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Steel Fibre Reinforced Concrete as a Structural Material: A Review

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Abstract - This Paper discusses the application of Steel Fibre Reinforced Concrete (SFRC) as a structural material in the modern construction practices as an more effective substitute to the conventional concrete. Use of SFRC has become more prominent nowadays and is likely to increase in future; hence it becomes very important to understand the role of various types of steel fibres that are used in SFRC, its geometrical, mechanical properties and strength outcomes that will surely enhance its application. Various types of steel fibres used are discussed in this paper, also what are the essential tests that are needed to perform on SFRC in order to predict its various mechanical properties that will compare its certain parameters with the conventional concrete.

Keywords: Steel fibre, concrete, Steel–concrete composite beams, SFRC, Compressive Strength,

I. Introduction

Use of Fibre reinforced concrete as a Structural material is something not new, its use to some extent has been seen several times as an old technique, but as the time changes, its importance and applications have evolved. Studies have proved that the use of Fibre Reinforced Concrete changes the properties of concrete that make it more useful material to be used as a structural component in Structures [5]. Use of Steel Fibre Reinforced Concrete(SFRC) is very prominent in the modern age as it is much cheaper, easier to use and experimental studies has shown it increases the strength of concrete to some extent.. Nowadays Steel Fibre Reinforced Concrete (SFRC) is widely used in the construction of many complex structures like industrial slabs, airfields, tunnels, elevated slabs, pedestrian bridges, roadways and many modular prefabricated buildings [9-14]. The SFRC has many benefits in the modern construction practices but the only disadvantage is that it decreases the workability and increases the stiffness of fresh concrete [6]. SFRC sometimes also used with certain admixtures like Fly Ash and silica fume, and shown a marginal increase in its workability as well with increasing the percentage of such admixtures [1]. The performance of the Steel Fibre Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete[6].

It can be said that the addition of steel Fibres has an influe nce on the stressstrain relationship in compression,and the level of critical stresses increases in conjunction with the a mount of steel Fibres added to the concrete mixture[2].

II. Types of Steel Fibres

Steel Fibre is a composite of metals. Steel Fibre for reinforcing concrete is defined as short, discrete lengths of steel Fibres with an aspect ratio (length to diameter ratio) of about 20 to 100, with different cross-sections, and which are small enough to be dispersed randomly in an unhardened concrete mixture using the usual mixing methods [8]. There are two methods by which Fibres can be classified according to their elasticity modulus or roots. From the elasticity module point of view, Fibres can be classified into two basic categories, namely those with a higher elastic modulus than concrete mix (called hard intrusion) and those with lower elastic modulus than concrete mix (called soft intrusion) [6]. On the basis of formation Steel Fibres can be categorized as a cold drawn wire Fibre with corrugated and flatted shape.

The five most popular steel Fibre types are: traditionally straight, hooked, crimped, coned, and deformed mechanically. The geometries of the described non-straight fibres is shown in Figure 1.1, 1.2 and 1.3.

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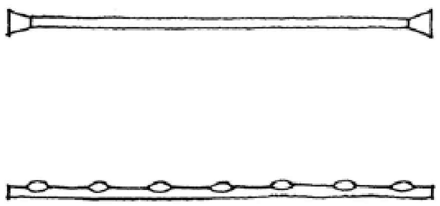
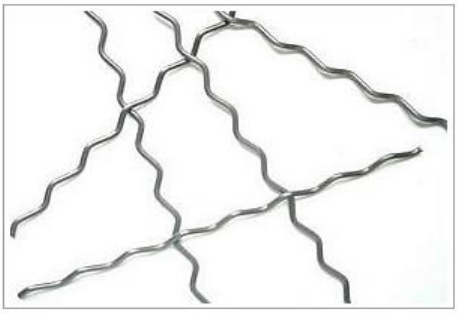


Coned and Mechanically Deformed Steel Fibres (Figure1.1)

Flatted shape Steel Fibre with Hook (Figure1.3) [15]



Corrugated Type Steel Fibre (Figure1.2) [15]

Concrete with Steel Fibre[8]

III. EFFECT OF ADDING STEEL FIBRES IN CONCRETE

A certain amount of steel Fibre in concrete can cause qualitative changes in the physical properties of concrete, greatly increasing cracking resistance, fatigue and Flexural Strength, toughness, durability and other properties [16]. [17] used 6 mm long steel Fibres are used to manufacture self sensing with tensile strain sensing properties.

