

Steel Fibre Reinforced Concrete Beams under Flexure

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ABSTRACT--- *This paper presents the results of experimental study conducted to examine the effectiveness of steel fibre in enhancing flexural capacity of high strength concrete (HSC) beams. In this study a total of twelve beams of 3 m length and 150mm x 250mm in cross-section were cast and tested in the laboratory. One beam served as control beam (without fibre), three beams were casted with different fibre volume fraction. Different grade of concrete (M60, M70 and M80) and different steel fibre volume fractions (0.5%, 1.0% & 1.5%) were the principal parameters considered in this study. All the beams were tested under four-point bending in a loading frame of capacity 750kN. Deflections were measured through appropriate instrumentations. The results showed that steel fibre reinforced concrete (SFRC) beams with 1% fibre volume fraction exhibit an increased strength, sufficient ductility, toughness and composite action until failure.*

1. INTRODUCTION

Fiber reinforced concrete is relatively a composite material in which steel or other fibers are introduced in the matrix as micro reinforcements so as to improve the tensile strength of concrete when two different kind of materials contrasting properties of strength and elasticity are combined together, they realize a great position of theoretical strength of stronger component and these combined materials are called two phase composites. In an ideal two phase composites, the strength of weak phase is thus improved by the strong phase

Usually a two phase composite material is a combination of one material with greater tensile strength and modulus of elasticity with another material of relatively low modulus of velocity. The high strength material is finally divided and evenly dispersed in a matrix and then mixed with low modulus material. Conventional reinforced concrete is a two phase composite only after cracking, when the cracked matrix is held by the reinforcing bars. On the other hand, when concrete is reinforced by short and closely phase fibers an ideal two phase composite is produced in the sense that even the cracking strength is increased by the closely phased fibers acting as crack arresters. The fiber have been produced from steel, carbon, glass, plastic, polypropylene, nylon, rayon, asbestos, basalt, and natural fibers such as cotton, sisal, coir etc in various shape and sizes. Steel fibers are generally being used for structural applications since they possess high modulus of elasticity and led to strong stiff composites.

M.C.Nataraja et.al (1998) has conducted for a study on steel fibre reinforced concrete under compression. Here the behaviour of steel fibre reinforced concrete under compression for cylinder compressive strength ranged from 30 to 50 N/mm². Round crimped fibres with three volume fraction of 0.5 percent, 0.75 percent and 1.0 percent and for two aspect ratios of 55 and 82 are considered. The effect of fibre addition to concrete on compressive strength was studied. It was concluded that the addition of fibres increases the compressive strength and toughness. Some square fitting line analyses were also done and some equations were proposed for compressive strength in terms of fibre reinforcing index (length of fibre x volume fraction).

H.V.Dwarakanath and T.S.Nagaraj(1998) were experimented the Flexural behaviour of fibre reinforced concrete beams. In this study fibres were put in two types of locations such as over the entire depth and one half the depth of the beam on the tension side. 20 numbers of 1.8m long reinforced concrete beams with steel fibres were tested under flexural

static loading. Midspan deflections and curvatures at salient points such as cracking, and ultimate points were compared. It is found that half depth mode of inclusion of fibres for under reinforced concrete beams and full depth mode of inclusion of fibres for over reinforced concrete beams.

Agrawal, A.K. Singh and Singhal D. (1996) studied the effect of fibre reinforcing index on the compressive strength and bond behavior of steel fibre reinforced concrete by using straight circular Galvanized Iron fibres with aspect ratios of 60, 80 and 100. The maximum fibre content was taken as 1.50% by volume of concrete. The results show an increase in compressive and bond strength of steel fibre reinforced concrete when compared to normal concrete. They also developed relationships to relate compressive and bond strength with fibre reinforcing index (FRI).

ParvizSoroushian&ZiadBayasi (1999) carried out experimental investigations on the relative effectiveness of straight, crimped rectangular, hooked - single and hooked - collated with aspect ratio of about 60 to 75. They observed slightly higher slumps with crimped fibres and hooked fibres are found to be more effective in enhancing the flexural and compressive behavior of concrete than the straight and crimped fibres.

