BEHAVIOUR OFSTEEL FIBRE REINFORCED CONCRETE: AN EXPERIMENTAL STUDY

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ABSTRACT:

The main objective of this investigation was to study the behavior of Steel Fiber Reinforced Concrete (SFRC). Hooked end fibers and corrugated fibers with aspect ratio of 55 were used to reinforce concrete. Specimens were cast without fibers and with fibers of dosage 0.5% and 1%. Tests were conducted for studying the compressive, tensile, flexural strength and energy absorption. Compressive test on cubes were conducted on cubes of size 150 mm x 150 mm x 150 mm. Fifteen beams of length 700 mm and cross-section 150 mm x150mm were cast, cured for 298days by immersion in water 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. Thirty panels were cast with dimension 500 mm x500 mm x50mm and 500 mm x 500 mm x100mm. Split tensile tests were conducted on 150 mm cylinders to evaluate the tensile strength of concrete. Static point load test was conducted on each panel to calculate the energy absorption, ductility index and secant stiffness was found.

KEYWORDS:

STEEL FIBRE REINFORCED CONCRETE, STATIC LOAD, PANELS, BEAMS, TOUGHNESS, ENERGY ABSORPTION.

INTRODUCTION

Concrete is one of the most versatile building materials. 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 fibers are added to concrete to overcome these disadvantages. The addition of fibers in the matrix has many important effects. Most notable among the improved mechanical characteristics of Fiber Reinforced Concrete (FRC) are its superior fracture strength, toughness, impact resistance, flexural strength resistance to fatigue, improving fatigue performance is one of the primary reasons for the extensive use of Steel Fiber 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 fibers 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 fibers. The fact is fibers of almost any description improve the ability of substances to withstand strain. The main reasons for adding steel 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. Steel fiber’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 (V_f). V_f 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 augments the flexural strength and toughness of the matrix. However, fibres which are too long tend to "ball" in the mix and create workability problems.

Unidirectional fibres uniformly distributed throughout the volume are the most efficient in uniaxial tension. While flexural strength may depend on the unidirectional alignment of the fibres dispersed for away from the neutral plane, flexural shear strength may call for a random orientation. A proper shape and higher aspect ratio are also needed to develop an adequate bond between the features and benefits of SFRC.

FIBRE MECHANISM

Fibres work with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism. The spacing mechanism requires a large number of fibres well distributed within the concrete matrix to arrest any existing micro-crack that could potentially expand and create a sound crack. For typical volume fractions of fibres, utilizing small diameter fibres or micro fibres can ensure the required number of fibres for micro crack arrest.

The second mechanism termed crack bridging requires larger straight fibres with adequate bond to concrete. Steel fibres are considered a prime example of this fibre type that is commonly referred to as large diameter fibres or macro fibres. Benefits of using larger steel fibres include impact resistance, flexural and tensile strengths, ductility, and fracture toughness and this was proved by Bayasi et al (1989).

WORKABILITY

A shortcoming of using steel fibres in concrete is reduction in workability. Workability of SFRC is affected by fibre aspect ratio and volume fraction as well the workability of plain concrete.As fibre content increases, workability decreases. Most researchers limit V_f to 2.0% and l/d to 100 to avoid unworkable mixes.In addition, some researchers have limited the fibre reinforcement index [V_f×(l/d)] to 1.5 for the same reason. To overcome the workability problems associated with SFRC, modification of concrete mix design is recommended. Such modifications can include the use of additives.

LITERATURE REVIEW

By using SFRC in a beam-column joint, some of the difficulties associated with joint construction can be overcome and a greater seismic strength can be provided. Michael Gebman (2001) made two half-scale joints, constructed to reflect U.S building code, two SFRC joints were constructed with a hoop spacing increased by 50%, and two SFRC joints were constructed with a hoop increased by 100%. Hooked-end steel fibres with a length of 1.2-in (31-mm), a diameter of 0.020-in (0.50-mm) and an aspect ratio of 60 were used at a volume fraction of 2%.

Gopalakrishnan et al (2003) 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.

After simulating a quasi-static earthquake loading, the SFRC joints were found to have dissipated more energy than the conventional joints. A 90% increase in energy absorption was found for SFRC joints with hoop spacing increased by 100%. A 173% increase in energy absorption was found for SFRC joints with hoop spacing increased by 50%.

SHEAR RESISTANCE

Large earthquakes result in high shear forces within the beam-column joint. To withstand such forces, hoop spacing is decreased within the joint region. This can sometimes result in congestion problems that can result in construction difficulty. SFRC can be used with increased hoop spacing to provide higher shear resistance.

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 increase.

