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EXPERIMENTAL STUDY ON FLEXURAL AND TENSILE PERFORMANCE OF FIBRE REINFORCED CONCRETE

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ABSTRACT

Concrete is one of the most widely used construction materials due to its versatility and good compressive strength; however, it possesses low tensile strength and limited resistance to cracking. To overcome these limitations, the incorporation of fibers in concrete has emerged as an effective technique to enhance its mechanical performance. This study presents an experimental investigation on the flexural and tensile performance of fiber reinforced concrete using micro steel fibers. In this research, concrete of grades M30 and M40 was prepared with varying percentages of micro steel fibers, namely 0%, 0.5%, 1%, 1.5% and 2% by volume. Standard specimens including cubes, cylinders and beams were cast and tested after curing periods of 7 and 28 days. The experimental program focused on evaluating compressive strength, split tensile strength, and flexural strength of the concrete. The results indicate that the inclusion of micro steel fibers significantly improves the tensile and flexural strength of concrete, along with enhanced crack resistance and ductility. It was observed that strength properties increase with an increase in fiber content up to an optimum level. However, the workability of concrete decreases as the fiber content increases, as evidenced by slump test results.

KEYWORDS: Fiber Reinforced Concrete, Micro Steel Fibers, Flexural Strength, Split Tensile Strength, Workability, and Crack Resistance.

1. INTRODUCTION

1.1 General

Concrete is composite material containing hydraulic cement, water, coarse aggregate and fine aggregate. The resulting material is a stone like structure which is formed by the chemical reaction of the cement and water. This stone like material is a brittle material which is strong in compression but very weak in tension. This weakness in the concrete makes it to crack under small loads, at the tensile end. These cracks gradually propagate to the compression end of the member and finally, the member breaks. The formation of cracks in the concrete may also occur due to the drying shrinkage. These cracks are basically micro cracks. These cracks increase in size and magnitude as the time elapses and the finally makes the concrete to fail. The formation of cracks is the main reason for the failure of the concrete. To increase the tensile strength of concrete many attempts have been made. One of the successful and most commonly used method is providing steel reinforcement. Steel bars, however, reinforce concrete against local tension only. Cracks in reinforced concrete members extend freely until encountering are bar. Thus need for multi directional and closely spaced steel reinforcement arises. That cannot be practically possible. Fiber reinforcement gives the solution for this problem so to increase the tensile strength of concrete a technique of introduction of fibers in concrete is being used. These fibers act as crack arrest or sand prevent the propagation of the cracks. These fibers are uniformly distributed and randomly arranged. This concrete is named as fiber reinforced concrete. The main reasons for adding fibers to concrete matrix is to improve the post cracking response of the concrete, i.e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material. The initial researches combined with the large volume of follow up research have led to the development of a wide variety of material formulations that fit the definition of Fiber Reinforced Concrete.

1.2 Fiber Reinforced Concrete

Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. So we can define fiber reinforced concrete as a composite material of cement concrete or mortar and discontinuous discrete and uniformly dispersed fiber. Fiber is discrete material having some characteristic properties. The fiber material can be anything. But not all will be effective and economical. Some fibers that are most commonly used are:

- Steel
- Glass

- Carbon
- Natural
- NBD

Steel fiber is one of the most commonly used fibers. Generally round fibers are used. The diameter may vary from 0.25 to 0.75 mm. The steel fiber sometimes gets rusted and loses its strength. But investigations have proved that fibers get rusted only at surfaces. It has high modulus of elasticity. Use of steel fibers makes significant improvements in flexure, impact and fatigue strength of concrete. It has been used in various types of structures. Glass fiber is a recently introduced fiber in making fiber concrete. It has very high tensile strength of 1020 to 4080Mpa.

