Performance of SFRC Beams under Combined State of Flexure and Compression

M S Jafri[1], and Mohd Israil[2]

Abstract**—**Present study is to investigate the behaviour of composite beams of M20 Grade of concrete mix having size of 100 mm x 100 mm x 500 mm with varying percentages of fibre content under a combined state of flexure and direct compression. Straight cylindrical fibres of length 28 mm and diameter of 0.28 mm with aspect ratio of 100 were used. Twelve beam specimens each with 0, 0.5, 0.75 and 1% fibre percentages by weight were cast. Therefore in total forty eight beams were cast. These beams were tested as simply supported beams in flexure along with direct compression of 0, 50, 100, and 125 kN. The beams were tested such that for each percentage of fibre content, all the four values of direct compression were applied for each set of three beams.

From the experimental study, it has been observed that the value of ultimate bending strength and deflection increases with the increase in the value of compression for a particular percentage of fibre content. The ductility increases as the value of compression increases for a particular percentage of fibres.

Keywords**—**Aspect ratio, compression, flexure, SFRC (Steel Fibre Reinforced Concrete), volume fraction

I. Introduction

STEEL fibre reinforced concrete (SFRC) may be defined as a composite material made with Portland cement, aggregate, and incorporating discrete fibres. The need for addition of fibres to plain, unreinforced concrete arises because it is a brittle material, with a low tensile strength and a low strain capacity. Adding steel fibres to the concrete matrix, to make Steel Fibre Reinforced Concrete (SFRC), initially inhibits the propagation of cracks and then maintains some measure of load carrying capacity even after a visible crack pattern is established. Conventional reinforcement, in the form of bars or mesh, also provides load carrying capacity after cracking is established, but has a negligible effect in terms of slowing down or retarding crack development.

SFRC has been used for a wide variety of applications, namely, pavements and overlays, industrial floors, hydraulic and marine structures, repairing and rehabilitation works.

However, there is still a lack of information on the modelling of SFRC structures.

M S Jafri[1] is with the Department of Civil Engineering, Aligarh Muslim University, Aligarh, (U. P.), 202002, India.

Mohd Israil[2] is with the University Polytechnic, Aligarh Muslim University, Aligarh, (U. P.), 202002, India.

II. Literature Review

Shah and Rangan [1] worked on ductility and fracture toughness of concrete with and without steel fibres and concluded that the ductility as well as fracture toughness of concrete improves. The fibres also increase substantially the ultimate concrete stain in the beam.

C.B. Kukreja, et al. [2] carried out experimental investigations on the direct tensile strength, indirect tensile strength and flexural tensile strength of the fibrous concrete and compared with the various aspect ratios of the fibres as 100, 80 and 60 respectively. They observed that maximum increase in direct tensile strength obtained by fibres of aspect ratio 80 with 1% as volume fraction.

Niyogi and Dwarkanathan [3] studied the action of moment and shear on the behaviour of fibre reinforced concrete beams. The principal variables are the concrete mix proportions, fibre volume fraction and shear span. They concluded that shear capacity decreases as a shear span/depth ratio increases.

Kukreja and Chawla [4] after conducting experimental investigations on concrete by using straight bent and crimped steel fibres with aspect ratio 80, they published a paper on “flexural characteristics of steel fibre reinforced concrete”. They concluded that, based on steel fibre content, its type and orientation, behaviour can range from brittle to very ductile, all for the same range of flexural strength.

Gopalakrishnan et al [5] 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.

I.H. Yang, C. Joh, B.S. Kim [6] examined the basic behaviour of ultra high strength concrete beams reinforced with steel fibres. The test results from this study provide more information to help establish a prediction model for the flexural strength and deflection of ultra high strength concrete beams under bending conditions.

III. Experimental Programme

An extensive experimental program has been executed to ascertain the flexural behaviour of steel fibre reinforced concrete beams when the beams are under combined state of compression. The experiments were conducted on concrete

mixes with different percentage of fibres 0%, 0.5%, 0.75% and 1% by weight. Also, the experiment was designed in a manner such that the combined studies of compression and flexure on beams could be studied. The experimental program involved the evaluation of the flexure strength of concrete beam with different value of compression 0, 50, 100 and 125 kN.

