International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-2, Issue-6, August 2013

An Experimental Investigation on Structural Performance of Steel Fibre Reinforced Concrete Beam

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Abstract- Conventional concrete loses its tensile resistance after the formation of multiple cracks. However, fibreous concrete can sustain a portion of its resistance following cracking to resist more loading. The Steel Fibre Reinforced Concrete (SFRC) has enhanced resistance against cracking and a better micro-crack arrest mechanism. Further, fibre reinforced concrete is found to have improved strengths against shear, flexure, tension and increased resistances against impact, fatigue, wear and enhanced toughness and ductility over that of RCC. In the present study an attempt has been made to investigate the effect of percentage of steel fibres on structural behavior of beams measured in terms of Load Deflection behavior, Ultimate load carrying capacity, Cracking Pattern and Mode of Failure and to investigate the effect of aspect ratio of steel fibres on structural performance of RC beams measured in terms of above parameter sand also to investigate the effect of mixed fibres (two types of fibres with different aspect ratios) on structural performance of RC beams.

Initially thirteen specimens of series (SV1, SVF1, SVF2 and SVF3) with different aspect ratio of fibres were tested. Finally, thirteen specimens of series (SV1, SVF1, SVF2 and SVF3) with volume fractions of 0.5%, 1.0%, 1.5% and 2% steel fibres were cast and tested.

The results obtained from the investigation indicated that addition of steel fibres in the concrete mix improved structural performance of beam measured in terms of ultimate load carrying capacity, stiffness, crack width, deflection. The presence of steel fibres in concrete mix also improved the post cracking behavior of the specimens of all the series due to crack arresting phenomenon. With the increase in the percentage of fibres from 0.05% to2% in the beam the deflection at peak load increased. The optimum fibre volume percentage for all the series was obtained as 1.5%. The structural performance of the specimens of the series SVF2 was best among all the series. It was also observed in the study that addition of fibres results in improvement in ultimate load carrying capacity of beams along with its area under the curve thus indicating improved toughness of the beams.

Index Terms- RCC, SFRC, SVF2, SVF3

I. INTRODUCTION

Concrete is one of the most widely used construction material. It has good compressive strength, durability, fire resistance and can be cast to fit any structural shape.

Manuscript received August, 2013.

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Providing steel reinforcements and prestressed tendons are used to offset these deficiencies, but these methods, too, fall short in arresting the micro cracks effectively. As an improvement to Reinforced Cement Concrete (RCC), the reinforced concrete with randomly distributed fibres provides an ideal two phase composite material. The Steel Fibre Reinforced Concrete (SFRC) has enhanced resistance against cracking and a better micro-crack arrest mechanism. Further, fibre reinforced concrete is found to have improved strengths against shear, flexure, tension and increased resistances against impact, fatigue, wear and enhanced toughness and ductility over that of RCC.

II. REINFORCED CONCRETE

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.

III. FIBRE REINFORCED CONCRETE

Fibre reinforced concrete can be defined as a composite material consisting of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete fibres. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibres. Fibre can de circular or flat. Fibres are often described by a convenient parameter called 'Aspect Ratio'. The aspect ratio of the fibre is the ratio of its length to an equivalent fibre diameter. Typical aspect ratio ranges from 50 to 150. Each type of fibre has its own characteristic properties and limitations. Steel fibre is one of the most commonly used fibres. Generally, round, straight fibres are used.

The diameter may vary from 0.25 to 0.75mm.Several studies have been conducted on Fibrous Reinforced Concrete Structure. Fiber material can be steel, cellulose, carbon, polypropylene, glass, nylon, and polyester.

IV. STEEL FIBRE REINFORCEMENT

The important properties of steel fibre reinforced concrete (SFRC) are its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under

Flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fibre composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading. Fiber shapes are illustrated in Figure 1.1

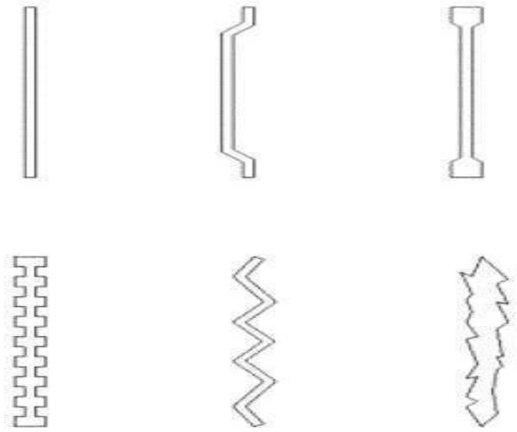

Figure 1.1 Shapes of steel fibres

V. 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. 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 behavior is material damage tolerance. In this fig Bridging action of steel fibres is shown.

