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Fracture Study on Steel Fibre Reinforced Concrete

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Abstract: *Concrete is a composite material used for construction world wide. The presence of cracks and pores inside concrete material is inevitable and it is necessary to investigate if they are stable or not. Hence problems related to fracture are vital in concrete. Fracture study assesses the ductile behaviour of concrete structures under loading using various fracture parameters. The present study aims at finding out how far the ductility of concrete can be improved by the addition of steel fibres in terms of fracture parameters by varying the fibre content. The fibre content was varied from 0% to 1% with an increment of 0.25%. Three point bending test on notched beams (fracture tests) were conducted for determination of fracture parameters. The tests were done as per the guidelines of International Union of Laboratories and Experts in Construction Materials, Systems and Structures(RILEM).*
Keywords - *Ductility, Fracture parameters, Notched beams, Three point bending tests.*

I. Introduction

Concrete is the most versatile material used in the field of civil engineering. Since concrete is a composite material, the presence of cracks and pores inside concrete cannot be controlled. So it becomes necessary to investigate whether these cracks are stable or not. Fracture mechanics is a valuable method for studying concrete behaviour under static loading. Fracture is a common but important problem in construction industry [6]. The severity of problem varies with the type and importance of the structure.

Fracture is defined as the separation of a component into, atleast, two parts. Fractures of a material occur when sufficient stress and work are applied on the atomic level to break the bonds that hold atoms together. The fracture behaviour in concrete is more complicated due to its heterogenous nature and the presence of large size Fracture Process Zone (FPZ) at the crack tip. Failure occurs for many reasons, including uncertainities in the loading or environment, defects in materials, inadequacies in design and deficiencies in construction and maintanence. Failure of a structure usually occurs due to catastrophic growth of cracks resulting in localization of stresses and there by affects the serviceability of the structure[3].

Steel Fibre-Reinforced Concrete (SFRC) offers a solution to the problem of cracking by making concrete tougher and more ductile. The randomly oriented steel fibres assist in controlling the propogation of micro-cracks present in the matrix, first by improving the overall cracking resistance of matrix itself, and later by bridging across even smaller cracks formed after the application of load on the member, thus preventing their widening in to major cracks [8].

The most common applications are pavements, tunnel linings, slabs, shotcrete, airport pavements, bridge deck slab repairs, and so on.

Here an attempt was made to study the fracture behaviour of normal concrete when its characteristics was modified by adding steel fibres in varying volume fractions.

II. Experimental Programme

2.1 Methodology Adopted

The experimental study consist of testing constituent materials and preparing a normal strength concrete of grade M25 with maximum aggregate size of 20 mm. steel fibres having an aspect ratio of 60 in volume fractions of 0%, 0.25%, 0.5%, 0.75% and 1% were used for the study. The experimental programme consist of three point bending test on notched beam specimens of size 500x100x100 mm with initial notch size of 30 mm for all the mixes with a span of 400 mm. The test is conducted as per the guidelines of RILEM. The details of the specimen for the fracture test are shown in Figure 1. During testing, the deflection was noted using dial guage.

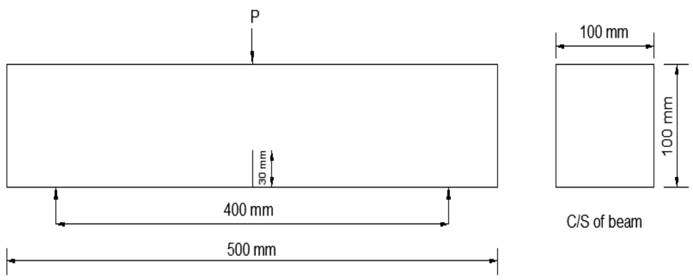

Fig. 1. Details of specimen for fracture test

The fracture parameters were determined using the formulae given by the technical committee RILEM [2].The parameters determined are the fracture energy, fracture toughness, stiffness and ductility.
Fracture energy (G_F) is determined using equation 1.

$$G_F = \frac{W_0 + 2mg\delta_0}{t(b-a)} \quad \text{....(1)}$$

Where, G_F - Fracture energy (N/m)
Wo - area under the load-deflection curve (Nm)
δ_0 - displacement corresponding to the maximum load (m)
m - weight of the beam between supports (N)
t - width of the beam (m)
b - breadth of the beam (m)
a - initial notch of the beam (m)
According to the RILEM, the fracture toughness K_{IC} is calculated using the equation 2.

$$K_{IC} = \frac{3PS\sqrt{\pi a}}{2bd^2} f(\alpha) \quad \text{....(2)}$$

Where, K_{IC} - fracture toughness(MPa√m)
P_{max} - peak load + self weight of the beam (N)
S, d and b are the span, depth, and width in mm, respectively of the testing beam; f(α) is geometry factor, which depends on the ratio of the initial crack length/notch depth (a) to the depth (d) of the beam. In case of S = 4d as applied in the current study, f(α) can be written as shown in equation 3.

$$f(\alpha) = \frac{[1.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)]}{\sqrt{\pi}(1+2\alpha)(1-\alpha)^{3/2}} \quad \text{...(3)}$$

Where, { α = a/d }.

2.2 Materials Used

The materials used for the study are ordinary Portland cement of grade 53, locally available river sand used as fine aggregate, coarse aggregates of 20 mm and 12.5 mm, steel fibre of 30 mm length and 0.5 mm diameter, Master Glenium B233 as superplasticizer and water of drinking quality. The properties of cement and aggregates are shown in Table 1 and 2 respectively.