Chunxiang and Stroeven (2000) investigated the effect of hybrid fibres on crack control. Mono-filament polypropylene fibre and three sizes of steel fibres were used. The total fibre content was varied from 0% to 0.95% by volume of concrete. The maximum dosage of superplasticizer used was 3.0% by weight of cement. The authors reported that large steel fibres & polypropylene fibre significantly influence the load bearing capacity of fibre concrete in the small displacement range and that proper hybrid fibre system can be more efficient than mono-fibre system.

Kaushik S.K., et al. (2003) carried out experimental investigation on the mechanical properties of reinforced concrete by adding 1.0% volume fraction of 25mm and 50 mm long crimped type flat steel fibres. It was observed that short fibres acts as crack arrestors and enhances the strength, where as long fibres contributed to overall ductility. They concluded that best performance was observed with mixed aspect ratio of fibres.

Ramakrishnan (2008) investigated the performance evaluation of synthetic fibre reinforced concrete for transportation structures. The non-metallic polyolefin fibres (50 mm long and 0.63 mm diameter) and dramix steel fibres (60 mm long and 0.8 mm diameter) were used in the construction of bridge deck overlays, pavements, barriers and white-topping. Different quantities of polyolefin fibres 11.9 and 14.8 kg/m³ were used. The authors reported that addition of fibres at 14.8 kg/m³ enhanced the structural properties of concrete. The author also reported that there was a slight increase in flexural strength and toughness, impact, fatigue, endurance limit and post-crack load-carrying capacity and this improvement was same or in some cases (such as impact) better than the enhancement achieved with the addition of 39.1 kg/m³ of steel fibres.

Yang et al (2011) examined the basic behavior of ultra high strength concrete beams reinforced with steel fibers. The principal parameters considered in their study were steel rebar ratio and the method of placing ultra high performance concrete. The authors reported that bending behavior of UHPC members was characterized by multi-microcracking and a localized macrocrack. In addition, numerical predictions for the ultimate bending moment capacity for test beams showed good agreement with experimental results.

Alberto Meda (2012) studied the effectiveness of fibre reinforced concrete (FRC) to improve the structural response of RC members under different loading conditions. Seven beams of size 200mm x 200mm x 4000mm were tested under four point bending scheme. Hook-ended steel fibres with an aspect ratio 50 were added to four beams in two different contents (V_f of 0.38% and 0.76%). The mean value of compressive strength of concrete was 40MPa and 55MPa. The authors concluded that overall ductility was strongly influenced by fibres also they concluded that fibres in beams having high reinforcement ratio avoid explosive concrete collapses due to their significant enhancement in concrete toughness under compression, depending on the amount and characteristics of fibres.

2. EXPERIMENTAL PROGRAM

To investigate the ductile behaviour of fibre reinforced high strength concrete beams, four full scale beams were cast and tested until failure under two point loading condition. The concrete used in the study had a compressive strength of 67, 76 and 83MPa. All beams were 3m long with 150 width and 250mm depth. All beams were reinforced with 3 bars of 12mm dia giving a steel ratio of 0.98% having yield stress of 537MPa, 2 bars of 10mm dia were provided as hanger bars and 8mm dia stirrups at 150mm spacing were also provided. Hook-ended steel fibres having a length of 60mm and diameter of 0.75mm. (Aspect ratio – $L/\phi = 80$) were added to the beams with different fibre volume fractions as 0%, 0.5%, 1.0% and 1.5%.

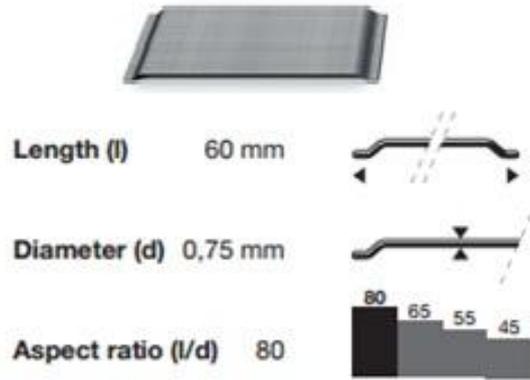


Figure .1 Geometry of hook-ended steel fibre.

