Experimental study on addition of Steel Fibres in Conventional Concrete

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Abstract. Fibre Reinforced Concrete (FRC) is a composite material which consists of constituents of conventional concrete along with the addition of fibres. The two major classifications of fibres are natural and artificial fibres. The main purpose of use of fibres in concrete is to arrest the formation and propagation of cracks in concrete. The purpose of this study is to compare the mechanical properties of Steel Fibre Reinforced Concrete with the Conventional Concrete. Steel fibres with four different percentages such as 0.5%, 1.0%, 1.5% and 2.0% were added to the concrete. Three different grades of concrete such as M40, M50, M60 were experimented in this study. Compressive strengths of cube specimens were calculated for these dosages with a curing period of 14 and 28 days. Optimization of the SFRC was done through the Compressive strength test results. It was observed that fibre dosage of 1.5% showed maximum values when compared with other percentages. With the optimized percentage of Steel Fibre, split tensile strength test was carried out. It was observed that the addition of steel fibres in concrete improved the compressive strength and split tensile strength of steel fibre reinforced concrete. At 28 days of curing with the addition of 1.5% of fibres, the compressive strengths of M40, M50 and M60 grades of concrete increased by 14.6%, 13.7% and 11.8% respectively compared with conventional concrete. Similarly, at 28 days of curing with the addition of 1.5% of fibres, the split tensile strengths of M40, M50 and M60 grades of concrete increased by 7.66%, 8.59% and 9.23% respectively compared with conventional concrete. In addition, a microstructural analysis was done to determine the material characterisation through Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD).

Keywords- Steel Fibre Reinforced Concrete, optimization, compressive strength, split tensile strength, hooked end, anchorage, crack arrestor

1. Introduction
Fibre Reinforced Concrete is a type of special concrete derived from addition of discontinuous and discrete fibres to conventional concrete to improve its physical, mechanical and durability properties. Different types of natural and artificial fibres are used in concrete matrix to form the Fibre Reinforced Concrete [4]. Fibres can also be placed with particular orientation or randomly according to its structural applications [1,2]. The properties of Steel Fibre Reinforced Concrete depend on the aspect ratio of the
fibre, length of the fibre, orientation and distribution of the fibre in the concrete matrix [1]. The structural properties such as compressive strength, tensile strength, flexural strength, impact strength and flexural toughness is improved in steel fibre reinforced concrete due to the addition of steel fibres [3]. Also, in addition to these properties, the ductility and durability also gets improved due to the addition of steel fibres to Conventional Concrete (CC). [3-5]. In the previous researches, the resistance to post cracking of the specimen or material was influenced by the geometry and orientation of steel fibres as investigated by Shah and Rangan [4]. Many researches have experimented on the influence of geometry of fibre, aspect ratio of the fibre, orientation of fibre and volume fraction of fibres over the Steel Fibre Reinforced Concrete [6-10]. From these researches it is concluded that the addition of steel fibre in concrete matrix improves the toughness of concrete. It also improves the flexural and tensile strength of concrete. It is also observed that the crimped or hooked end steel fibres are more effective than the other types of steel fibres due to high anchorage provided by these fibres in the concrete matrix [11-13]. The Steel Fibre Reinforced Concrete (SFRC) also prevents the development of cracks and propagation of cracks in concrete [14,15].

1.1 Present work
This study mainly focuses on the optimization of Steel Fibre Reinforced Concrete in three different grades of concrete such as M40, M50 and M60. The cube compressive strengths of Steel Fibre Reinforced Concrete with various percentages of steel fibres such as 0%, 0.5%, 1.0%, 1.5% and 2.0% were calculated. With the optimized percentage of steel fibre, the split tensile strength of Steel Fibre Reinforced Concrete was calculated. The results of Steel Fibre Reinforced Concrete were compared with the Conventional Concrete. A microstructural analysis such as Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) was done to the steel fibres and Steel Fibre Reinforced Concrete to evaluate the development of cracks and to study the characteristics of the fibre.

2. Materials and Test programs
This study focuses on the optimization of percentage of Steel Fibres in Concrete with the compressive strength test results and supported by split tensile strength. Three different grades of concrete such as M40, M50 and M60 grades have been adopted in this experimental investigation. Four different dosages of steel fibres such as 0%, 0.5%, 1.0%, 1.5% and 2.0% have been used in this study. With the optimum dosage of steel fibre, the split tensile strength of Steel Fibre Reinforced Concrete was calculated.

2.1 Materials

2.1.1 Steel Fibre
The hooked end steel fibres have a length of 60 mm, a diameter of 0.75 mm and an aspect ratio of 80 was used in this research work. Figure 1 shows the steel fibre used in this research work. The properties of steel fibre used for this experimental study are shown in Table 1.

