EXPERIMENTAL INVESTIGATION ON THE FLEXURAL BEHAVIOR OF STEEL FIBER IN CONCRETE

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Abstract- Concrete is valuable for construction because of its strong resistance to compression, but it can break easily under bending stresses. To improve both the durability and service life of concrete, its flexural strength must be enhanced. This study intends to evaluate whether infusing 5% steel fibers by cement weight can lead to better flexural strength and crack resistance in concrete than plain cement concrete (PCC). Workability is assessed by testing slump on samples of concrete made with and without steel fibers. The performance of the mixes is evaluated in flexural tests and the samples are also checked visually to observe the pattern of cracking. Slump values and crack patterns are recorded to observe the impact of steel fibers on concrete's behavior. The slump of SFRC is smaller than that of PCC, demonstrating that the fiber content decreases the workability of concrete. SFRC has showed a higher bending strength i.e. 28% more than PCC. Examining the surface shows that SFRC forms less and narrower cracks, showing that steel fibers randomly arranged make the material tougher. The findings indicate that 5% steel fibers ensure stronger flexural behavior in concrete.

Keywords- Steel Fiber Reinforced Concrete, Flexural Strength, Crack Resistance, Workability

1 Introduction

Although conventional plain concrete is very brittle, it is the most popular construction material globally. The more strength a PC has, the more brittle it can become [1]. The composition of concrete includes aggregates and paste. As the paste hardens due to the chemical reaction of the cement and water, the aggregates are bound together by the paste, which is made of cement and water, to make a rock like mass [2]. Being weak in tension, concrete inevitably forms cracks when put under tensile stress [3] [4] [5]. Concrete, particularly at low strains, is extremely brittle, and owing to the low strain capacity of the material in tension, it has low toughness. The trend of high-performance concrete in the current infrastructure sector is such that, steel fibers are being increasingly used to overcome brittleness and insufficient tensile strength in plain concrete [6]. Steel fibers offer crack-arresting enhancements that are attributed to risen flexural toughness and post-cracking loads [7]. Being a widely used material due to its high compressive strength, it is shown that concrete has major limitations: brittleness and low tensile strengths. It has been shown that the addition of dispersed fibers is an effective means of improving toughness and controlling crack propagation. The implementation of fiber reinforcement to concrete structures enhances toughness, as well as the overall performance.

Fibers in concrete help in increasing the strength, toughness, cracking and tension performance of the concrete, since the randomly distributed fibers restrict the unstable propagation of the cracks at micro and macro levels [8]. Research has declared that steel fibers enhance not only strength at ultimate limit, but also serviceability performance particularly in resistance of width of crack [9]. SFRC has demonstrated better mechanical properties than concrete reinforced using other synthetic fibers (i.e., polyvinyl alcohol, polypropylene) in terms of improved post-cracking tensile resistance, toughness, ductility, impact resistance, fatigue strength [10]. The mechanical strength of SFRC is enhanced as long as the volume fraction of steel fibers ranges between 0% and 2%, and begins to decrease with the volume fraction further than 2% [11]. Recently, increased fiber dispersion and the use of hybrid systems have demonstrated potential to address these problems without losing their crack control abilities [12]. Fibers make concrete stronger, tougher and more resistant to cracking by preventing crack growth at each level. Steel fibers stand out because they can distribute tension and stop cracks from growing. Even so, too much fiber can form clustering and new hybrid systems are designed to prevent this.

The flexural performance is one of key parameters used to ascertain the structural performance of the reinforced concrete member and it has been illustrated that steel fibers improve the performance in these members under any form of loading conditions [13]. Although ASTM C1609 [14] and EN 14651 [15] explain how to test flexural performance, they do not clearly describe the ways microcracking occurs. Recent techniques such as digital image correlation (DIC), now allow detailed observation of deformation and very small cracks [16]. Advanced characterization methods add to the traditional tests, helping us better understand how SFRC resists cracks from the start of loading through to the final point of failure. [17]When the surface of steel fibers is deliberately roughened or irregularly profiled, ingress of such fibers leads to a large increase in the degree of mechanical friction and interlocking within the interface, which then slows onset and advancement of cracks under flexural loading [18]. Still, a consistent way to relate micromechanical observations to the overall flexibility of hybrid fiber systems is yet to be found, especially when these systems have a mix of steel and other fibers [19]. Knowledge about how fibers in SFRC influence crack width is still limited, despite the usual testing procedures. Advanced tools such as digital image correlation help scientists discover more about microcracking and crack resistance. Even so, the link between small-scale properties and the performance of hybrid fiber systems has yet to be fully explored.