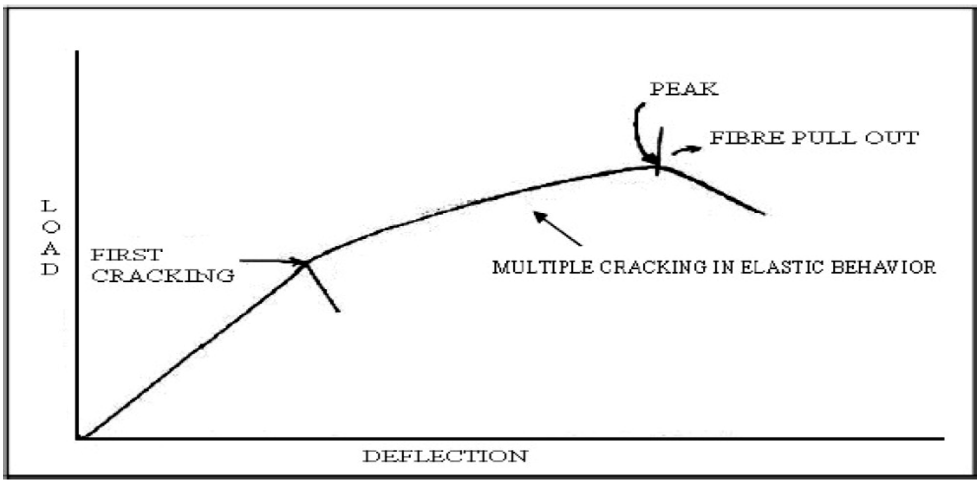

Figure.1.1Fiber Mechanism.

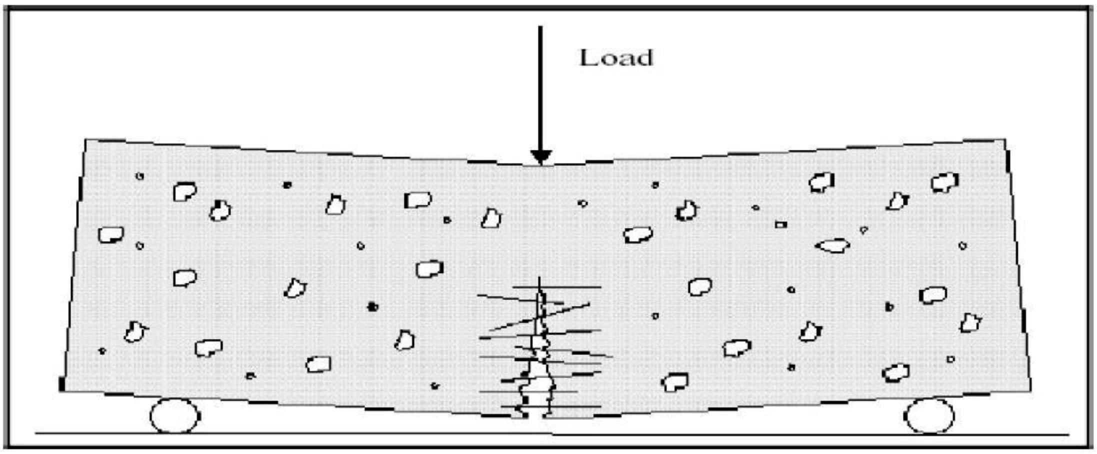

Figure.1.2 Pullout Mechanism.

1.7.1 Composition of Steel Fiber Reinforced Concrete

The components of Steel Fiber Reinforced Concrete (SFRC) can be explained with the help of the Figure given below.

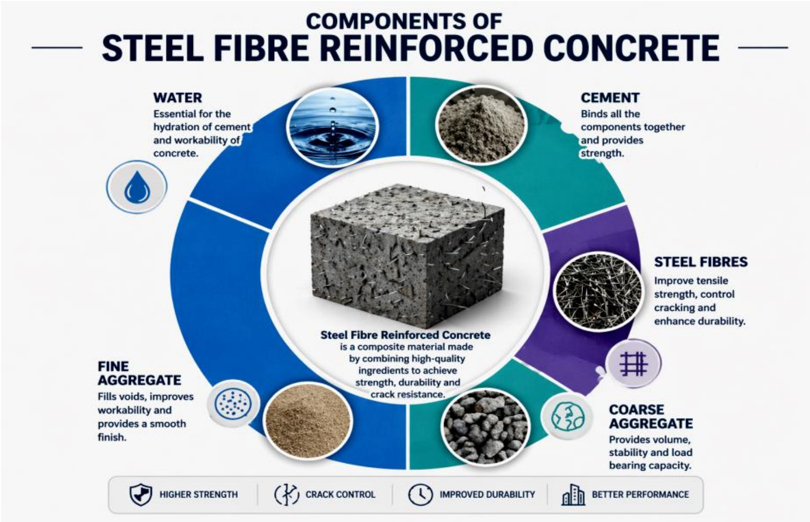

Figure 1.3 Components of Steel Fiber Reinforced Concrete.

