EXPERIMENTAL STUDY ON THE BEHAVIOUR OF THE STEEL FIBER REINFORCED CONCRETE

N. AKSHAYA B. NITHIN G. SANTHOSH YADAV D. DILEEP

Mr.D. VARUN KUMAR

(Assistant Professor) Department of Civil Engineering

SREE DATTHA INSTITUTE OF ENGINEERING AND SCIENCE

ABSTRACT

The objective of this investigation was to study the behaviour of Steel Fibre Reinforced Concrete (SFRC). Hooked end fibres and corrugated fibres with aspect ratio of 55 were used. Specimens were cast without fibres and with fibres of 0.5% and 1%. Tests were conducted for studying the compressive, tensile, flexural strength and energy absorption.Compressive and split tensile tests were conducted on cubes and cylinders respectively. 15 Beams of dimension 700x150x150mm were cast and tested under two point loading to find flexural strength, toughness and stiffness. An empirical equation for finding the toughness index was developed based on fibre percentage.500x500x50mm and 500x 500x100mm. Static point load test was conducted on each panel to calculate the energy absorption, ductility index and secant stiffness was found.

1. INTRODUCTION

Concrete is one of the most versatile building materials. It can be cast to fit any structural shape from a cylindrical water storage tank to a rectangular beam or column in a high-rise building. The advantages of using concrete include high compressive strength, good fire resistance, high water resistance, low maintenance, and long service life. The disadvantages of using concrete include poor tensile strength, low strain of fracture and formwork requirement. The major disadvantage is that concrete develops micro cracks during curing. It is the rapid propagation of these micro cracks under applied stress that is responsible for the low tensile strength of the material. Hence fibres are added to concrete to over come these disadvantages. The addition of fibres in the matrix has many important effects. Most notable among the improved mechanical characteristics of Fibre Reinforced Concrete (FRC) are its superior fracture strength, toughness, impact resistance, flextural strength resistance to fatigue, improving fatigue performance is one of the primary reasons for the extensive use of Steel Fibre Reinforced Concrete (SFRC) in pavements, bridge decks, offshore structures and machine foundation, where the composite is subjected to cyclically varying load during its lifetime. Today the space shuttle uses fibres in heat shield ties to control the effects of thermal expansion and the human body's strongest and most flexible structures, muscles are made up of fibres. The fact is fibres of almost any description improve the ability of substances to withstand strain.

The main reasons for adding steel fibres 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 Fibre Reinforced Concrete. Steel fibre's tensile strength, modulus of elasticity, stiffness modulus and mechanical deformations provide an excellent means of internal mechanical interlock. This provides a user friendly product with increased ductility that can be used in applications of high impact and fatigue loading without the fear of brittle concrete failure.Thus, SFRC exhibits better performance not only under static and quasi- statically applied loads but also under fatigue, impact, and impulsive loading.

CONVENTIONAL REINFORCED CONCRETE

Johnston (1994) found that tensile strength of concrete is typically 8% to 15% of its compressive strength. This weakness has been dealt with over many decades by using a system of reinforcing bars (rebars) to create reinforced concrete; so that concrete primarily resists compressive stresses and rebars resist tensile and shear stresses. The longitudinal rebar in a beam resists flexural (tensile stress) whereas the stirrups, wrapped around the longitudinal bar, resist shear stresses. In a column, vertical bars resist compression and buckling stresses while ties resist shear and provide confinement to vertical bars. Use of reinforced concrete makes for a good composite material with extensive applications.

Steel bars, however, reinforce concrete against tension only locally. Cracks in reinforced concrete members extend freely until encountering a rebar. Thus need for multidirectional and closely spaced steel reinforcement arises. That can't be practically possible. Steel fibre reinforcement gives the solution for this problem

FIBRE REINFORCED CONCRETE

Fibre reinforced concrete is a concrete mix that contains short discrete fibres that are uniformly distributed and randomly oriented. As a result of these different formulations, four categories of fibre reinforcing have been created. These include steel fibres, glass fibres, synthetic fibres and natural fibres. Within these different fibres that character of Fibre Reinforced Concrete changes with varying concrete's, fibre materials, geometries, distribution, orientation and densities.

The amount of fibres added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibres) termed Volume Fraction (Vf). Vf typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). Fibres with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the modulus of elasticity of the fibre is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increase in the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix. However, fibres which are too long tend to "ball" in the mix and create workability problems.