Although plain concrete is commonly used, it breaks easily under stress because it does not have much tensile strength. The addition of dispersed steel fibers greatly improves the toughness and bending ability of concrete by crossing over cracks and managing the stress better. Such materials hold back crack formation and slower crack propagation, enhancing how the material absorbs energy and performs afterwards. The challenge of fiber clustering at high volumes persists, but technology such as DIC and the growth of hybrid fiber systems could offer good solutions for controlling cracks and enhancing flexural strength of concrete.

2 Research Methodology

2.1 Raw Material

Ordinary Portland Cement, sand, coarse aggregate and clean water are the raw materials used to make plain concrete. A standard mix of cement, sand and coarse aggregate in the ratio of 1:2:4, with a water-cement ratio of 0.5, was used for regular structural applications. SFRC used the basic materials of regular concrete, like cement and coarse aggregate, along with water, together with 2-in long steel fibers at 5% of the cement weight. These fibers were positioned throughout the mix layer by layer to improve its toughness, ability to resist cracks and overall mechanical strength.

2.2 Mix Design

2.2.1 Plain Concrete (PC)

The mixture consisted of a 1:2:4 ratio (cement: sand: coarse aggregate) and a water-cement ratio of 0.5. The specimens used were 4 cylinders and 3 beamlets for evaluating strength and workability. Materials were dry-mixed first and then water was added to make the mix workable. A slump test was carried out first to confirm how workable the material was. Concrete was gradually layered in pre-oiled molds, compacted with a tamping rod, smoothed, labelled and then cured in water for 28 day after being demolded at 24 hours. Mix design of Plain Cement Concrete is shown in Table 1 and Figure 1 represents the slump test performed on PCC.

Table 1 Plain Concrete Mix Design

Component	Ratio	Weight (kg)
Cement	1	6.5
Sand	2	13
Coarse Aggregate	4	26
Water (w/c = 0.5)	0.5	3.25

Figure 1 PCC Slump Test

2.2.2 Steel Fiber Reinforced Concrete (SFRC)

The same mixture (1:2:4, with a water-cement ratio of 0.5) was put together by adding 5% 2-inch steel fibers. Three containers were used to divide the materials (cement, sand, aggregates and steel fibers) into three sections for layered mixing. Materials and fibers were distributed in the mixer in three layers, so fibers were equally distributed. Materials were dry-mixed first and then water was added to make the mix workable. A slump test was carried out first to confirm how workable the material was. Then, the SFRC was poured into molds, tamped with rod, smoothed, labelled, then demolded after 24 hours and immersed in water for curing for 28 days. Mix design of Steel Fiber Reinforced Concrete is shown in Table 2 and Figure 2 represents the slump test performed on SFRC.

Table 2 SFRC Mix Design

Component	**Weight (kg)**	**Fiber Addition**
Cement	6.5	–
Sand	13	–
Coarse Aggregate	26	–
Steel Fibers	0.325	5% of cement
Water	3.25	–

Figure 2 SFRC Slump Test

2.3 Testing and Parameters

2.3.1 Testing Procedures

Tests on fresh concrete were carried out to assess how well both Plain Cement Concrete (PCC) and Steel Fiber Reinforced Concrete (SFRC) could be mixed and poured. For the slump test, the slump cone had a height of 300 mm, a base with a

200 mm diameter and a top diameter of 100 mm, as per ASTM C143. Immediately after mixing, the slump value was observed to ensure that the assessment of the concrete's workability was correct. A visual observation was necessary to observe for segregation and bleeding and to ensure that the fibers were evenly distributed in the SFRC mixture. Flexural strength tests on beam samples were done for the hardened concrete after 28 days to determine its structural behavior under bending loads.