Figure 1.4 Brass Coated Micro Steel Fiber.

1.9 Objective

The specific objectives of the study are as follows:

a) To compare the properties of Steel Fiber Reinforced Concrete (SFRC) with normal concrete.

b) To study the influence of varying percentages of micro steel fibers on the strength characteristics of concrete.

c) To evaluate the mechanical properties of M30 and M40 grade concrete with fiber contents of 0%, 0.5%, 1%, 1.5%, and 2% at curing periods of 7 and 28 days.

d) To determine the effect of fiber addition on the following properties of concrete:

- Compressive strength
- Split tensile strength
- Flexural strength

e) To assess the workability characteristics of fiber reinforced concrete using:

- Slump test
- Compaction factor test

2. Literature Review

2.1 Tensile Behavior of High Performance Hybrid Fiber Reinforced Concrete

P.R. Kannnan Rajkumar and P.R. Kannan Rajkumar[1]

Summary: The actions of fibers at various volumes of fractions in high strength concrete have achieved a good tensile strength. Based on the experimental investigation carried out the following conclusions are drawn. It is possible to produce fiber concrete composites using steel fibers (micro steel), with an enhanced tensile performance compared to concrete without fibers. Fiber inclusion of all types increased compressive strength, although this increase was not that significant and could have been obtained with simpler and more economical methods like reducing water-cement ratio. Micro steel fiber proved to be efficient in strengthening the matrix.

2.2 Performance of Steel Fiber Reinforced Concrete

Author: Milind V.Mohod[2]

Summary: Following conclusions were drawn from the work carried out;

1. It is observed that the workability of steel fiber reinforced concrete gets reduced as the percentage of steel fibers increases.
2. Compressive strength goes on increasing by increase in steel fiber percentage up to the optimum value. The optimum value of fiber content of steel fiber reinforced concrete was found to be 1%.
3. The flexural strength of concrete goes on increasing with the increase in fiber content up tothe optimum value. The optimum value for flexural strength of steel fiber reinforced cement concrete was found to be 0.75%
4. While testing the specimens, the plain cement concrete specimens have shown a typical crack propagation pattern which leaded into splitting of beam in two piece geometry. But due to addition of steel fibers in concrete cracks gets ceased which results into the ductile behaviour of SFRC.

3. Experimental Investigations

3.1 Experimental Program

In order to study the interaction of Steel fibers (straight) with concrete under compression, flexure, split and tension, various cylinders were casted respectively. The experimental program was divided into six groups.

Each group consists of cubes, cylinders and beams, of 15x15x15cm, 10x20cm and 15x15x50 cm respectively.

- The first group is the control concrete with 0% fiber
- The second group consisted of 0.5 % of Steel fibers, by total volume of concrete
- The third group consisted of 1% of Steel fibers, by volume of concrete
- The fourth group consisted of 1.5% of Steel fibers by volume of concrete
- The fifth group consisted of 2% of Steel fibers by volume of concrete

3.2 Materials and Tests

3.2.1 Cement

The cement used in this experimental investigation is ordinary Portland cement 53 grade. Storage of cement requires extra special care to preserve its quality and fitness for use. To prevent its deterioration it is necessary to protect it from rain, winds and moisture.

Figure 3.1 Cement.

Table 3.1 Chemical Composition of O.P.C.

Oxide	% Content
CaO	60-67
SiO2	17-25
Al2O3	3-8
Fe2O3	0.5-6.0
MgO	0.1-0.4

Na_2O+K_2O	0.1-1.3
SO3	1.0-3.0

3.2.2 Fine Aggregate

Initially observation showed the presence of various impurities and moisture. The impurity was removed by sieve analysis. It had cubical or rounded shape with smooth surface texture. The specific gravity of Fine aggregate was 2.65.

3.2.3 Coarse Aggregates

The coarse aggregate used in this experimental investigation are of 20 mm S and below sizes, crushed angular in shape. The aggregates are free from dust before used in the concrete.