FIBRE - MATRIX INTERACTION

The tensile cracking strain of cement matrix (less than 1/50) is very much lower than the yield or ultimate strain of steel fibres. As a result, when a fibre reinforced composite is loaded, the matrix will crack long before the fibres can be fractured.

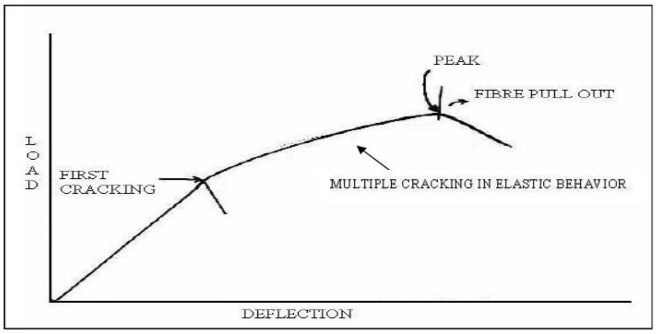
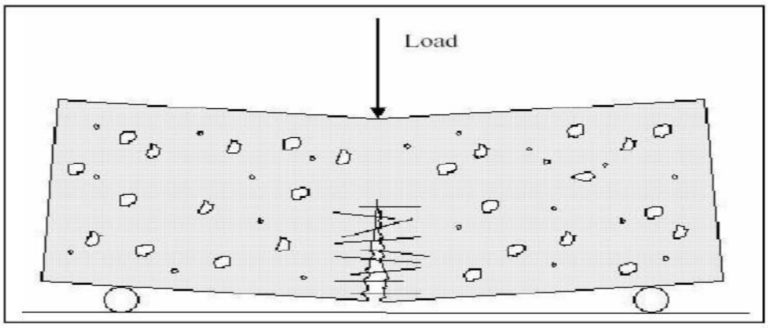


Figure 1.1: Fibre mechanism

BRIDGING ACTION

Pullout resistance of steel fibres (dowel action) is important for efficiency. Pullout strength of steel fibres significantly improves the post- cracking tensile strength of concrete. As an SFRC beam or other structural element is loaded, steel fibres bridge the cracks, as shown in figure 1.2. Such bridging action provides the SFRC specimen with greater ultimate tensile strength and, more importantly, larger toughness and better energy absorption.

An important benefit of this fibre behaviour is material damage tolerance. Bayasi and Kaiser (2001) performed a study where damage tolerance factor is defined as the ratio of flexural resistance at 2-mm maximum crack width to ultimate flexural capacity. At 2% steel fibre volume, damage tolerance factor according to Bayasi and Kaiser was determined as 93%.



2. OBJECT IVE OF THE EXPERIMENT

The objective of the present study was to investigate experimentally the properties of Steel Fibre Reinforced Concrete (SFRC) with the following test results:

1) Compressive strength

2) Split Tensile strength

3) Flexure strength

4) To establish the load-deflection curves

5) Toughness indices of the beam specimens

6) To calculate the stiffness of beam specimens

7) To develop an empirical equation for calculating toughness index

8) To evaluate the energy absorption capacity of the panel specimens

9) To calculate the ductility index of panel specimens

10) To find secant stiffness for panels

And these test results are compared with conventional concrete of M40 grade.

3. LITERATURE REVIEW

The Indian scenario offers the widest opportunities, but equally the greatest challenge to the scientists, engineers and concrete technologists in the use of fibre-cement composites in the construction industry. Research and development work on FRC composites started in India in early 1970s. A number of studies have been reported on the flexural behaviour of Steel Fibre Reinforced Concrete (SFRC) beams and Slurry Infiltrated Fibre reinforced Concrete (SIFCON) elements with particular reference to improvements in cracking resistance, stiffness and ductility. If there is a specific Indian standard code for steel fibre reinforced concrete it will give positive impact on Indian infrastructure development. Construction and maintenance provide an unlimited scope for wide range of applications where the unique properties of FRC materials can be used to the advantage of society, and to contribute to better quality of living.

Gopalakrishnan at (2003) of Structural Engineering Research Centre (SERC), Chennai have studied the properties of steel fibre reinforced shotcrete namely the toughness, flexural strength, impact resistance, shear strength ductility factor and fatigue endurance limits. It is seen from the study that the thickness of the Steel Fibre Reinforced Shotcrete (SFRS) panels can be considerably reduced when compared with weld mesh concrete. The improvements in the energy absorption capacity of SFRS panels with increasing proportions of steel fibres are clearly shown by the results of static load testing of panels. This investigation has clearly shown that straight steel fibres of aspect ratio 65 can be successfully used in field application.