2.3.2 Key Parameters

The key parameters focused on included the workability, flexural strength and the first-crack strength of both Plain Cement Concrete (PCC) and Steel Fiber Reinforced Concrete (SFRC). Slump test results were used to evaluate the workability and flexural and first-crack strengths were evaluated using a Universal Testing Machine and ASTM C1609. The findings from these tests show how the concrete behaves mechanically and how resistant it is to early cracks. Table 3 below lists the measured results for the various parameters.

Table 3 Key Parameters of Test

Parameter	Testing Method	Equipment Used	Measured Values
Workability	ASTM C143	Slump Cone, Tamping Rod	PCC: 125 mm SFRC: 12.5 mm
Flexural Strength	ASTM C1609	UTM	PCC: 3.540 ± 1.2 MPa, SFRC: 4.95 ± 0.5 MPa
First-Crack Strength	ASTM C1609	UTM	PCC: 3.1 ± 1.26 kN @ 0.8 mm, SFRC: 4.5387 ± 0.54 kN @ 0.9 mm

3 Results

3.1 Flexural Behavior

3.1.1 Plain Concrete

Figure 3 shows the flexural characteristics of plain concrete. From part (a), the curve shows load increasing smoothly up to the peak and when it exceeds the peak, the load decreases unexpectedly, suggesting a brittle failure. In part (b) pictures the experiment done during the flexural test, revealing how a plain concrete beam breaks suddenly once it reaches its maximum load, as seen by obvious cracking and debris.

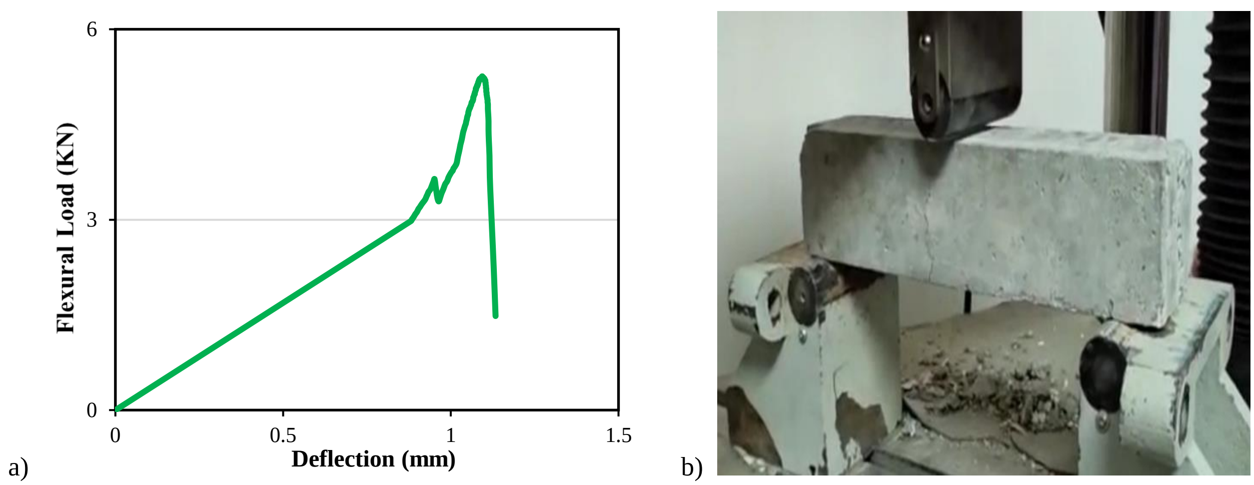
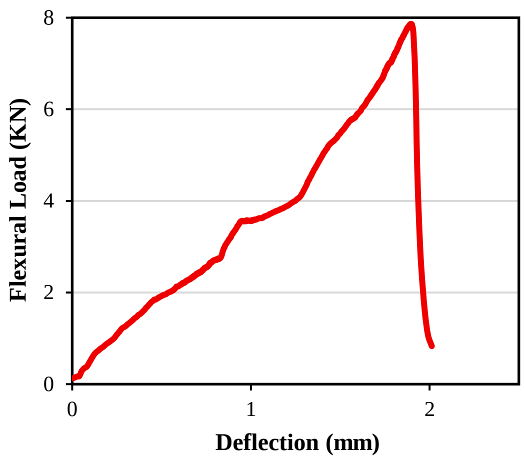


Figure 3 a) Load-deflection curve of plain concrete under flexural loading showing brittle failure behavior, b) Experimental setup and failure mode of plain concrete beam during flexural strength testing.