DYNAMIC RESISTANCE

Dynamic strength of concrete reinforced with various types of fibres subjected to explosive charges, dropped weights and dynamic tensile and compressive load has been measured. The dynamic strength of various types of loading was 5 to 10 times greater for fibre reinforced than for plain concrete. The greater energy requirement to strip or pull-out the fibres provides the impact strength and the resistance to spalling and fragmentation. Steel fibre concrete was found to provide high resistance to the dynamic forces of cavitations under high head, high velocity water flow conditions .Still greater cavitations resistance was reported for steel fibre concrete impregnated with the polymer. An impact test has been devised for fibrous concrete which uses 10-lb hammer dropping on to steel ball resting on test specimen. For fibrous concrete, the number of blows to failure is typically several hundred compared to 30 to 50 for plain concrete. Ests show that that the dynamic stiffness of SFRC beams in the uncracked state was only marginally high (15% for a fibre volume content of 1%) than for reinforced concrete beams. However large increase in stiffness in the post cracking stage was observed: but this was nearly the same for all the fibre volumes studies (0.5% to 1%).

The damping values exhibited by SFRC beams showed significant scatter. Researchers concluded that the average in the uncracked state, applicable to design of machine foundation is 1% critical. Equation are also formulated from the test results to estimate the dynamic stiffness in the beams in post cracking stage for use in the designs involving SFRC elements in blast and earthquake resistant structures.

Tests concluded on SFRC specimens by Jacob et al at Institute of Material and Structure Research, Yugoslavia also showed that the inclusion of fibres improve the dynamic properties of concrete. It is also found that resistance to blow fatigue are improved by the addition of fibre. Resistance to blow was investigated using the Charpystricking pendulum an improvement in toughness was reported.

EXPERIMENTAL INVESTIGATIONS

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

The first group is the control (Plain) concrete with 0% fibre (PCC) The second group consisted of hooked end steel fibre of V_f 0.5%. The third group consisted of hooked end steel fibre of V_f 1.0%. The fourth group consisted of corrugated steel fibre of V_f 0.5%. The fifth group consisted of corrugated steel fibre of V_f 1.0% (CSFRC 1.0) (Table 1 and 2). A schematic representation of the current experimental has been shown in the figure 1.

TABLE 1 DESIGNATION OF BEAMS

S. No.	Type of fibre	Fibre (%)	Specimen ID
1	-	0	B-a
2	-	0	B-b
3	-	0	B-c
4	Hooked	0.5	BHF-0.5a
5	Hooked	0.5	BHF-0.5b
6	Hooked	0.5	BHF-0.5c
7	Hooked	1.0	BHF-1.0a
8	Hooked	1.0	BHF-1.0b
9	Hooked	1.0	BHF-1.0c
10	Corrugated	0.5	BCF-0.5a
11	Corrugated	0.5	BCF-0.5b
12	Corrugated	0.5	BCF-0.5c
13	Corrugated	1.0	BCF-1.0b
14	Corrugated	1.0	BCF-1.0b
15	Corrugated	1.0	BCF-1.0b

TABLE 2 DESIGNATION OF PLATES

S. No.	Thickness	Type of fibre	Fibre (%)	Specimen ID
1	50 mm	-	0	P1-a
2	50 mm	-	0	P1-b
3	50 mm	-	0	P1-c
4	**100 mm**	**-**	**0**	**P2-a**
5	**100 mm**	**-**	**0**	**P2-b**
6	**100 mm**	**-**	**0**	**P2-c**
7	**50 mm**	**Hooked**	**0.5**	P1HF0.5-a
8	50 mm	Hooked	0.5	P1HF0.5-b
9	50 mm	Hooked	0.5	P1HF0.5-c
10	100 mm	Hooked	0.5	P2HF0.5-a
11	100 mm	Hooked	0.5	P2HF0.5-b
12	100 mm	Hooked	0.5	P2HF0.5-c
13	50 mm	Hooked	1.0	P1HF0.5-a
14	50 mm	Hooked	1.0	P1HF0.5-b
15	50 mm	Hooked	1/0	P1HF0.5-c
16	100 mm	Hooked	1.0	P2HF0.5-a
17	100 mm	Hooked	1.0	P2HF0.5-b
18	100 mm	Hooked	1.0	P2HF0.5-c
19	50 mm	Corrugated	0.5	P1HF0.5-a
20	50 mm	Corrugated	0.5	P1HF0.5-b
21	50 mm	Corrugated	0.5	P1HF0.5-c
22	100 mm	Corrugated	0.5	P2HF0.5-a
23	100 mm	Corrugated	0.5	P2HF0.5-b
24	100 mm	Corrugated	0.5	P2HF0.5-c
25	50 mm	Corrugated	1.0	P1HF0.5-a
26	50 mm	Corrugated	1.0	P1HF0.5-b
27	50 mm	Corrugated	1.0	P1HF0.5-c
28	100 mm	Corrugated	1.0	P2HF0.5-a
29	100 mm	Corrugated	1.0	P2HF0.5-b
30	100 mm	Corrugated	1.0	P2HF0.5-c