A. Properties of Concrete Constituents

The determination of the properties of the constituents of concrete is necessary to ensure that they do not contain any deleterious element which may affect the behaviour of the composite or they may not conform to the specified requirement necessary to achieve a standard of performance.
Ordinary Portland cement of 43 grade was used throughout the experimental investigation. The recommendations stated in IS 4031: (1999) have been strictly adhered to during the investigation. The experimental values of specific gravity, soundness (mm, Le Chatelier's test), normal consistency, initial and final setting times, compressive strengths at 7 and 28 days of cement were 3.15, 2mm, 29.5%, 34 and <600 minutes, 21 and 40 MPa against the recommended values of 3.15, 10mm (Max.), 30%, 30(min.) and 600 minutes (max.), 33 and 43MPa.

The fine aggregate used was locally available coarse sand lying in grading zone II with specific gravity and fineness modulus as 2.45 and 2.83. The test procedures as mentioned in IS-383: (1970) were followed to determine the properties of fine/coarse aggregates.

The locally available crushed stone aggregate, mainly quartzite in mineralogical composition, of maximum nominal size of 10 mm and 20 mm was used as coarse aggregate. The specific gravity and fineness modulus of 10 mm and 20 mm aggregate were 2.60, 5.92 and 2.64, 6.98 respectively.

As per recommendations of IS: 456 (2000), the water to be used for mixing and curing of concrete should be free from deleterious materials. Potable water was used in the present study in all operations demanding control over water quality.

Commercially available steel wires were cut in the length of 2.8 cm (0.28 mm dia, aspect ratio =100) and used as steel fibres in the concrete mix in the proportion of 0, 0.5, 0.75 and 1.0% by weight.

B. Mix Design Procedure

As per the guidelines of IS-10262: (1982), the normal strength concrete mix (M20) was prepared. To obtain normal strength fibrous concrete, plain steel fibres were added at the rate of 0.0, 0.5, 0.75 and 1.0% by weight. The proportioning of cement, fine aggregate and coarse aggregate was 372, 579.6 and 1159.85 kg/m³ for water cement ratio 0.5 and was applicable for every percentage of fibres.

C. Specimens

For the assessment of compressive strength of concrete at various fibre contents cubes of 150 mm × 150 mm × 150 mm and cylinders of 150 mm diameter and 300 mm height were cast. To determine the flexural behaviour of FRC beams, 48 beams each of size 100 mm × 100 mm × 500 mm were cast.

D. Mixing, Casting and Curing

After the preliminary tests on the constituents of concrete confirmed the suitability of ingredients and the design mix was found to be satisfactory, the task of casting the beams, cubes and cylinders was taken up. The available laboratory equipments were utilized in the accomplishment of this experimental program. The guidelines in the IS-10262: (1982) were strictly adhered to in the process of mixing of concrete.

The beams were demoulded 24 hours later and after labelling were put under water for a period of 28 days for curing. After 28 days, the concrete specimens were taken out and dried sufficiently and were tested at room temperatures. The beams were tested under two point loading arrangement and the central deflection was noted.

E. Testing of Specimens

The experiment involves the assessment of the compressive as well as flexural behaviour of plain and fibre reinforced concrete. This brings in the requirement of different kind of experimental arrangements, the details of which are given below.

F. Measurement of Compressive Strength of SFRC Cubes

After 28 days curing, the cubes were taken out of curing tanks and dried sufficiently to be tested under compression for the measurement of compressive strength at room temperature. Also, the longitudinal deformations were measured using two dial gauges placed on the opposite faces on the cubes. The strains were evaluated using these dial gauge readings. Graphs were plotted between the mean strain and mean stress to bring out the stress strain relationship in varying concrete mixes with different percentages of fibres.

G. Measurement of Splitting Tensile Strength of SFRC Cylinders

The fibre reinforced concrete cylinders were tested to assess their splitting tensile strength. In the process, the cylinders were placed on the compression testing machine in a lying down position with the longitudinal axis of the cylinders perpendicular to the longitudinal axis of the loading arrangement. The deflections were measured at two diametrically opposite points using dial gauges having a least count of 0.01 mm and mean deformation was evaluated.