3.1.2 Steel Fiber Reinforced Concrete

Figure 4 represents how well steel fiber reinforced concrete (SFRC) performs against flexure. The load-deflection curve in (a) observes a better response to cracking and in (b), the fibers inside the specimen prevent it from fracturing and keep the structure intact.



a)

b)

Figure 4 (a) Load-deflection curve of Steel Fiber Reinforced Concrete; (b) SFRC specimen under three-point bending test.

3.2 Flexural Properties

A material's flexural properties reveal its bending behavior, ultimately showing how strong it is, how stiff it is and whether it will resist cracking or deformation. Such attributes are especially needed for assessing fiber-reinforced concrete, where higher post-crack strength and energy absorbed are sought. Commonly, modulus of rupture, flexural toughness and how the load affects the deflection are obtained through testing by ASTM C1609. Flexural Toughness Index (FTI) measures the capacity of a material to absorb energy having already cracked to a point of failure due to flexural (bending) loading. It applies in assessing the ductility and post cracking of fiber-reinforced concrete (FRC). The Table 4 illustrates the main flexural characteristics found by studying the data:

Table 4 Comparison of Flexural Strength Between PCC and SFRC

Specimen	Peak Load (kN)	Modulus of Rupture (MPa)	E1 (GPa)	E2 (kPa)	FTI (MPa)
PCC	5.248 ± 1.26	3.540 ± 1.2	1.3 ± 0.70	1.2 ± 0.1	1 ± 0.15
SFRC	6.724 ± 0.54	4.5387 ± 0.5	0.8 ± 0.02	1.3 ± 0.3	1.6 ± 0.2

4 Practical Implementation

Stee Fiber Reinforced Concrete (SFRC) is suitable for many construction projects because of its strong ability to flex and resist cracks. In industrial floors, airport pavements and heavy-duty slabs, Steel Fiber Reinforced Concrete (SFRC) is now commonly used to increase fatigue performance, load distribution, surface life as well as minimizing slab thicknesses and spacing between joints [20]. This helps prevent the terrible damage that occurs when water seeps into the pavement. Energy absorption and flexibility in beams and joints can be improved in SFRC structures, so fiber dosages of 5% may replace some conventional reinforcement. With SFRC in precast concrete, it is possible to create elements that are thinner and lighter, resistant to cracks and made in less time and at less expense. Cement composites are useful for repairs and reconstruction, as they supply immediate, secure overlays for restoring the strength of bridge decks and parking areas resistant to shrinking. A successful fiber-reinforced concrete mix is based on careful adjustment of the recipe so that fibers are distributed evenly and the mix can be handled without loss of shape, plus quality control. Overall, SFRC makes projects cheaper, less time-consuming to complete and more study, so it is commonly selected for many infrastructure projects.

5 Conclusion

The objective of this study was to improve the bending strength of plain cement concrete by including steel fibers. Using standard mix recipes and particular test methods (ASTM C143, C78 and C1609), both PCC and SFRC were produced, set aside to cure and tested. Following are conclusions from the experimental study:

- SFRC demonstrated better strength, the ability to take greater loads and toughness which means it is more able to handle loads than PCC.
- After being cracked, SFRC resisted forces due to fiber bridging, but PCC broke without warning, showing brittle behavior.
- Although there was a slight decrease in workability because of the fiber, SFRC kept a good slump, making it suitable for building sites.

Because of fiber bridging, SFRC remained tougher and more resistant to cracks than PCC. Even with workability slightly reduced, SFRC slump stayed sufficient for building purposes.

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