![Steel Fibre](image1.jpg)
Table 1. Properties of Steel Fibre used in the concrete

| Property of Steel Fibre | Value     |
|-------------------------|-----------|
| Shape                   | Straight  |
| Surface                 | Plane     |
| Cross-section           | Circular  |
| Anchorage               | Hooked ends|
| Length                  | 60 mm     |
| Diameter                | 0.75 mm   |
| Aspect ratio            | 80        |

2.1.2 Cement
In this experimental investigation, OPC grade 53 cement was used confirming IS: 12269-2013. The specific gravity was calculated as 3.18.

2.1.3 Fine aggregate
The fine aggregate used in this experimental study is the locally available river sand with its maximum size 4.75 mm confirming to zone II specification with respect to IS 2386 – 1963. The specific gravity was calculated as 2.56.

2.1.4 Coarse aggregate
The coarse aggregates used were crushed stone with size 20 mm and 12.5 mm confirming to IS 2386 – 1963. The coarse aggregates were graded with 40% of 12.5 mm aggregates and 60% of 20 mm aggregates. The specific gravity was calculated as 2.69.

2.1.5 Admixture
Superplasticizer was also used to improve the workability of the concrete since steel fibres reduce the workability of concrete.

2.2 Mix Proportions
In this study, three different concrete grades were adopted such as M40, M50 and M60. The mix designs were calculated and designed using IS 10262-2009 as reference. The mix proportions for different grades are shown in Table 2.

Table 2. Recommended Mix Proportions of different grades

| Constituents            | Quantity        |
|-------------------------|-----------------|
|                         | M40             | M50              | M60              |
| Cement (kg/m³)          | 328.33          | 394              | 443.25           |
| Fine aggregate (kg/m³)  | 792.9           | 739.25           | 703.85           |
| Coarse aggregate (kg/m³)| 1240.18         | 1206.15          | 1148.88          |
| Chemical admixture (kg/m³)| 6.57           | 7.88             | 8.86             |
| Water/Cement ratio      | 0.45            | 0.40             | 0.40             |
3. Experimental program

3.1 Compressive strength Test
The Compressive strength test was conducted by casting cube specimens of size 150×150×150 mm according to the specifications given in IS 516:2018 as shown in Figure 2. The concrete specimens were cast for conventional concrete and for different percentages of Steel Fibre such as 0.5%, 1.0%, 1.5% and 2.0%. The concrete cube specimens were cast, demoulded and cured in water for two different curing period of 14 and 28 days. Three specimens were cast for each percentage and curing period. After the curing period the concrete cube specimens were tested in Universal Compression Testing Machine as shown in Figure 3. With the compressive strength test results the optimum percentage of Steel Fibre Reinforced Concrete was determined. The same procedure was followed for all three grades M40, M50 and M60 grades of concrete.

![Figure 2. Cube specimen.](image1)

![Figure 3. Testing of cube specimen in CTM.](image2)

3.2 Split tensile strength test
The split tensile strength test was conducted by casting cylindrical specimens of size 150mm diameter and 300mm height according to the specifications given in IS 516:2018 as shown in Figure 4. The concrete specimens were cast for conventional concrete and for optimum percentage of Steel Fibre Reinforced Concrete. The concrete cylindrical specimens were cast, demoulded and cured in water for two different curing period of 14 and 28 days. Three specimens were cast for each percentage and curing period. After the curing period the concrete cylindrical specimens were tested in Universal Compression Testing Machine as shown in Figure 5. The same procedure was followed for all three grades M40, M50 and M60 grades of concrete.

![Figure 4. Cylindrical specimen.](image3)

![Figure 5. Testing of cylindrical specimen in CTM.](image4)
4. Test Results and Discussion

4.1 Compressive Strength

The cube specimens were tested in Compression Testing Machine after curing period of 14 and 28 days. Three cube specimens were cast for each percentage and curing period. The average compressive strengths of three cubes were determined as shown in Table 3, 4 and 5. The compressive strength test results showed that addition of steel fibres to concrete improved the compressive strength of concrete. The optimum dosage of steel fibre was derived at 1.5% by volume. With 1.5% fibre dosage for M40 grade of concrete, the compressive strength increased by 13.7% and 14.6% for 14 and 28 days respectively compared with conventional concrete. With 1.5% fibre dosage for M50 grade of concrete, the compressive strength increased by 10.4% and 13.7% for 14 and 28 days respectively compared with conventional concrete. With 1.5% fibre dosage for M60 grade of concrete, the compressive strength increased by 9.3% and 11.7% for 14 and 28 days respectively compared with conventional concrete. The graphical representation of compressive strengths of conventional and Steel Fibre Reinforced Concrete are shown in Figure 6, 7 and 8.