3.2.4 Water

Water to be used in the concrete work should have following properties:

- It should be free from injurious amount of soils
- It should be free from injurious amount of acids, alkalis or other organic or inorganic impurities.
- It should be free from iron, vegetable matter or any other type of substances, which are likely to have adverse effect on concrete or reinforcement.
- It should be fit for drinking purposes.

The function of water in concrete

- It acts as lubricant
- It acts as a chemically with cement to form the binding paste for coarse aggregate and reinforcement
- It enables the concrete mix to flow into form work.

3.2.5 Fiber

The brass coated micro steel fiber used in the experiment is obtained from suppliers available in the Chhattisgarh region**.**

Micro brass coated steel fiber is a new type of additive for reinforcing concrete, which has the high tensile strength, and improve the concrete's unity obviously.

Material: low carbon cold drawn steel wire Tensile strength :> 2850Mpa Length: 6 mm Diameter:0.2+/-0.02mm Aspect ratio: 35-100.)

Micro steel fibers has the advantages comparing with steel bars in the fields below,

- Ultra high performance concrete
- Reactive powder concrete

- Reinforcing mortar

3.3 Mixing of Specimen

Hand mixing is adopted throughout the experimental work. First the materials cement, fine aggregate, coarse aggregate, steel Straight fibers weighed accurately as per the above mentioned calculations.

The sand is laid in a layer of approximately 10 cm thick. Then cement is added to the sand and mixed thoroughly to get a uniform colour. The coarse aggregate is spread on the ground and then the cement-sand mixture is mixed with it to get a uniform matrix. The steel Straight fibers of 6 mm lengths are dispersed in the water. The water along with the fiber is added to the mixture and mixed thoroughly to get a uniform mass in colour and consistency. After mixing the fresh concrete is tested for the workability using compaction factor and slump tests.

Figure 3.2 Mixing of Specimen.

Figure 3.3 Mixing of Concrete.

3.4 Tests on Fresh Concrete

3.4.1 Compaction Factor Test

It is one of the most efficient tests for measuring the workability of concrete. This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. Compaction factor = weight of partially compacted concrete/ weight of fully compacted concrete

The compacting factor is calculated for various percentages of steel fibers. Workability is the property of concrete which determines the amount useful internal work necessary to produce full compaction. As per IS 6461-1972, workability is defined as "the ease which it can be mixed, transported, placed and compacted easily."

Figure 3.4 Compaction Testing Machine.

Table 3.2 Compaction Factor Value.

Percentage of Fiber Added	Compaction Factor
0	0.82
0.5	0.79
1	0.77
1.5	0.71
2.0	0.69

3.4.2 Slump Test

Slump test is the most commonly used method for measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It is used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch.

Procedure

- Dampen the slump test mould and place it on a flat, moist, nonabsorbent, rigid surface, like a steel plate.
- Fill the mould to 1/3 full by volume and rod the bottom layer with 25 evenly spaced strokes.
- Fill the mould to 2/3 full and rod the second layer with 25 strokes penetrating the top of the bottom layer.
- Heap the concrete on top of the mould, and rod the top layer with 25 strokes penetrating the top of the second layer.
- Strike off the top surface of the concrete even to the top of the mould.
- Remove the mould carefully in the vertical direction (take about five seconds).
- Immediately invert and place the mould beside the slumped concrete and place the rod horizontally across the mould, and measure the slump, in cm.

Figure 3.5 Slump Test.

Table 3.3 Slump Test Value.

Percentage of Fibers Added	Slump Value (in cm)
0	2.1
0.5	1.2
1.0	0.7
1.5	0.6
2.0	0.2

3.4.3 Casting of Specimens

For casting the cubes, beam and cylinder specimens, standard cast iron metal moulds of size 150x150x150 cubes, 100x100x500 mm beam and 100x200 mm cylinder moulds are used. The moulds have been cleaned of dust particles and applied with mineral oil on all sides, before the concrete is poured into the moulds. Thoroughly mixed concrete is filled into the mould in three layers of equal heights followed by tamping. Then the mould is placed on the table vibrator for a small period. Excess concrete is removed with trowel and top surface is finished to smooth level.

Figure 3.6 Casting of Specimens.

3.4.4 Curing

After casting the moulded specimens are stored in the laboratory and at a room temperature for 24 hours from the time at addition of water to dry ingredients after this period the specimens are removed from the moulds immediately submerged in clean and fresh water. The specimens are cured for 7 and 28 days in the present work.