H. Measurement of Flexural Behaviour of SFRC Beams

The fibre reinforced concrete beams were tested under two point loading to determine their central deflection using a plate to support the dial gauges on both sides. To achieve a condition of pure bending, the beams were very carefully levelled and the loads were applied at exactly one-third of the span on both the sides from the centre of the beam. The central deflection was measured in the area of pure bending. The dial gauges having a least count of 0.01 mm were used for the measurement of deflection at centre and at one-third span. Load was applied using a hydraulic jack of 500 kN capacity. Fig. 1 shows the details of the test setup and location of dial gauges. Fig.2 shows failed beam specimens.

Fig. 1 Test setup

Fig. 2 Failed Specimen

IV. Results and Discussion

A. Behaviour of SFRC Cubes under Compression

In the present experimental programs, cubes of size 150 mm × 150 mm × 150 mm were tested under uniaxial compression. The study involves the testing of M20 grade concrete with varying percentage of fibre content varying from 0 to 1.0 percent (0, 0.5, 0.75 and 1.0%) by weight and stress-strain diagrams are shown in Fig. 3.

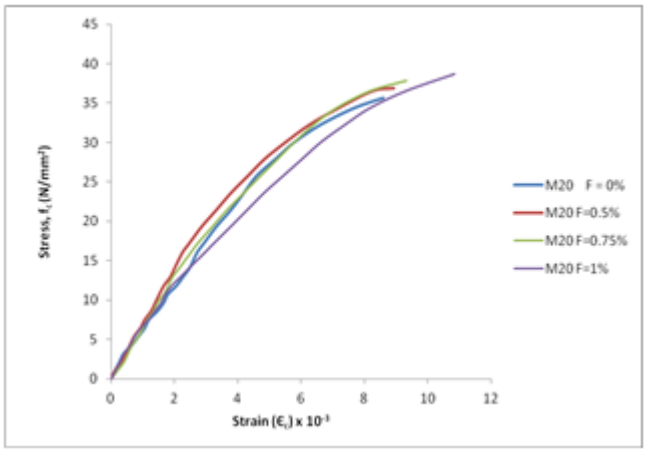

Fig. 3 Combined stress strain curve for M20 cubes with different fibre contents

B. Behaviour of SFRC Cylinders in Splitting Tensile Strength Test

In the present experimental programme, splitting tensile tests were performed on cylinders of 150 mm diameter and 300 mm height. The study involves the testing of M20 grade of concrete with varying percentage of fibre content varying from 0 to 1.0 percent (0, 0.5, 0.75 and 1.0%) and stress-strain diagrams are shown in Fig. 4

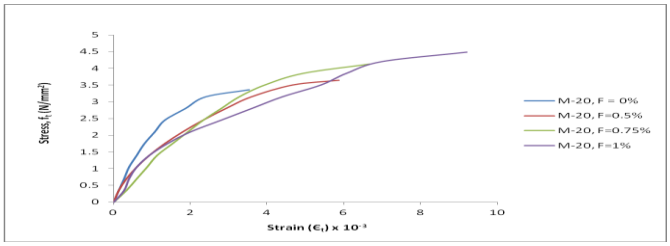

Fig. 4 Combined stress strain curve for M20 cylinders with different fibre contents

C. Behaviour of SFRC Beams With 0.75% Fibre Content

Similar to the cases (0%, 0.5%and 1.0%), the beams containing 0.75% of fibre were subjected to a confining compression 0, 50, 100, 125 kN. When the value of compressive load was 0 tonne, the beams failed at an ultimate bending stress of 5.6 MPa with an ultimate deflection of 0.585 mm. The bending stress capacity further increased to 20 MPa with the deflection rising to 1.985 mm on raising the compression to 50 kN. The beams subjected to a compression of 100 kN were found to carry an ultimate bending stress of 23.2 MPa and failed at a central deflection of 2.65 mm. On subjecting the beams to a compression of 125 kN, the bending stress capacity of the beams increased to 30.4 MPa. The deflection in these specimens was observed to be 3.28 mm. The beams carried an ultimate load of 14, 50, 58 and 76 kN at a confining compression of 0, 50, 100 and 125 kN. Load Deflection Curves for F=0.75% with different values of compression are shown in Fig. 5.