TEST SETUP

CUBE COMPRESSION TEST

This test was conducted as per IS 516-1959. The cubes of standard size 150 mm x150 mm x150mm were used to find the compressive strength of concrete. Specimens were placed on the bearing surface of UTM, of capacity 300 tones without eccentricity and a uniform rate of loading of 140 Kg/cm^2 per minute was applied till the failure of the cube. The maximum load was noted and the compressive strength was calculated. The results are tabulated in Table 5.1

Cube compressive strength (σ_{cc}) in MPa = P_f/A_b

SPLIT TENSION TEST

This test was conducted as per IS 5816-1970. The cylinders of standard size 150mm diameter and 300 mm height was placed on the UTM with capacity 200tones, with the diameter horizontal. At the top and bottom two strips of wood where placed to avoid the crushing of concrete specimen at the points where the bearing surface of the compressionxesting machine and the cylinder specimen meets. The maximum load was noted down. The results are tabulated in Table 5.2

The spilt tensile strength (T_{sp}) = $2P/\pi dl$ (MPa)

TABLE 5 COMPRESSIVE STRENGTH

Specimen type	Average compressive strength (MPa)		
	Days		
	3	7	28
PCC	25.77	39.59	59.89
HSFRC 0.5	24.50	37.29	58.24
CSFRC0.5	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 6 TENSILE STRENGTH

Specimen Type	Average Tensile Strength (MPa)		
	Days		
	3	7	28
PCC	2.5	3.54	4.81
HSFRC 0.5	2.90	4.76	5.19
CSFRC 0.5	3.40	5.02	4.83
HSFRC 1.0	4.01	5.66	6.37
CSFRC 1.0	3.82	5.29	6.27

FLEXURAL TEST

SFRC beams of size 150x150x700mm were tested using a servo controlled UTM (MTS) as per the procedure given in ASTM C-78. The specimen was turned on its side with respect to its position as moulded and centred on the bearing block. The beam was simply supported over a span of 600mm, and a two point loading system was adopted having an end bearing of 50mm from each support. The load applying block was made into contact with the surface of the specimen at the third point between the supports. The UTM was operated at a rate of 0.1mm/min, load and displacement was recorded constantly. The first crack load and the corresponding deflection were noted. The loading was continued up to six times the first crack deflection. The maximum load was measured. It took about 40 minutes to complete the test on each specimen. The results are tabulated in Table 5.3

The modulus of rupture was calculated using the formula, The modulus of rupture (f_b) =Pl/bd^2

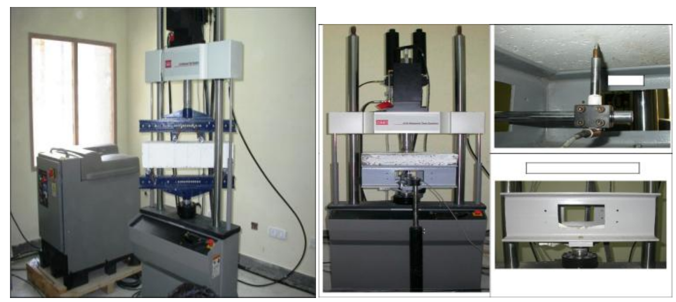

FIGURE 2 BEAM TEST SETUP

TOUGHNESS

Toughness was calculated as the energy equivalent to the area under the load deflection curve as per the procedure given in the American society for testing and material's ASTM C-1018.Toughness index was calculated as the number obtained by dividing the area up to a specified deflection by the area up to the first crack deflection. The first crack is the point on the load deflection curve at which the curve first becomes non linear (approximately the onset of cracking on the matrix). Toughness indices I_5 and I_{10} were calculated as area up to 3.0 times and 5.5 times the first crack deflection by the area up to a first crack deflection respectively. Toughness indices are tabulated in Table 5.4.

STIFFNESS

Stiffness is an important property which determines the rigidity of the material. Stiffness is the ability of the material to resist deformation under the applied load. Stiffness of the beam specimen was found as the slope of the load-deflection curve up to the elastic region of the curve.

EMPIRICAL EQUATION

The empirical equations for finding the toughness indices were found using the I_5 and I_{10} values from the experimental results using Microsoft Excel office program. If the toughness was known the percentage of fibres required can be calculated easily. Empirical Equations for CSFRC and HSFRC are given in the Figure 3 and Figure 4 respectively.