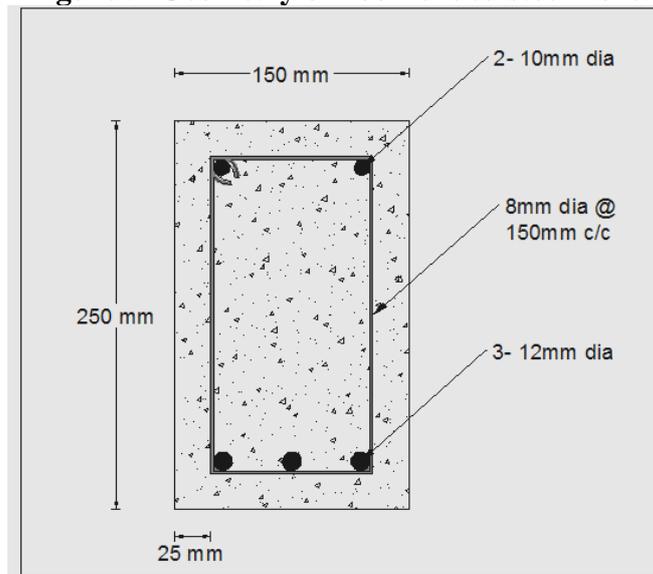


Figure .2 Geometry of beam



Figure .3 Test Set- Up and Instrumentation

Table 1. Properties of steel fibre

Si. No	Fibre properties	Fibre Details
		Steel
1	Length (mm)	60
2	Size/Diameter (mm)	0.75 mm dia
3	Aspect Ratio	80
4	Density (kg m ⁻³)	7850
5	Specific Gravity	-
6	Young's Modulus (GPa)	210
7	Tensile strength (MPa)	1225
8	Shape	Hooked at ends

3. TEST SET-UP AND PROCEDURE

All the beams were tested under four-point bending in a loading frame of 500kN capacity. The deflections at mid-span and load points were measured using dial gauges of 0.01mm accuracy. Crack widths were measured using a crack detection microscope of 0.02mm accuracy. The loading arrangement & instrumentation adopted is shown in Figure 3. Table 2 summarises the test results at yield and ultimate stage of fibre reinforced High Strength Concrete beams.

4. LOAD- DEFLECTION RESPONSE

Load- deflection response of tested beams was shown in Figure 4. exhibits three regions of behaviour. At low load levels, the steel fibre reinforced concrete beam stiffness is relatively high indicating that the concrete behaves in a linear elastic manner. As the load increases, the extreme fibre stresses in bending increase until the tensile strength of concrete is reached. This causes flexural cracking initially in the constant moment region. Flexural cracking causes a marked reduction in stiffness as shown by a sudden change of gradient in the response.

After the concrete cracks in the tension zone, a greater portion of the tensile component of the bending moment is carried by the steel reinforcement. As the beam rotation increases further, the rebar stress increases throughout the constant moment zone. Eventually, the yield stress of steel is reached at one or more points. Such loss of material stiffness results in a reduction in the overall stiffness of the beam and the ability of the section to support the tensile component of the bending moment are reduced. This is shown by the second marked change in gradient of the response.

Flexural cracks formed in the constant moment zone extend vertically upwards and become progressively wide as the load is increased. Cracks are also initiated in the shear spans of the beam with increased loads. The final failure of the beam is characterized by large strains in the steel reinforcement & substantial deflection near collapse accompanied by extensive cracking. An overall evaluation of the load-deflection curves indicate that steel fiber reinforced concrete beams with 1% fibre volume fraction exhibit higher load carrying capacity and ductility.