3.5 Test on Hardened Concrete

3.5.1 Cube Compression Test

This test was conducted as per IS 516-1959. The cubes of standard size 150x150x150mm were used to find the compressive strength of concrete. Specimens were placed on the bearing surface of UTM, of capacity 100 tones without eccentricity and a uniform rate of loading of 550 Kg/cm^2 per minute was applied till the failure of the cube. The maximum load was noted and the compressive strength was calculated.

Cube compressive strength (fck) in MPa = P/A

Where,

P = cube compression load

A = area of the cube on which load is applied (=150 x150= 22500 mm^2)

Figure 3.7 Compression Testing Machine.

3.5.2 Flexural Test

SFRC beams of size 100x100x500mm are tested using a flexure testing machine. The specimen is simply supported on the two rollers of the machine which are 600mm apart, with a bearing of 50mm from each support. The load shall be applied on the beam from two rollers which are placed above the beam with a spacing of 200 mm. The load is applied at a uniform rate such that the extreme fibers stress increases at 0.7 $N/mm^2/min$ i.e., the rate of loading shall be 4 KN/min. The load is increased till the specimen fails. The maximum value of the load applied is noted down. The appearance of the fracture faces of concrete and any unique features are noted.

The modulus of rupture is calculated using the formula.

$\sigma_s = Pl/bd^2$, where,

P = load in N applied to the specimen

l =length in mm of the span on which the specimen is supported

b = measured width in mm of the specimen

d = measured depth in mm of specimen at the point of failure

Figure 3.8 Flexure Testing Machine.

3.5.3 Split Tensile Test

SFRC cylinders of size 10 cm (dia) x 20 cm (height) are casted. The test is carried out by placing a cylindrical specimen horizontally between the loading surface of a compression testing machine and the load is applied until the failure of the cylinder, along the vertical diameter. When the load is applied along the generatrix, an element on the vertical diameter of the cylinder is subjected to a horizontal stress of $2P/\pi ld$.

Figure 3.9 Split Tensile Testing Machine.

4. RESULTS AND DISCUSSIONS

4.1 Cube Compression Test Values of M30 Grade SFRC at 7 and 28 Days Curing

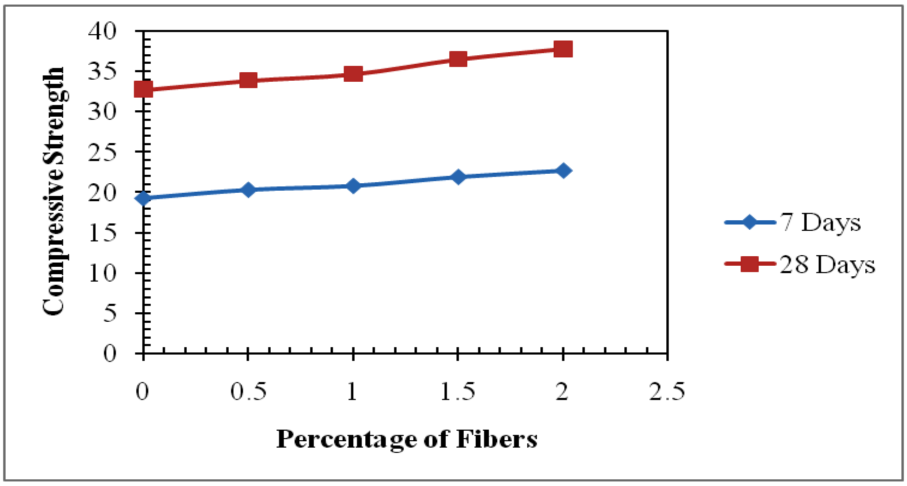

Figure 4.1 Compressive Strength Vs Percentage of Fiber.