IV. PROPERTIES OF STEEL FIBRE REINFORCED CONCRETE

Nowadays Steel Fibre Reinforced Concrete is widely used as important building material in civil engineering applications such as bridges and road engineering, and the associated experimental study of the mechanical properties of concrete will also be fruitful. Some of the important Properties to consider are as follows:

1.1. Compressive Strength:

Brittleness with low tensile strength and strain capacities of ultra high strength concrete (UHSC) can be overcome by the addition of steel Fibres [26].

UHSC's compressive strength increased with steel Fibres applied at different volumes Faults. The strength showed a maximum fraction at 0.75% but a slight decrease at 1.0% and 1.5% fraction compared to 0.75 percent, which is still 10.6 percent higher than before the addition of Fibre [27].

In an experimental research performed by [28] on SFRC, the variation of compressive strength for different grade of concretes for SFRC(0%, 0.5%, 1%, 1.5% steel Fibre reinforced concrete) is shown by the Tabular representation as follows:

Days of Curing	Volume of Steel Fibres(%)	COMPRESSIVE STRENGTH(N/mm2)			
		M20	M25	M30	M40
3days	0%	13.2	15.69	19.41	27.17
	0.50%	15.2	18.34	22.87	32.91
	1%	17.11	20.63	25.6	36.4
	1.50%	18.69	22.12	27.89	39.39
7days	0%	18.9	24.6	32.21	41.45
	0.50%	21.11	28.78	37.37	47.67
	1%	24.38	33.1	42.81	54.37
	1.50%	27.73	35.71	46.03	59.93
28days	0%	28.7	33.4	41.37	52.76
	0.50%	32.98	37.83	46.79	60.8
	1%	37.93	43.74	53.76	68.79
	1.50%	41.02	48.03	59.86	75.84

Table- 1: Compressive Strength of Concrete

The experimental work performed by [3] shows that the increase in percentage of steel fibre in concrete subjected to hogging moment increases its compressive strength.

1.2. Tensile Strength:

As per experimental study done by [27], the strength enhancing ultra high reinforced steel Fibre capacity Concrete strength (SFRC) containing 0.5%, 0.75%, 1.0%

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and 1.5% volume of hooked-end steel Fibres. Compared with the counterpart for plain ultra high-strength concrete (UHSC).Increase of SFRC compressive resistance. Compared to UHSC, 0.5 percent volume fractions, 0.75 percent, 1.0 percent, and 1.5 percent steel Fibre.

$$\text{Strength-effectiveness} = \frac{\text{SFRC strength - UHSC strength}}{\text{UHSC strength}} \times 100\%$$

Specimen	Fiber volume fraction V_f [%]	Compressive strength f_{cf} Measured [MPa]	Compressive strength f_{cf} Strength-effectiveness* [%]	Splitting tensile strength f_{tf} Measured [MPa]	Splitting tensile strength f_{tf} Strength-effectiveness* [%]
UHSC	0.00	103.6	—	5.05	—
SFRC-0.50	0.50	115.4	11.4	6.98	38.2
SFRC-0.75	0.75	119.7	15.5	9.38	85.7
SFRC-1.00	1.00	116.3	12.3	9.49	87.9
SFRC-1.50	1.50	114.6	10.6	9.69	91.9

Table 1: Compressive strength and splitting tensile strength of SFRC

The tensile strength increases significantly as the volume of steel Fibres is increase is similar to the grade of concrete [3, 28].

1.3. Shear Strength:

Previous work has shown that addition of Steel Fibres significantly increases concrete's shear strength [30]. The ultimate shear strength of SFRC which contains 1% by volume of Steel Fibres increases by up to 170% compared to RC without Steel Fibres [31]. The ultimate shear strength of SFRC which contains 1% by volume of SFs increases by up to 170% compared to RC without SFs [30, 32].