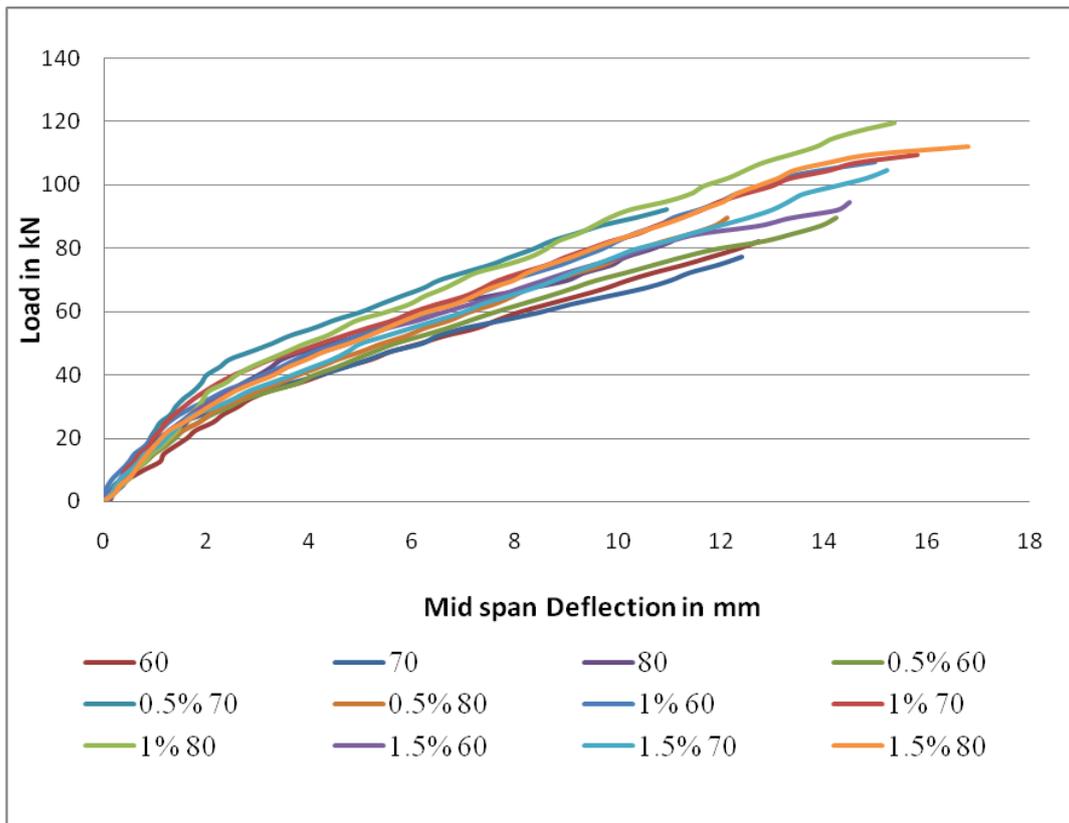


Figure. 4 Load vs Deflection

5. EXPERIMENTAL RESULTS AND DISCUSSION

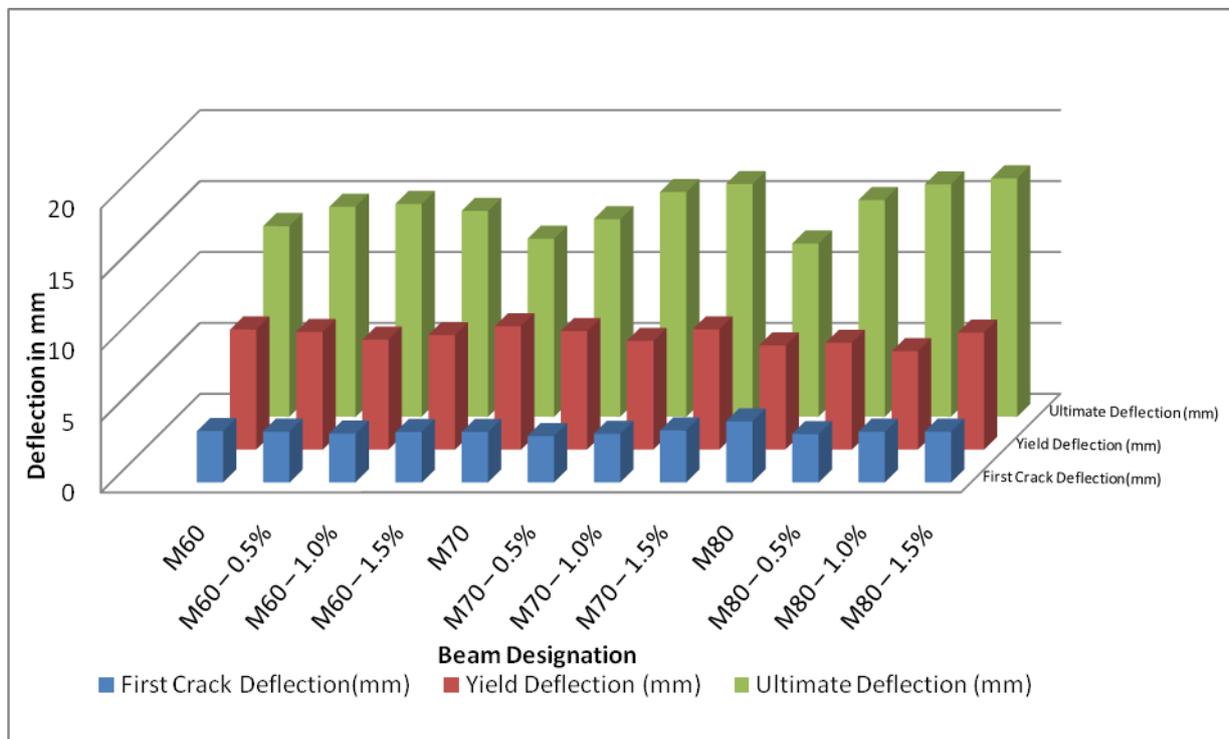


Figure. 5 Deflection at various load levels

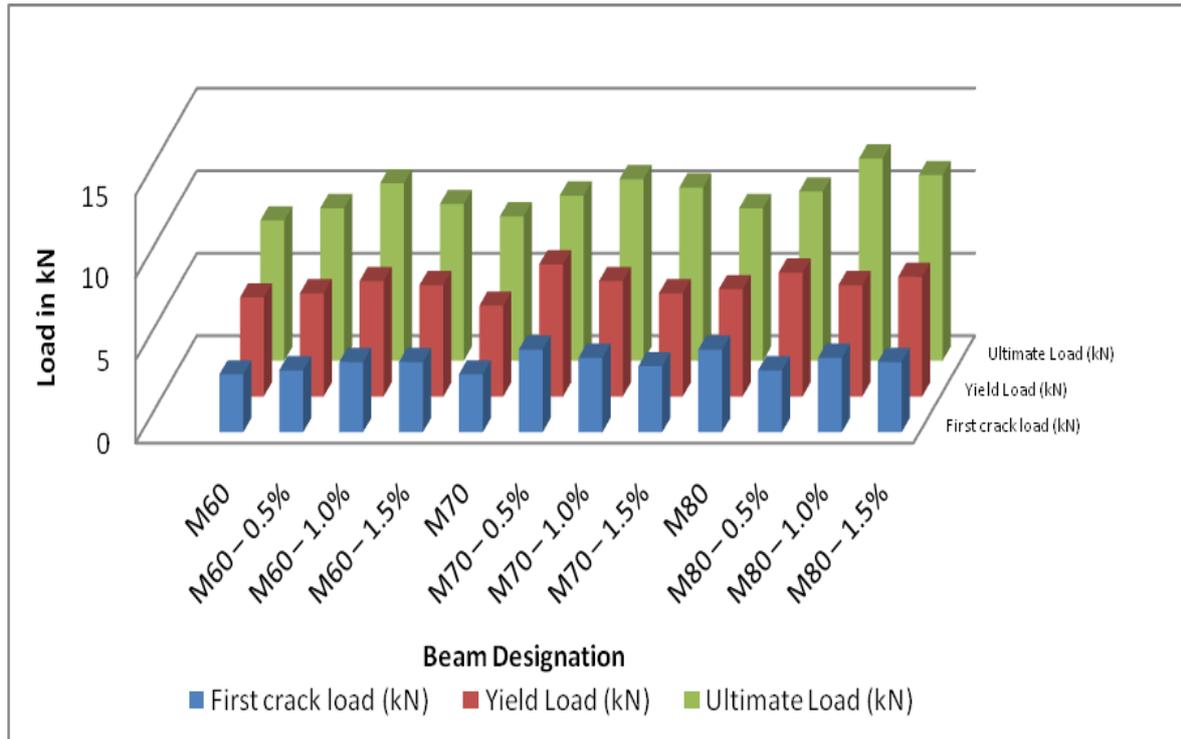


Figure. 6 Load at different levels

The Figure.5 and Figure.6 encapsulates the results at first crack, yield and ultimate stage of steel fibre reinforced concrete beams and control beam. The first crack load were obtained through visual examination at the stage the steel fibre reinforced concrete beams with M70 grade concrete having 1% fibre volume fraction exhibit a maximum increase of 28.57% compared with the control specimen. At the stage of loading beyond which the load deflection response was not linear the yield load was obtained. At the stage steel fibre reinforced concrete beams with M70 grade concrete having 1% fibre volume fraction exhibit an increase upto 16.66% compared with the control specimen. The ultimate loads were obtained at the loading stage beyond which the beam would not sustain additional deformation at the same load intensity a maximum increase of 32.35% was exhibited by the steel fibre reinforced concrete beams with M80 grade concrete having 1% fibre volume fraction. It can be observed from the Figure.5 and Figure.6 that, all load levels a significant increase in strength was achieved by steel fibre reinforced concrete beams having 1% fibre volume fraction. This may be attributed to the increase in tensile cracking strength of concrete due to bridging action of fibre composites.