4.2 Split Tensile Test Values of M30 Grade SFRC at 7 and 28 Days Curing

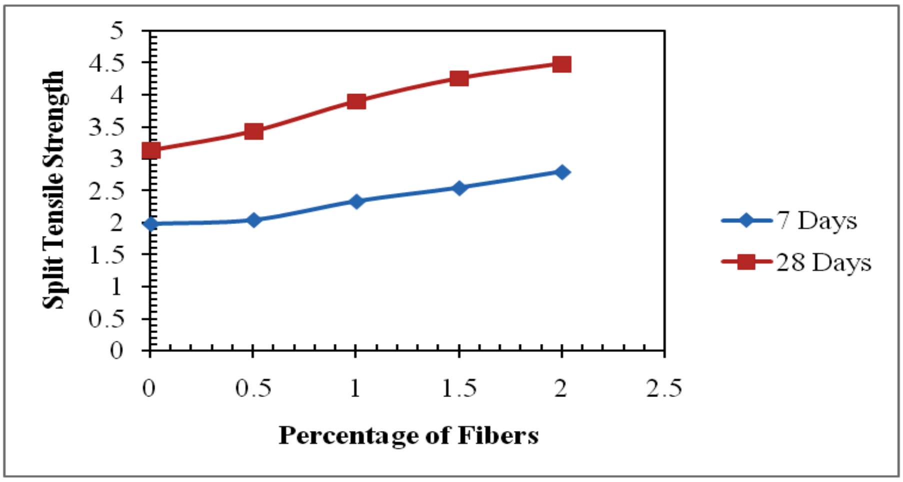

Figure 4.2 Split Tensile Strength Vs Percentage of Fiber.

4.3 Flexural Test Values of M30 Grade SFRC at 7 and 28 Days Curing

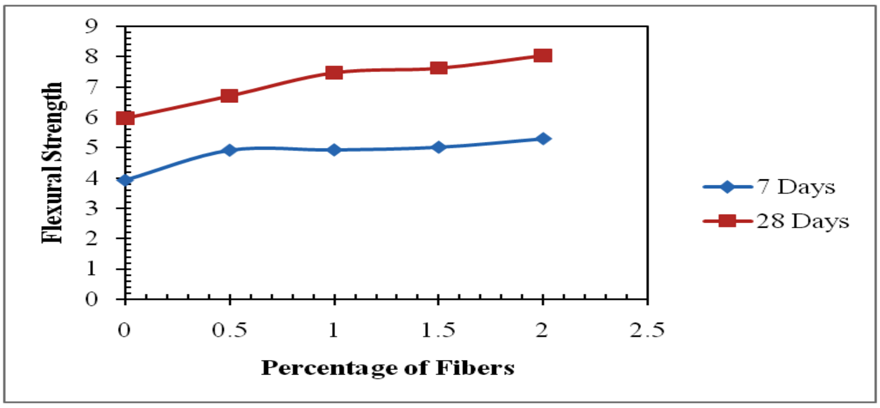

Figure 4.3 Flexural Strength Vs Percentage of Fiber.

4.4 Cube Compression Test Values of M40 Grade SFRC at 7 and 28 Days Curing

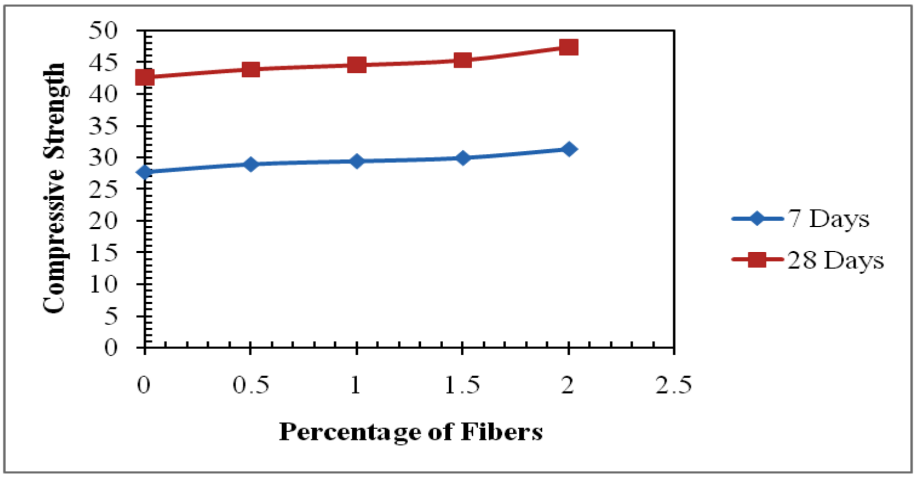

Figure 4.4 Compressive Strength Vs Percentage of Fiber.