V. TESTING ON SFRC

The main objective of testing SFRC members is to investigate various important properties for the consumptive use of it. Various mechanical properties of SFRCs helps to understand its behavior as a structural element and limitations as well. Some of the important Tests performed for SFRC are as follows:

1.4. Ultrasonic pulse velocity test of SFRC:

Ultrasonic pulse velocity test is a kind of non-destructive test method carried out, involving ultrasonic pulse velocity test applied to different SFRC mixtures. The theory of this test is that sound velocity in a solid material (V) is a function of the square root ratio of its Young's Modulus (E) to its density (ρ) [18]. The equation is as follows according to Polish standards:

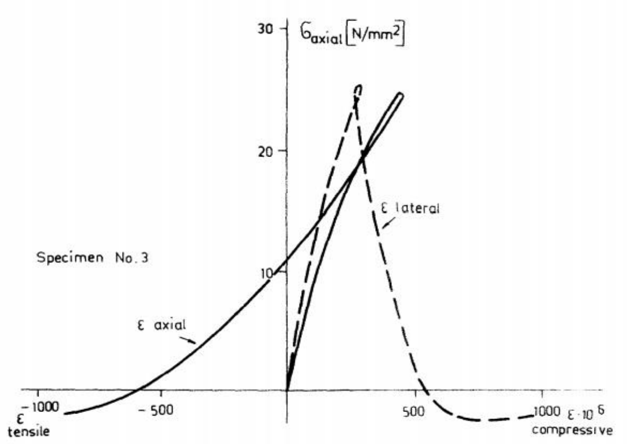
$$E = V\,2.\,\rho$$

This relationship can be used to evaluate the elasticity modulus and thus as a means of testing the concrete consistency.

The test is also useful for detecting voids, corrosion caused by frost or fire and uniformity of concrete in similar elements [22]. The ordinary concrete's pulse velocity depends on the aggregate elasticity modulus and the aggregate content of the mix. Steel reinforcement is also well known to contribute to increased ultrasonic pulse velocity. Both of these drawbacks have led the ultrasonic pulse velocity test to be rarely used to determine the characteristics of reinforced concrete made from steel Fibre (SFRC) [18].

1.5. Tri-axial loading Tests on SFRC:

The stress-strain relationships were obtained for the direct tension and flexure control tests and the typical stress-strain curves for the tri-axially tested specimens and shown in figure



Stress-strain curves for the specimen in triaxial loading [23]

1.6. Uniaxial Tension Test for SFRC:

Uniaxial tension test was performed for SFRC and an experimental program was conducted by [24] to investigate the pre- and post-cracking behavior of a single SFRC mix through uniaxial stress tests with varying boundary conditions (fixed-fixed (FF), rotating-rotating (RR), and fixed-rotating (FR)). For each research set-up four specimens were produced. The steel Fibres were 35 mm in length, 0.55 mm in diameter and 1340 MPa in ultimate notional tensile force. The dosage of Fibres used in this analysis was 60 kg / m3. The concrete was delivered through a local prepared mixing plant and shipped to Laboratory without the included Fibres in this combination. The specified concrete compressive strength was 40 MPa (the compressive strength of the measured cylinder concrete was 63 MPa at the time of the test), and the coarse aggregate used was basalt with a maximum particle size of 10 mm. The Fibres were inserted into the Stirrer on site and mixed 10 minutes beforehand To cast exemplars. A standard drop in

Test was used to evaluate the operability of the New SFRC, and the recession assessed Found 200 mm long. The test

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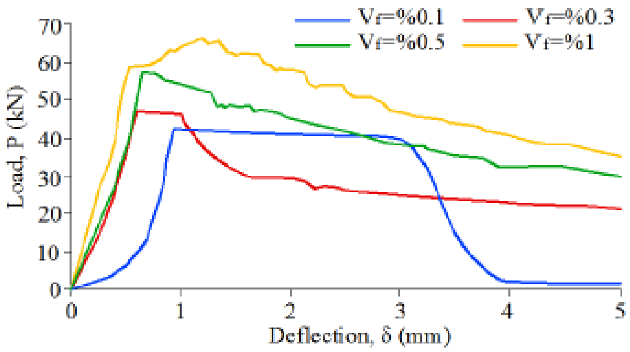
result shows Concrete Elastic Deformations near the crack there are negligible relative to the opening of the ripple; also the concentrations of shape-induced tensile stress are low and can be heterogeneous, and the specimen's ability to redistribute stresses in the experiment [24].