Table 4. Ductility indices of tested beams

Beam Designation	Deflection Ductility	Energy Ductility	Curvature Ductility
M60	1.795	1.921	39.316
M60 – 0.5%	2.299	2.46	40.506
M60 – 1.0%	2.527	2.704	50.267
M60 – 1.5%	2.391	2.559	44.128
M70	1.667	1.783	36.507
M70 – 0.5%	2.026	2.168	35.7
M70 – 1.0%	2.58	2.761	51.326
M70 – 1.5%	1.934	2.069	35.689
M80	1.663	1.78	36.438
M80 – 0.5%	2.032	2.174	35.804
M80 – 1.0%	2.364	2.529	47.022
M80 – 1.5%	2.123	2.272	39.177

It can be observed that the steel fibre reinforced concrete beams exhibit increase in deflection with increase of fibre content at ultimate load level when compared to the control beam. The increase in deflection was found to be 11.60% for M60 grade concrete with volume fraction, 22.32% for M70 grade concrete with volume fraction 1.5% and 25.59% for M80 grade concrete with volume fraction 1.5% when compared to the control beam.

The ductility values of tested beams were calculated based on deflection and energy absorption. The deflection ductility values were calculated as the ratio between deflections at ultimate point to deflection at the yield point. The energy ductility value were calculates as the ratio of cumulative energy absorption at ultimate stage to the cumulative energy absorption