4.5 Split Tensile Test Values of M40 Grade SFRC at 7 and 28 Days Curing

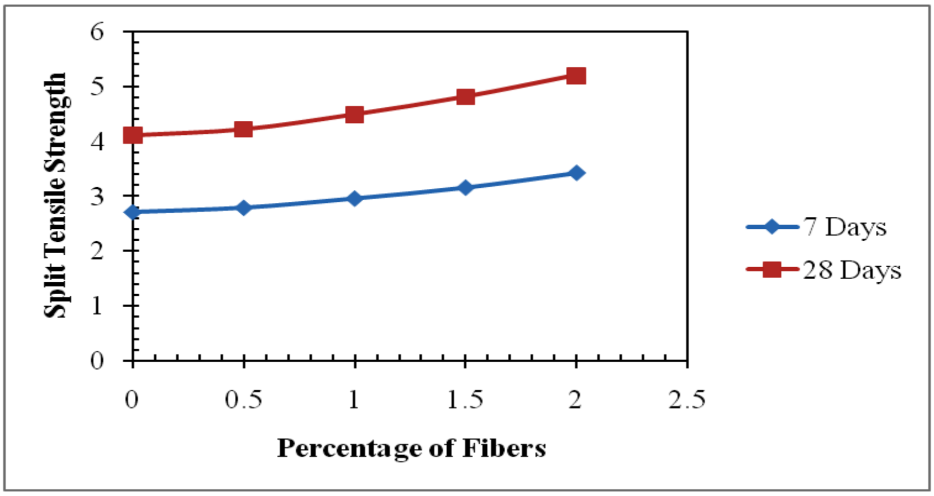

Figure 4.5 Split Tensile Vs Percentage of Fiber.

4.6 Flexural Test Values of M40 Grade SFRC at 7 and 28 Days Curing

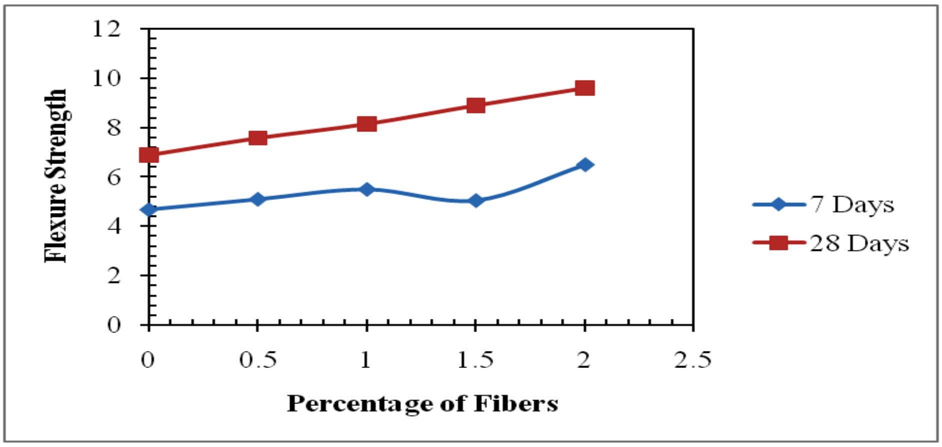

Figure 4.6 Flexure Strength Vs Percentage of Fiber

4.7 DISCUSSIONS

4.7.1 Compressive Strength and Split Tensile Strength (M30)

The variation in the compressive stress and split tensile stress with respect to changes in the fiber content can be observed. From the results obtained, it is clear that the compressive and split tensile strength of concrete is maximum when the fiber content is 2% of the concrete. So comparing the variation of strength between the plain concrete and fiber reinforced concrete (2%). Comparing the compressive strength of plain concrete and concrete with various percentages of fibers after 28 days of curing:

Table 4.13.

Plain Concrete (N/mm^2)	SFRC (N/mm^2)	Percentage Increase in Strength
0	32.73	0
0.5	33.88	3.51
1	34.68	5.90
1.5	36.51	11.50
2	37.80	15.49

Comparing the split tensile strength of plain concrete and concrete with various percentages of fibers after 28 days of curing:

Table 4.14.

Plain Concrete (N/mm^2)	SFRC (N/mm^2)	Percentage Increase in Strength
0	3.13	0
0.5	3.43	9.60
1	3.90	24.60
1.5	4.26	36.10
2	4.49	43.45

From the tables it is clear that the strength of SFRC with 2% fiber has increased by 15.49% for compression, 43.45% under split tension compared to the plain concrete.

