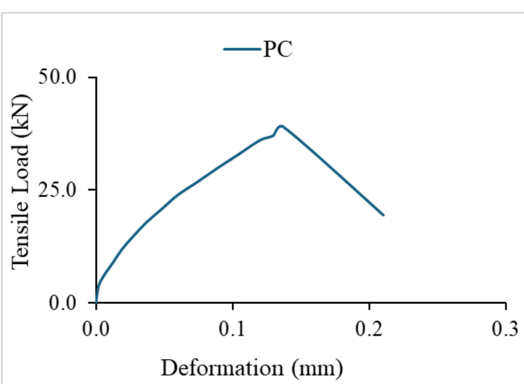
## 3.1 Tensile Behaviour

The tensile behavior of concrete is significantly enhanced by the addition of steel fibers, as demonstrated by the increase in tensile strength from 6.5 MPa in plain concrete to 8.25 MPa in Steel Fiber Reinforced Concrete (SFRC). Steel fibers act as crack arresters by bridging microcracks and limiting their propagation under tensile stress. This results in improved tensile capacity, greater ductility, and enhanced resistance to cracking. As a consequence, the concrete can sustain higher loads even after initial cracking, minimizing the risk of sudden brittle failure. These improvements contribute to increased structural resilience, durability, and long-term performance. The effectiveness of this reinforcement is visually evident in Figure 1, which displays the tested specimen after undergoing split tensile loading.

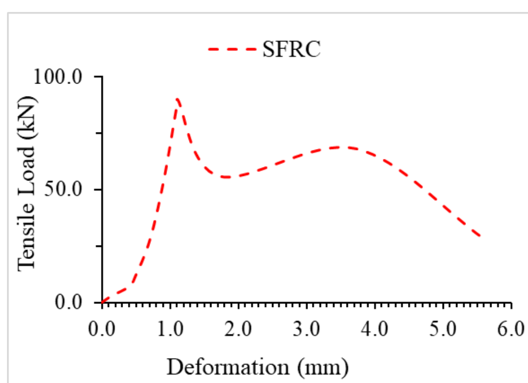
*Figure 1: Tested specimen under splitting tensile load*

## 3.2 Load-deformation Behaviour

The load-deformation behavior of plain concrete (PC) and Steel Fiber Reinforced Concrete (SFRC) is illustrated in Figure 2(a) and Figure 2(b), respectively. The curve for PC, shown in Figure 2(a), exhibits a steep rise to the peak load followed by a sudden drop, indicating a brittle failure mode with minimal energy absorption. In contrast, Figure 2(b) displays the load-deformation response of SFRC, which demonstrates a more ductile behavior. The SFRC reaches a higher peak load and shows an extended post-peak region, indicating its ability to sustain additional load after cracking. This behavior highlights the improved toughness, energy absorption, and post-crack performance of SFRC compared to conventional plain concrete.




a)




b)

*Figure 2: Load-deformation curve, a. Plain concrete, and b. Steel fiber reinforced concrete*

### *3.3 Enhanced Tensile Performance with Steel Fibers*

Concrete has low tensile strength, making it susceptible to cracking under tension. Steel fibers help overcome this limitation by bridging cracks and improving both tensile strength and ductility. This results in greater toughness, allowing the material to deform more without sudden failure. Consequently, fiber-reinforced concrete is better equipped to handle both tensile and flexural stresses. To further illustrate this improvement, Figure 3 presents a bar chart comparing the tensile load capacities of plain concrete (PC) and Steel Fiber Reinforced Concrete (SFRC). The chart clearly shows SFRC's superior performance in both strength and post-crack behavior, making it ideal for applications requiring enhanced durability and crack control.

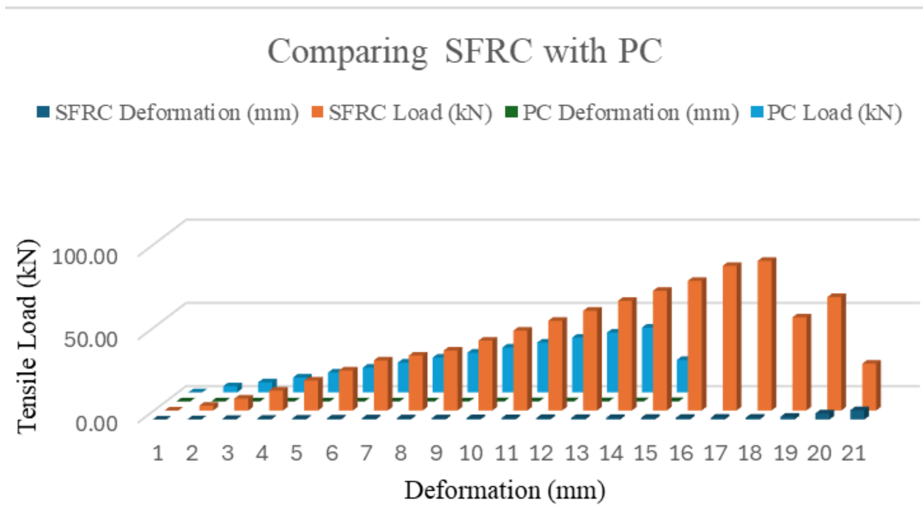



*Figure 3: Comparison of Tensile Load and Deformation Behaviour of SFRC and PC*

## 4 Practical Implementation

Future research should aim to optimize the mix design and fiber dosage to achieve a balance between improved mechanical properties and sufficient tensile strength. Investigating advanced techniques to strengthen the bond between steel fibers and the concrete matrix could further enhance performance. Detailed studies on the long-term durability, environmental resistance, and structural applications of SFRC are essential to support its widespread adoption. In addition, the development of standardized guidelines, supported through collaboration with industry professionals, will be important for integrating SFRC into mainstream construction practices. However, potential cost implications and scalability challenges in large-scale applications should also be considered to ensure practical feasibility. These efforts will help enable the practical use of SFRC in a variety of infrastructure projects. Overall, the findings of this study highlight the potential of SFRC as a sustainable and energy-absorbing material, contributing to the advancement of eco-friendly and resilient construction solutions.

## 5 Conclusions and Recommendations

Based on the findings from the experimental investigation conducted on Steel Fiber Reinforced Concrete (SFRC) specimens, the following conclusions can be drawn regarding its tensile strength and post-cracking behavior in comparison to plain concrete (PC):

1. Workability: The addition of steel fibers significantly reduces workability, with slump values dropping from 125 mm (PC) to 12.5 mm (SFRC). This is due to fiber-induced water absorption and mix congestion. Proper mix design and placement techniques are essential to ensure uniform compaction and performance.
2. Tensile Strength: SFRC showed a 26.9% increase in tensile strength compared to PC, rising from 6.5 MPa to 8.25 MPa. Steel fibers bridge microcracks and prevent propagation, improving both strength and structural integrity.

3. Load-Carrying Capacity and Toughness: Load-deformation results indicate that SFRC retains load capacity after cracking and exhibits a more ductile failure mode. This highlights its improved toughness and energy absorption, making it ideal for structural applications under tension.
4. Crack Resistance and Durability: SFRC enhances crack control, reducing crack width and spacing. These improvements support long-term durability and make SFRC a suitable option for pavements, overlays, and other crack-sensitive structures.

In conclusion, SFRC improves tensile performance, ductility, and crack resistance compared to plain concrete. While workability is reduced, proper mix management can address this issue. The findings support the wider use of SFRC in sustainable and resilient structural applications. Future research should explore long-term durability and field performance for broader adoption.

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