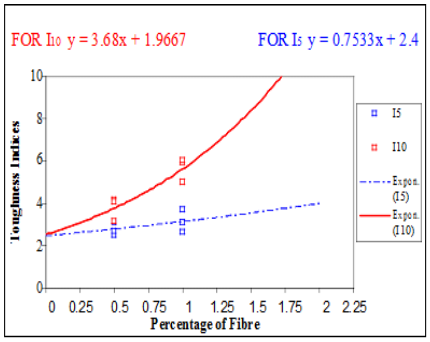

FIG. 3 EQUATION FOR CSFRC

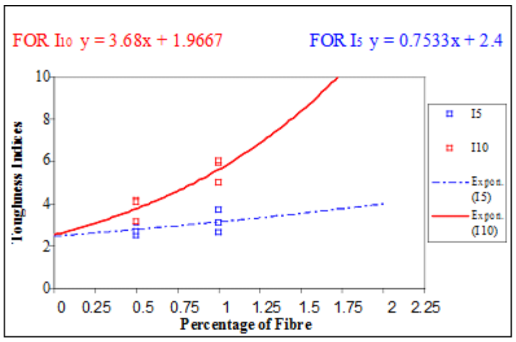

FIG. 4 EQUATION FOR HSFRC

STATIC LOAD TEST

Static load test was performed on panels of dimension 500 mm×500 mm×50 mm and 500 mm×500 mm×100mm. The specimen was placed on a simply supported condition on all four sides and a concentrated load was applied over an area of 61sq.cm.

The actuator as operated at a rate of 1.5 mm/min and the corresponding load & deflection was measured as per the European Specification for Sprayed Concrete (EFNARC). The bottom deflection was also monitored using a Linearly Variable Differential Transducer (LVDT). The testing was continued till a deflection of 25mm or failure which ever occurred earlier. The energy absorption up to the deflection of 25mm was calculated as area under load deflection curve for that deflection, with an increment of 2mm.

CASTING OF SPECIMENS

The specimens were cast using OPC with specific gravity 3.15 conforming to IS 269-1976. River sand conforming to IS 2386 Pt I with specific gravity 2.65with water absorption 0.99% and dry loose bulk density 1592 kg/m3. Crushed granite stone aggregates of maximum size of 20 mm as per IS 2386 (part III) of 1963 was used. Its specific gravity of coarse aggregate ws 2.73 and water absorption 0.25%, and dry loose bulk density 1500 kg/m3.As per IS 456-2000 recommendations, potable water was used for mixing of concrete. Hooked end steel fibres conforming to ASTM A820 and Belgium standard 1857 with diameter of 0.55 m and aspect ratio pf 55 was used. Corrugated steel fibres was used which had a length of 25 mm and a diameter of 0.45 mm resulting in an aspect ratio of about 55 which conformed to ASTM A820. The materials were weigh batched. After casting the specimens were cured with potable water.

CURING OF SPECIMENS

The test specimens were stored in place free from vibration and kept at a temperature of 27˚±2˚C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients. After this period, the specimen were marked and removed from the moulds and immediately submerged in clean fresh water and kept there until taken out prior to test. The specimens were allowed to become dry before testing. The panels were cured by dry curing method, i.e. moist gunny bags were covered over the panels.

RESULTS AND DISCUSSION

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. The tensile strength was found to be maximum with volume fraction of 1%.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 he 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 (Fig. 5).The 100mm thick panel absorbed the maximum energy of 1010Nm with Hooked end steel fibre with volume fraction 0.5% for a deflection of 20mm.Secant stiffness was found to be maximum for corrugated fibre with volume fraction 1%.

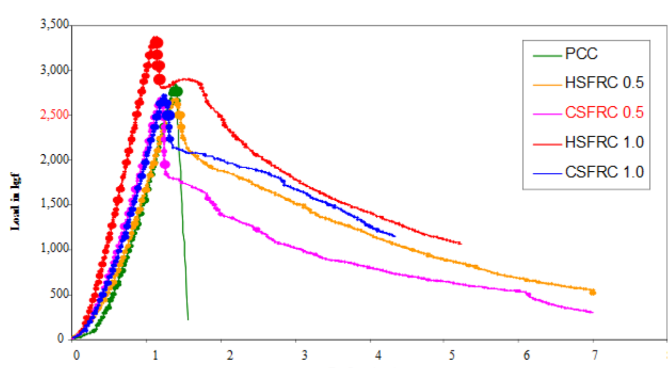

FIG. 5 LOAD-DEFLECTION CURVE

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