1.7. Split Tensile Test:

The addition of Fibres to concrete significantly improves its tensile strength and a good correlation exists between the st rength of the splitting tensile and the volume fraction of the fibre, as well as between the strength of the splitting tensile and the index of Fibre strengthening. Splitting tensile strength and flexural resistance testing are preferred to evaluate SFRC tensile efficiency. The splitting test of tensile strength needs a standard cube or cylinder specimen while the flexural strength test requires a heavy beam specimen with larger dimensions provided by most norms [25, 26]. Hardened concrete experiments were carried out in water on 28 days of cured concrete specimens. According to the TS EN 12390-3 (2010) and the TS EN 12390-6 (2010) specifications, compressive and splitting tensile strength tests were evaluated for the investigation of mechanical properties. Additionally, in accordance with the TS 10515 (1992) standard, a 4-point flexural strength test was performed using 150 environ1505500 mm of beam specimens. Load-deflection data of the SFRC specimens were collected during flexural strength tests. The maximum flexural resistance of SFRC specimens was determined using peak load. Toughness values for maximum 5 mm midpoint displacement value of the beam specimens were taken into account as the area under the load-deflection curves. Figure shows typical load-deflection curves of SFRC specimens [25]. The toughness of SFRC is significantly higher than normal concrete without Fibres (ACI 544.1R, 2002),



Load-deflection curves of SFRC specimens.

1.8. Workability Test:

[28] Workability is carried out by conducting the slump test and compaction factor test as per IS 1199-1959 on ordinary concrete and Fibre reinforced concrete. The properties of fresh concrete can be evaluated by slump cone test & compaction factor test with W/C ratio 0.4. The result of properties are given in

S.No.	Mix type (SF %, SF&FA %)	Slump value(mm)	compaction factor
01	MS0(0.0%, 0.0%&0.0%)	78	0.952
02	MS1 (0.5%, 5%&5%)	23	0.820
03	MS2 (0.5%, 10%&10%)	38	0.810
04	MS3 (0.5%, 15%&15%)	49	0.902
05	MS4 (1.0%, 5%&5%)	18	0.801
06	MS5 (1.0%, 10%&10%)	21	0.786
07	MS6 (1.0%, 15%&15%)	31	0.802
08	MS7 (1.5%, 5%&5%)	12	0.740
09	MS8 (1.5%, 10%&10%)	15	0.792
10	MS9 (1.5%, 15%&15%)	19	0.810

VI. Benefits of SFRC

- Steel Fibres' beneficial influence in concrete depends on many factors, such as type , shape, length, cross section, strength, Fibre content, bond strength of steel Fibres, matrix strength, mixing design and concrete mixing [6].
- Steel Fibres also improves the Brittle Nature of the Concrete.
- Steel Fibres increase the tensile strength of the matrix, thereby improving the flexural strength of the concrete.
- Increase ductility of the concrete
- SFRC is more durable and serviceable than conventional Reinforced Concrete [29].
- In SFRC structures, corrosion in concrete structures due to cracks is less severe than in conventional RC structures[19- 21, 4].

VII. Applications of SFRC

- There are numerous applications of steel Fibre reinforced concrete (SFRC) for large blocks such as heaw vibrating equipment foundations, dolos armor units, spillways, road overlays, etc [23].
- Adding Steel Fibres increases the stability, ductility and integrity of conventional RC members under earthquake and blast loads (dynamic loads) [6].
- Increases the strength of RC members to shear. As a result, the shear strength of the slabs will increase and sudden punching failure can be transformed into a slow ductile failure [37].
- SFRC may be found in prefabricated items such as manhole coverings, concrete tubing, and machine bases and frames.
- Can provide enhanced impact resistance to traditional RC members, enhancing local damage and spreading resistance (spalling) [37].
- Adding SFs can prevent crack growth and crack widening; this may allow the use of high-strength steel bars without undue crack width or duty load deformation [38, 39].

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VIII. Conclusion

- Increasing percentage of steel fibre in SFRC (V_f) provides higher flexural strength of SFRC, another relationship has been revealed between flexural strength, tensile strength splitting and Vf value varying from 0.1% to 1% [25]. This concludes an important relation in designing of SFRC members.
- Tensile Strength of the ultra high reinforced steel Fibre capacity from 0 percent to 1.5 % hooked based steel Fibre reinforced concrete increases considerably.
- The strength-effectiveness showed at each volume fraction a maximum for splitting tensile strength, and compressive strength [27].
- Further study is required to understand the effect of other Fibre types, such as straight steel Fibres and synthetic Fibres.
- The concrete's compressive strength increases considerably as the volume of steel Fibres increases from 0.5 percent to 1 percent and the increase is nearly similar to all the normal concrete grade that is M20, M25, M30, M40.
- Higher percentage of Steel Fibres slump was down.
- Performance of the Steel Fibre Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete
- Addition of Steel Fibres into Concrete somehow decreases the adhesion between cement and aggregates [2].

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