Krishnamoorthy et al (2000) of SERC, Chennai have carried out investigations to find out the influence of corrosion of steel fibres on the strength of SFRC. There concrete specimens were subjected to accelerated corrosion and it was found that there was no corrosion of steel fibres in SFRC even after 250 cycles of corrosion. Additions of steel fibres in concrete matrix have resulted in decreased crack width. It was also noted that the addition of steel fibres in concrete results in delayed cracking of concrete.

Lakshmipathy and Santhakumar (1986) presented results of SFRC frame testing conducted at Anna University. Two frames, representing a 7 level single bay frame, were constructed at 1/4 scale; one frame was made out of reinforced concrete and the other out of SFRC. Fibres with a length of 1.57-in (40-mm) and an aspect ratio of 100 were used at a volume fraction of 1%. An earthquake loading was simulated by applying load via hydraulic jacks at the 7th, 5th and 3rd levels of the frame.

Craig et al (1984) examined the shear behaviour of 21 short columns under double curvature bending. The steel fibres used had a length of 1.18-in (30-mm), an aspect ratio of 60 and were used at volume fractions of 0.75% and 1.5%. It was found that the failure mode changed from explosive to ductile as steel fibre content increased.

Jindal and Hassan (1984) found that the shear resistance of SFRC joints was greater than that of conventional joints. Steel fibres with a length of 1-in (25-mm), and an aspect ratio of 100 were used at a volume fraction of 2%. It was observed that SFRC increased the shear and moment capacities by 19% and 9.9% respectively. It was also observed that the failure mode for SFRC specimens was ductile.

Kaushik et al (1987) found that a strength ratio of 1.67 can be achieved with the addition of 1.5% volume fraction of steel fibres with aspect ratio of 100 and the average maximum strain in fibre reinforced concrete beams were of the order of 0.007 as compared to 0.0035 for plain reinforced concrete beams.

EXPERIMENTAL PROGRAM

In order to study the interaction of steel fibres with concrete under compression, split tension, flexure and static load, 45 cubes, 45 cylinders, 15 beams, 30 panels was casted respectively. The experimental program was divided into five groups.

Each group consists of 9 cubes, 9 cylinders, and 3 beams, 3 panels of 50mm thickness and 3 panels of 100 mm thickness.

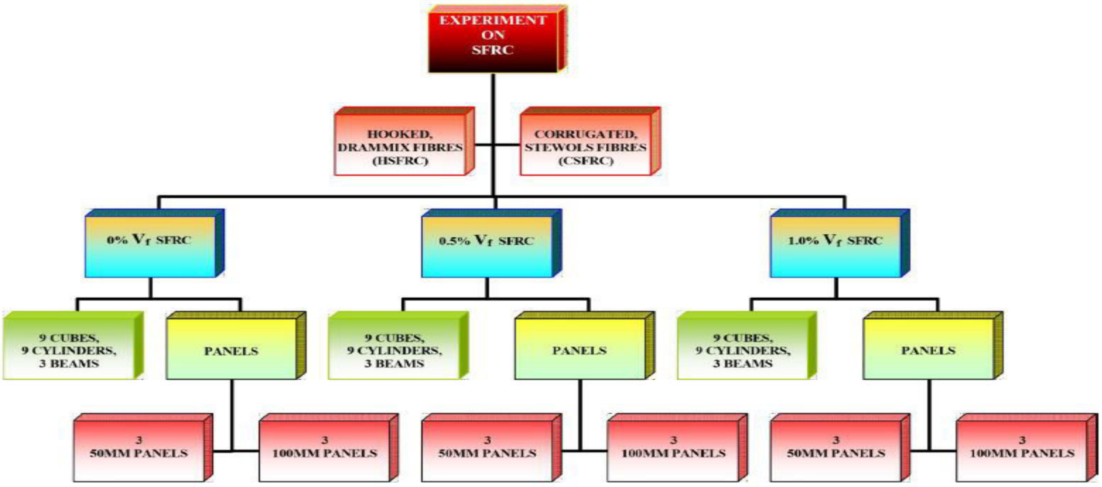
D The first group is the control (Plain) concrete with 0% fibre (PCC)