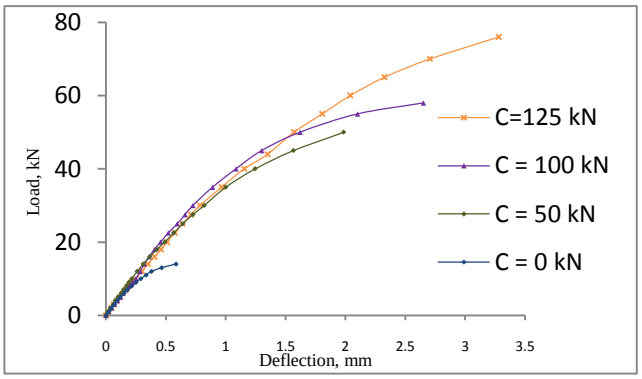

Fig. 5 Combined Load Deflection Curves for F=0.75% with different values of compression

V. CONCLUSIONS

1. In all the beams the ultimate bending strength and ultimate central deflection increase as the compression increases for a particular percentage of fibres.
2. For each value of direct compression, the value of ultimate bending strength increases as the percentage of fibres increases up to 0.75%. But on further addition of fibres, the ultimate bending strength decreases for all values of direct compression.
3. However in beams without compression, the ultimate bending strength and central deflection increases with the increase in the percentage of fibres even after 0.75%.
4. The value of central deflection at ultimate load increases with the increase of percentage of fibres for a particular value of compression in the beams.
5. For 0.75% fibre content, the value of ultimate bending strength increases from 5.6 MPa to 30.4 MPa by a maximum of 437.5% when the value of applied direct compression is increased from 0 kN to 125 kN.
6. For 0.75% fibre content, the value of central deflection increases from 0.585 mm to 3.28 mm by a maximum of 460.7% when the compression is increased from 0 to 125 kN.
7. For a direct compression of 125 kN, the value of ultimate bending strength increases from 20 MPa to 30.4 MPa by a maximum of 52% as the percentage of fibre content increases from 0 to 0.75% but on further addition, it decreases.

REFERENCES

[1] S. Shah, and B. Rangan: *Effect of Reinforcement on Ductility of Concrete*, ASCE, 96: 1167-1184 (1970)

[2] C. B. Kukreja, S.K. Kaushik, M.B. Kanchi, and O.P. Jain: *Flexural characteristics of steel fibre reinforced concrete*, Indian Concrete Journal, pp.184-188 (1980)

[3] S. Niyogi, and G. Dwarakanathan: *Fibre Reinforced Beams Under Moment and Shear*, Journal of Struct. Engg., 111(3), 516–527 (1985) http://dx.doi.org/10.1061/(ASCE)0733-9445(1985)111:3(516)

[4] C.B. Kukreja, and Sanjeev. Chawla: *Flexural characteristics of steel fibre reinforced concrete*, Indian Concrete Journal, pp. 246-252 (1989)

[5] S. Gopalakrishnan, T.S. Krishnamoorthy, B.H. Bharatkumar, and K. Balasubramanian: *Performance Evaluation of Steel Fibre Reinforced Shotcrete*, National seminar on advances in concrete technology and concrete structures for the future, Annamalai University (2003)

[6] I.H. Yang, C. Joh, B.S. Kim : *Flexural strength of ultra high strength concrete beams reinforced with steel fibres*, Procedia Engineering, Science Direct Volume 14, 2011, Pages 793-796 (2011)

[7] A.M. Shende, A.M. Pande, M. Gulfam Pathan: *Experimental Study on Steel Fibre Reinforced Concrete for M-40 Grade*, International Refereed Journal of Engineering and Science (IRJES), Volume 1, Issue 1, PP. 043-048 (2012)