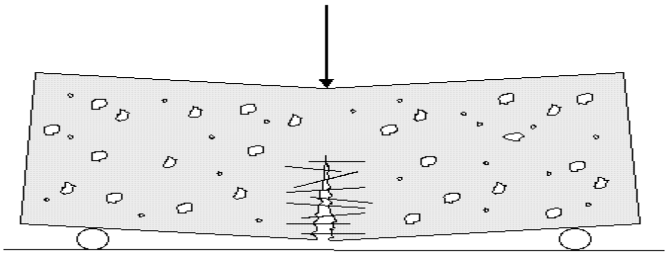

Figure 1.2 Bridging Action of Steel Fibre

VI. STRUCTURAL USE OF SFRC

As recommended by ACI committee 544 'when used in structural application, SFRC should only be used in a supplementary role to inhabit cracking, to improve resistance to impact or dynamic loading, and to resist material disintegration in structural members where flexure and tensile loads will occur. The reinforcing steel must be capable of supporting the total tensile load'. Thus there are a number of techniques for predicting the strength of beam reinforced only with steel fibres, there are no predictive equations for large SFRC beam, since these would be expected to contain conventional reinforcing bar as well.

For beams containing fibres and continuous reinforcement bar, the situation is complex, since the fibre act in two ways:

- They permit the tensile strength of SFRC to be used in design, because the matrix will no longer lose its load carrying capacity at first crack load.
- They improve the bond between the matrix and the reinforcing bars by inhibiting the growth of cracks emanating from the deformation of the bar.

VII. APPLICATIONS OF SFRC

The use of SFRC over past thirty years has been so varied and so widespread, that it is difficult to categorize them. The common applications are pavements, tunnel linings, pavements and slabs, shortcrete airport pavements, bridge deck slab repairs and so on. There has also been some recent experimental work on roller compacted concrete reinforced with steel fibres. The list is endless, apparently limited only by the ingenuity of the engineers involved. The fibres themselves are unfortunately, relatively expensive; a 1% steel fibre addition will approximately double the material cost of concrete, and this has tended to limit the use of SFRC to special applications.

VIII. ADVANTAGES OF STEEL FIBRES

(1) Creates more ductile concrete with reduced cracking.
(2) Reduce the effect of shrinkage curling.
(3) More economical than conventional steel solutions.
(4) Fast installation thereby reducing schedule time.
(5) Easy material handling.
(6) Supported by large manufactures.
(7) Very durable
(8) Does not interfere with guide wire signals.
(9) Does not cause concrete delaminations.
(10) Can replace wire mesh in most elevated slabs.

IX. EXPERIMENTAL PROGRAMME

The experimental work involved casting and testing of conventionally reinforced beam and steel fibre reinforced concrete beam. The work was carried out in following steps:

- Analysis of salient properties of the materials to be used.
- Designing of a workable mix of M25 grade using graded coarse aggregate of 20 mm maximum size.
- Fabrication of test specimens and test cubes and cylinders.
- Testing of specimens.

Comparing test results of conventional and steel fibrous reinforced concrete beam in terms of First crack load, Maximum crack width, Load-deflection behavior, Moment rotation behavior, Ultimate load carrying capacity.

X. MATERIAL USED

The material used for this experimental work are cement, fine aggregates, coarse aggregates, water, steel fibres and reinforcing steel.

CEMENT: Ordinary Portland cement 53 grade of Ultra Tech Aditya Birla make conforming to IS: 8112-1989[28] was used in the present study. Washed sand obtained from D.T.H Concrete batching plant, near IOCL refinery road, Panipat was used as fine aggregate with specific gravity 2.67 and fineness modulus 2.36

conforming to I.S.–383-1970. The crushed type coarse aggregates of 20mm and 10mm size were obtained from D.T.H Concrete batching plant, near IOCL refinery road, Panipat with Fineness Modulus 8.28, and Water Absorption 0.32% and Specific Gravity 2.71, conforming to I.S.-383-1970.