at yield stage. The Ductility indices of tested beams are presented in Table 4. The deflection ductility of SFRC beams with M70 grade concrete having 1% Vf showed a maximum increase of 43.73%. The energy ductility of SFRC beams with M70 grade concrete having 1% Vf showed a maximum increase of 43.72%. The curvature ductility of SFRC beams with M70 grade concrete having 1% Vf showed a maximum increase of 51.32%.

The steel fibre reinforced concrete beams exhibit more number of cracks with lesser widths at all load levels.

6. CONCLUSIONS

Based on the experimental test results the following conclusions were drawn

- The optimum fibre volume fraction was 1%.
- All the beams were failed under flexure mode only.
- SFRC beams with M80 grade concrete and 1% fibre volume fraction resulted in higher load carrying capacity. The percentage increase ultimate load was 32.35%.
- SFRC beams with M70 grade concrete and 1% fibre volume fraction showed enhanced deflection ductility. The maximum increase in deflection ductility was 43.73%
- SFRC beams with M70 grade concrete and 1% fibre volume fraction showed enhanced energy ductility. The maximum increase in energy ductility was 43.72%
- SFRC beams with M70 grade concrete and 1% fibre volume fraction showed enhanced curvature ductility. The maximum increase in curvature ductility was 51.32%

7. REFERENCES

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