D The second group consisted of hooked end steel fibre of Vf 0.5% (HSFRC 0.5)

D The third group consisted of hooked end steel fibre of Vf 1.0% (HSFRC 1.0)

D The forth group consisted of corrugated steel fibre of Vf 0.5% (CSFRC 0.5)

D The fifth group consisted of corrugated steel fibre of Vf 1.0% (CSFRC 1.0)



Schematic representation of the experiment

CUBE COMPRESION TEST

Compression testing machine for cylinder

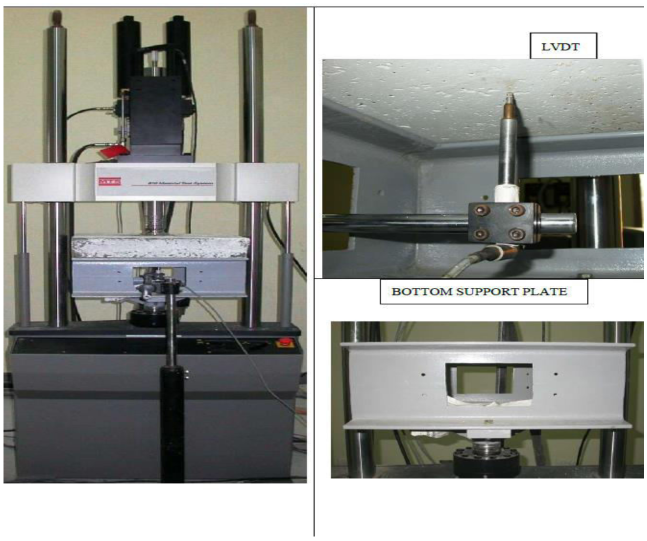
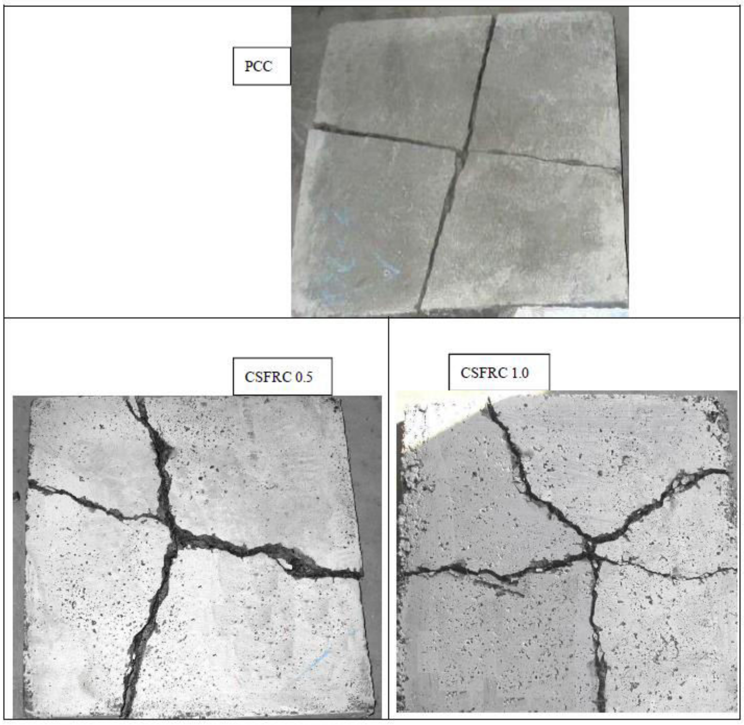