4.7.2 Flexural Strength (Modulus of Rupture)

From the results obtained, it is inferred that the most significant increase in the Modulus of Rupture is obtained on addition of 2 percent of fibers. So, comparing the values of modulus of rupture:

Table 4.15

Plain Concrete (N/mm^2)	SFRC (N/mm^2)	Percentage Increase in Strength
0	5.96	0
0.5	6.70	12.41

1	7.47	25.33
1.5	7.622	27.85
2	8.04	35.23

From the tables it is clear that the strength of SFRC with 2% fiber has increased by 35.23% for flexure compared to the plain concrete.

4.7.3 Compressive Strength and Split Tensile Strength (M40)

The variation in the compressive stress and split tensile stress with respect to changes in the fiber content can be observed. From the results obtained, it is clear that the compressive and split tensile strength of concrete is maximum when the fiber content is 2% of the concrete. So comparing the variation of strength between the plain concrete and fiber reinforced concrete (2%). Comparing the compressive strength of plain concrete and concrete with various percentages of fibers after 28 days of curing:

Table 4.16

Plain Concrete (N/mm^2)	SFRC (N/mm^2)	Percentage Increase in Strength
0	42.60	0
0.5	43.88	3.0
1	44.55	4.5
1.5	45.33	6.4
2	47.40	11.26

Comparing the split tensile strength of plain concrete and concrete with various percentages of fibers after 28 days of curing:

Table 4.17.

Plain Concrete (N/mm^2)	SFRC (N/mm^2)	Percentage Increase in Strength
0	4.12	0
0.5	4.23	2.6
1	4.49	8.9
1.5	4.80	16.5
2	5.20	26.2

From the tables it is clear that the strength of SFRC with 2% fiber has increased By 11.26% for compression, 26.2% under split tension compared to the plain concrete.

4.7.4 Flexural Strength (Modulus of Rupture)

From the results obtained, it is inferred that the most significant increase in the Modulus of Rupture is obtained on addition of 2 percent of fibers. So, comparing the values of modulus of rupture:

Table 4.18.

Plain Concrete (N/mm^2)	SFRC (N/mm^2)	Percentage Increase in Strength
0	6.89	0
0.5	7.50	8.8
1	8.10	17.56
1.5	8.90	29.17
2	9.60	31.33

From the tables it is clear that the strength of SFRC with 2% fiber has increased by 31.33% for flexure compared to the plain concrete.

5. CONCLUSIONS

5.1 Conclusion

The present study highlights the significant influence of straight steel fibers on the properties of concrete. The incorporation of micro steel fibers has resulted in noticeable improvement in the mechanical performance of concrete when compared to conventional concrete.

Steel fibers used in this study are non-absorbent in nature and do not affect the water absorption characteristics of concrete. The inclusion of fibers enhances the overall structural behavior by improving crack resistance, ductility, and load-carrying capacity. With a better understanding of fiber characteristics and their interaction with the concrete matrix, fiber reinforced concrete can be effectively utilized in structural applications, particularly in earthquake-prone regions.

Results for M30 Concrete:

- Compressive strength increased by 15.49% at 2% fiber content.
- Split tensile strength increased by 43.45% at 2% fiber content.
- Flexural strength (modulus of rupture) increased by 35.23% at 2% fiber content.

Results for M40 Concrete:

- Compressive strength increased by 11.26% at 2% fiber content.
- Split tensile strength increased by 26.2% at 2% fiber content.
- Flexural strength (modulus of rupture) increased by 31.33% at 2% fiber content.

According to the experimental study, adding steel fibers to concrete greatly improves its tensile and flexural qualities while also somewhat increasing its compressive strength. Steel fiber reinforced concrete is a very useful material for contemporary construction methods since the best improvement in strength characteristics was seen at higher fiber content.

5.2. Scope for Further Study

The present study provides a foundation for further research on steel fiber reinforced concrete. However, several areas remain open for detailed investigation:

- Further study can be done for determining the deflections and durability of concrete.
- Further study on the seepage characteristics of the steel fibers.
- As the failure of SFRC is ductile, further studies on retrofitting of damaged structures constructed of this concrete can be undertaken.

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