WATER: Potable water was used for the experimentation. High Yield Strength Deformed (HYSD) 'TOR' steel bars are used. The reinforcing bars conformed to the requirements of IS: 1786-1985[24].

XI. INSTRUMENTATION

LOADING ARRANGEMENT: The load was applied using a hydraulic jack operated with test cylinder plant, less than two points loading. Since the jack provide only single point load, for converting the single point load to two point load a specially fabricated loading arrangement consisting of a pair of stiff mild steel channel section welded face to face was used. 25 mm diameter mild steel roller was used to apply load to the specimen. The roller was placed under the channel section served to transmit the applied load to beam specimen as two point load, To prevent the sliding away of the roller on channel section and on the specimen, roller was laterally confined between two 12 mm diameter mild steel runners welded to the channel section, which acted as guide rails for the rollers. Plate - 3.3 shows the specimen with the loading arrangement in place. The applied load was measured with the help of a cylinder plant of 600KN capacity.

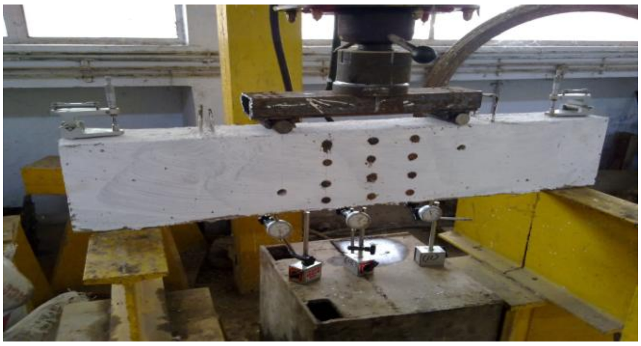

Figure 1.3 Loading Arrangement

MECHANICAL STRAIN GAUGES: DEMEC strain gauges of 4 inches size were used for measuring surface strains at different points of the specimen. The least count of the gauge was 0.0001 inches. The gauge was used with stainless steel studs of 10mm diameter having a punch mark on one surface. The plain surface of each stud was pasted to the specimen by quick fix cementing solution. The punch mark on the study was to accommodate the conical point knob of the strain gauge.

DEFLECTION DIAL GAUGES: Baty dial gauges with magnetic bases were used to measure deflection at different points of the specimen. The least count of the gauges was 0.01mm.

CRACK MEASURING INSTRUMENT: A crack measuring instrument manufactured by W. H. Mays, U.K. was used for measuring the width of cracks at each stage of loading. The least count of the instrument was 0.1 mm.

INCLINOMETER: Inclinometer procured from W. H. Mayes, were used for measuring rotation. The least count of these Inclinometers was 60".

Figure 1.4 Confinement of a Beam-Column joint

XII. CONCLUSIONS

The present study was undertaken to investigate the behavior of steel fibrous reinforced concrete beams with conventional longitudinal reinforcement and shear reinforcement. In all, 13 beams were cast and tested. Based on the experimental results obtained from the present study, the conclusions have been drawn on the behavior of fibrous reinforced concrete beams and are reported in this study. The following conclusions can be drawn:

I. The addition of steel fibres in the concrete mix resulted in improved structural performance measure in terms of ultimate load carrying capacity, crack widths, deflection and curvature ductility factor of beam specimens of all the series.
II. The optimum fibre volume percentage for all the series was obtained as 1.5%. The further increase in fibre content reduced the load carrying capacity of the specimens due to poor compaction of concrete because of balling of fibres.

III. The structural performance of the specimens of the series SVF2 was best among all the series. However, the structural performance of the specimens of series SVF3 containing mixed fibres (65% fibres of aspect ratio 60 and 35% fibres of aspect ratio 83.33) is also comparable to the specimens of series SVF2 in terms of ultimate load. However, the behavior of the specimens of series SVF3 was best in terms of crack width and deflection.

IV. With addition of steel fibres in concrete mix of the specimens the appearance of first crack was delayed. The presence of steel fibres also improved the post cracking behavior of the specimens of all the series due to crack arresting phenomenon.

V. The fibrous concrete specimens also exhibited better rotation capacity at ultimate load as compared to non fibrous concrete specimens.

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