Figure 4.7 Wooden moulds for panels

Figure 5.18 Panel failure in static load

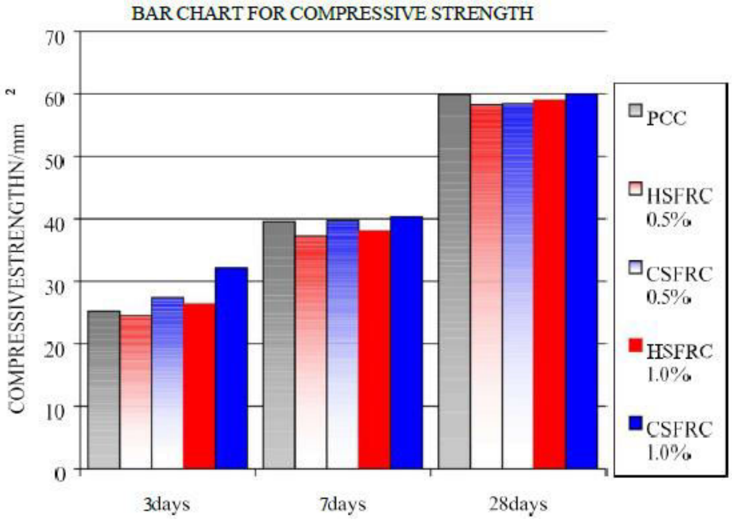
Figure 5.19 First crack in panel



5. RESULTS

Table 5.1 COMPRESSIVE STRENGTH

Specimen Type	Average Compressive strength in N/mm²		
	3days	7 days	28 days
PCC	25.27	39.59	59.89
HSFRC 0.5	24.50	37.29	58.24
CSFRC 0.5	27.38	39.76	58.43
HSFRC 1.0%	26.32	38.04	59.01
CSFRC 1.0	40.35	32.17	60.00



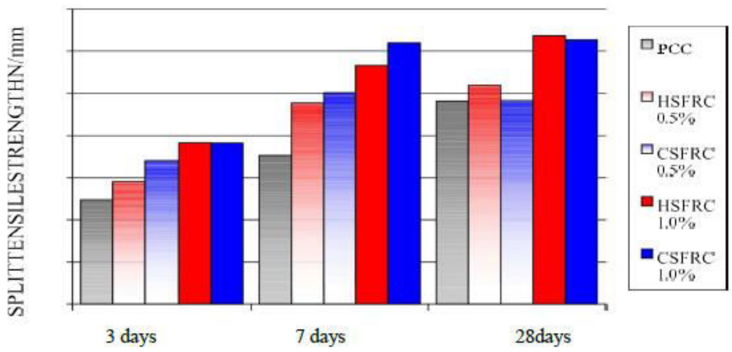
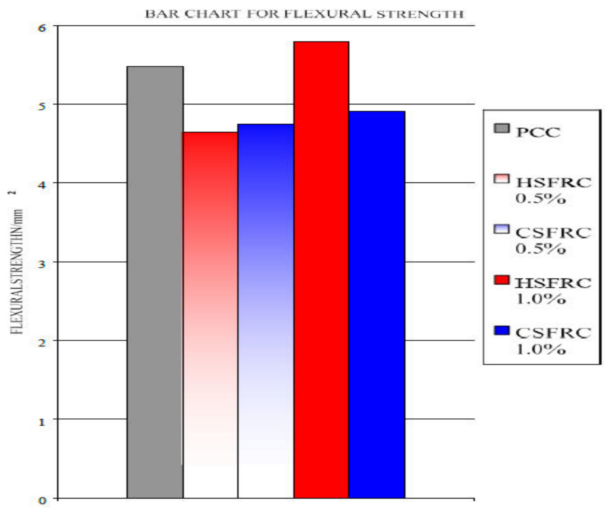


TABLE 5.3 FLEXURAL STRENGTH



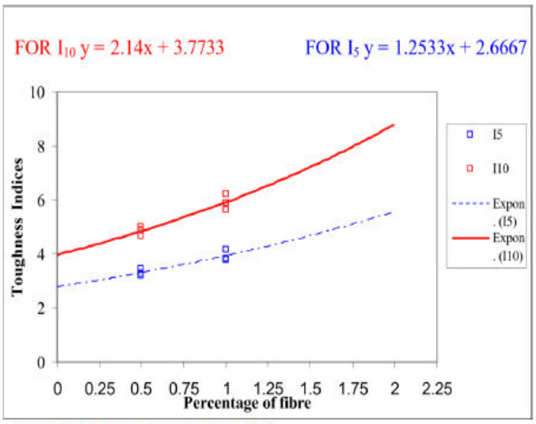


Figure 5.5 Empirical Equations for HSFRC

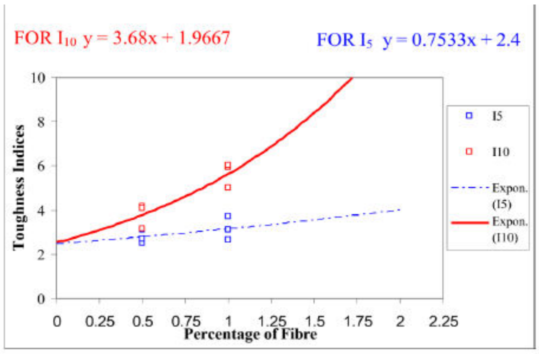


Figure 5.4 Empirical Equations for CSFRC

CONCLUSIONS

The following results are inferred based on the experimental results discussed on the previous chapters.