Table 3. Average compressive strength values for M40 grade of concrete

| Specimen   | Compressive strength (N/mm²) |
|------------|------------------------------|
|            | 14 Days | 28 Days |
| Conventional | 35.9    | 40.9    |
| 0.5% SFRC   | 37.5    | 42.1    |
| 1.0% SFRC   | 39.4    | 44.1    |
| 1.5% SFRC   | 40.8    | 45.7    |
| 2.0% SFRC   | 40.0    | 44.7    |

Table 4. Average compressive strength values for M50 grade of concrete

| Specimen   | Compressive strength (N/mm²) |
|------------|------------------------------|
|            | 14 Days | 28 Days |
| Conventional | 43.4    | 50.1    |
| 0.5% SFRC   | 45.5    | 52.8    |
| 1.0% SFRC   | 46.6    | 53.1    |
| 1.5% SFRC   | 47.9    | 55.8    |
| 2.0% SFRC   | 46.8    | 54.2    |
Table 5. Average compressive strength values for M60 grade of concrete

| Specimen  | Compressive strength (N/mm²) |
|-----------|------------------------------|
|           | 14 Days | 28 Days |
| Conventional | 53.7    | 60.2    |
| 0.5% SFRC  | 56.3    | 62.1    |
| 1.0% SFRC  | 56.7    | 62.9    |
| 1.5% SFRC  | 58.7    | 65.9    |
| 2.0% SFRC  | 57.5    | 63.5    |

Figure 6. Graphical representation of Compressive strength results for M40 grade of concrete

Figure 7. Graphical representation of Compressive strength results for M50 grade of concrete
4.2 Split tensile Strength

The cylindrical specimens were tested in Compression Testing Machine after curing period of 14 and 28 days. Three cylindrical specimens were cast for optimum percentage and curing period. The average split tensile strengths of three cubes were determined as shown in Table 6. The split tensile strength test results showed that addition of steel fibres to concrete enhanced the split tensile strength of concrete. With the 1.5% optimum dosage of Steel Fibre, split tensile strength was calculated. For M40 grade of concrete, the split tensile strength increased by 13.7% and 14.6% for 14 and 28 days respectively compared with conventional concrete. For M50 grade of concrete, the split tensile strength increased by 10.4% and 13.7% for 14 and 28 days respectively compared with conventional concrete. For M60 grade of concrete, the split tensile strength increased by 9.3% and 11.7% for 14 and 28 days respectively compared with conventional concrete. The graphical representation of split tensile strengths of conventional and Steel Fibre Reinforced Concrete are shown in Figure 9, 10 and 11.

Table 6. Average split tensile strength values of CC and SFRC for M40, M50 and M60 grades of concrete

| Specimen       | Split tensile strength (N/mm²) | M40    | M50    | M60    |
|----------------|--------------------------------|--------|--------|--------|
|                | 14 Days                        | 28 Days| 14 Days| 28 Days| 14 Days| 28 Days|
| Conventional   | 4.16                           | 4.44   | 4.64   | 4.89   | 5.14   | 5.3    |
| 1.5% SFRC      | 4.36                           | 4.78   | 4.74   | 5.31   | 5.29   | 5.8    |
4.3 Microstructural analysis

A microstructural analysis of Steel fibre used in this study was carried out. Microstructure of SFRC was studied by X- Ray Diffraction (XRD), Scanning Electron Microscopy (SEM). Steel fibre reinforced
concrete surfaces of age 28 days was prepared for scanning electron microscopy. A thin section of the sample was made and pasted on a glass plate. They were examined and the microstructural SEM images are shown in Figure 12 and 13. The SEM images of Steel Fibre Reinforced Concrete showed that there was good bonding between the steel fibre and the concrete matrix. The SEM images also showed that the pores in the Steel Fibre Reinforced Concrete was lesser. Thereby increasing the strength of concrete. Similarly, thin sections of group of Steel fibres was tested for X-Ray Diffraction to determine the crystallography of the steel fibre. The XRD results were calculated for two theta (2θ) value ranging from 0 to 90 degrees. The XRD pattern of hooked end steel fibre used in this study is shown in fig 14.

![Figure 12. SEM image of surface of steel fibre](image1)

![Figure 13. Microstructural SEM image of SFRC](image2)

![Figure 14. XRD pattern of hooked end Steel Fibre](image3)

5. **Conclusion**
1. From the experimental results obtained from this study it is concluded that the addition of steel fibres to conventional concrete improves the compressive and split tensile strengths of the concrete.
2. Addition of steel fibres reduces the workability of fresh concrete which was counteracted by the addition of superplasticizers.
3. The optimum percentage of Steel Fibre Reinforced Concrete was obtained at 1.5% of steel fibre by volume.
4. The other dosages such as 0.5%, 1.0% and 2.0% also showed improved compressive and split tensile strengths whereas 1.5% dosage showed the highest increase in values.
5. At 2% volume fraction of steel fibres, the workability of Steel Fibre Reinforced Concrete reduced greatly. 
6. Due to reduced workability uniform distribution of fibres through the concrete matrix was difficult. Hence the compressive and split tensile strength values were reduced at 2% addition of steel fibres. 
7. The formation of cracks was comparatively less in Steel Fibre Reinforced Concrete when compared with conventional concrete due to the addition of steel fibres. 
8. Hooked end steel fibres provided more anchorage between the fibres and the cement matrix and hence propagation of cracks was also reduced. 
9. The microstructural SEM images of Steel Fibre Reinforced Concrete showed that there was good bonding between the steel fibre and the concrete matrix.

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