- Addition of steel fibres to concrete increases the compressive strength of concrete marginally.
- The addition of steel fibres increases the tensile strength.
- By the addition of steel fibres the flexure strength was found to decrease marginally.
- The addition of fibres to concrete significantly increases its toughness and makes the concrete more ductile as observed by the modes of failure of specimens.
- The stiffness of beams was studied and was found to be maximum for hooked end fibre with 1% volume fraction.
- The empirical equations developed in this experiment can be used for calculating the toughness indices or percentage of fibre whichever is required.
- The ductility of steel fibre reinforced concrete was found to increase with increase in volume fraction of fibres and the maximum increase was observed for hooked fibres with 1% volume fraction.

- The improvement in the energy absorption capacity of steel fibre reinforced concrete panels with increasing percentage of steel fibre was clearly shown by the results of the static load test on panels.

REFERENCES

1. ASTM C-1018 (1997) "Standard Specification for flexural toughness and first crack strength of fibre reinforced concrete & shotcrete" American society for testing and materials
2. ASTM C1116 (1997) "Standard Specification for fibre reinforced concrete & shotcrete" American society for testing and materials
3. ASTM C78-97 (1997) "Standard Specification for flexural strength of concrete" (Using simple beam with third point loading) American society for testing and materials
4. ASTM A820-97 (1997) "Standard Specification for steel fibres for reinforced concrete" American society for testing and materials
5. ACI 506.1R.84 (1984) "State of the art report on fibre reinforced shotcrete" ACI committee report, American Concrete Institute
6. ACI Committee 544 (1984) "Guide For Specifying, Mixing, Placing, and Finishing Steel Fibre Reinforced Concrete", American Concrete Institute.
7. "Measurement of Fibre Reinforced Concrete," ACI Committee 544, American Concrete Institute Materials Journal, Vol. 85, No. 6, pp. 583-593, American Concrete Institute 1988.
8. I.S: 10262-1982 "Indian code for recommended guidelines for concrete mix design".
9. I.S 456-2000 "Indian code of practice for plain and reinforced concrete (Fourth Revision)".
10. I.S 516-1959 "Indian code for method of tests for concrete".
11. Bayasi, Z. Bhatacharya, R. and Posey, M. (1989) "Fibre Reinforced Concrete: Basics and Advancements," Proceedings, Symposium on Advancements in Concrete Materials, Bradley University, pp. 1-1 to 1-27.
12. Bayasi, Z. and Kaiser, H. (April 2001) "Steel Fibres as Crack Arrestors in Concrete." The Indian Concrete Journal.
13. Craig, R., S. Mahadev, C.C. Patel, M. Viteri, and C. Kertesz. "Behaviour of Joints Using Reinforced Fibrous Concrete." Fibre Reinforced Concrete International Symposium, SP-81, American Concrete Institute, Detroit, 1984
14. Craig, R. McConnell, J. Germann, N. Dib, and Kashani, F. (1984) "Behaviour of Reinforced Fibrous Concrete Columns." Fibre Reinforced Concrete International Symposium, SP-81, American Concrete Institute, Detroit, pp. 69-105.
15. Gopalakrishnan, S. Krishnamoorthy, T.S. Bharatkumar,B.H. and Balasubramanian, K.(December 2003) "Performance Evaluation of Steel Fibre Reinforced Shotcrete" National seminar on advances in concrete technology Henager,

16. C.H. (1977) "Steel Fibrous, Ductile Concrete Joint for Seismic Resistant Structures." Reinforced Concrete Structures in Seismic Zones, SP 53-14, American Concrete Institute, Detroit,
17. Jindal, R. and Hassan, K. (1982) "Behaviour of Steel Fibre Reinforced Concrete Beam-Column Connections." Fibre Reinforced International Symposium, SP-81, American Concrete Institute, Detroit, pp. 107-123.
18. Johnston, C. (1994) "Fibre Reinforced Concrete." Significance of Tests and Properties of Concrete and Concrete-Making Material, ASTM STP 169C, and concrete structures for the future, Annamalai University pp. 371-386.