Table 1 Properties of cement

SL. No.	Test conducted	Result	Standard value
1	Specific gravity	3.07	3.15
2	Standard consistency consistency	36%	26% - 33%
3	Initial setting time	70 minutes	Greater than 30 min
4	Fineness	1%	Less than 10%

Table 2 Properties of aggregates

SL. No.	Test conducted	Fine Aggregate	Coarse Aggregate	
			20 mm	12.5 mm
1	Specific gravity	2.43	2.84	2.85
2	Bulk density	1.24 g/cc	1.56 g/cc	1.56 g/cc
3	Void ratio	0.45	0.81	0.82
4	Porosity	22.2%	44.78%	45.3%
5	Fineness modulus	3.62	-	-
6	Grading zone	II	-	-

The gradation curves for fine aggregate is shown in Fig. 2.

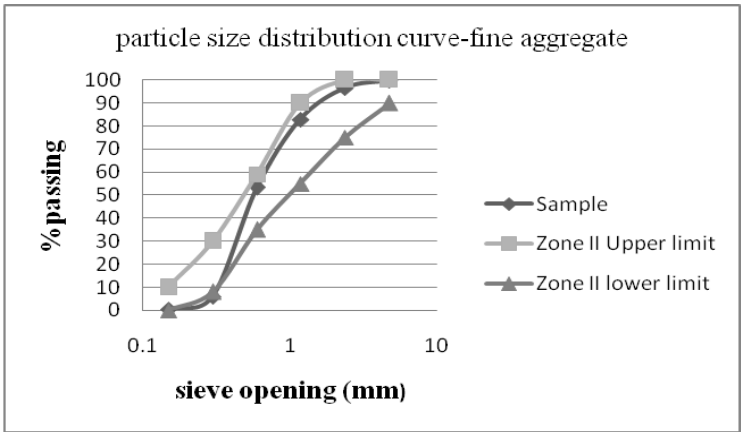

Fig. 2 Gradation curve for fine aggregate

Mix design of M25 grade concrete was carried out as per IS 10262-2009. Straight type steel fibre with an aspect ratio of 60 was used in the experimental study. The mix was confirmed based on a slump of 90 mm and 28 day cube compressive strength of 31.55 MPa. The final mix arrived and mix designation is shown in Table 3 and 4 respectively.

Table 3. Mix Proportioning

Material	Cement	Fine aggregate	Coarse aggregate	Water
Weight (Kg/m^3)	420	552	1258	190.65
Ratio	1	1.31	2.99	0.45

Table 4. Mix Designation

SL.No	Mix Designation	Percentage volume of fibre
1	CFV0	0 (Without notch)
2	CF0	0
3	CF1	0.25
4	CF2	0.5
5	CF3	0.75
6	CF4	1

1.3 Casting of specimens

The moulds for the beam specimen were prepared. Specimens with and without steel fibre were cast for conducting fracture test. Three specimens were cast for each mix. Specimens without notch were also cast. The concrete beam specimens were left without disturbance until it attained a hardened state. The notch apparatus were removed after 2 hours and the specimens were immersed in water for a period of 28 days. Fig. 3 shows the Fracture specimens with notch.

Fig. 3 Fracture specimens with notch

1.4 Fracture testing method

The specimens were subjected to three point bending under simply supported end condition. The deflection was noted using dial guage. The Fracture test setup and loading arrangement are shown in figures 4 and 5 respectively.

Fig. 4 Fracture test setup

Fig. 5 Loading arrangement for fracture test

III. Results and discussion

The point bending test was carried out on beams having 100x100 mm cross section and an effective span of 400 mm to determine the fracture parameters. The results obtained are the average of the three test results.

3.1 Fresh properties of concrete

The addition of steel fibre affects the fresh properties of concrete and was measured using slump test. A superplasticizer dosage of 0.3%-0.5% was required to maintain the fresh properties within the workable limits. The results are shown in Table 5.

Table 5. Fresh properties of concrete

SL. No.	Mix Designation	Slump (mm)
1	CF0	90
2	CF1	88
3	CF2	85
4	CF3	82
5	CF4	80

3.2 Load-Deflection characteristics

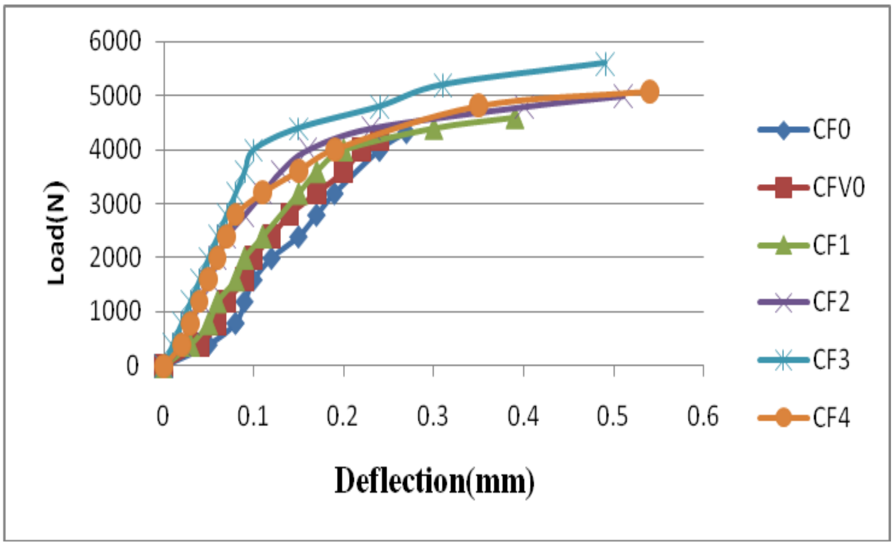

Fig. 6 Load-Deflection behaviour of beam specimens

The deflections were noted at every 400 N load increments with the help of a dial guage. The plot of load-deflection for fracture specimens are as shown in figure 6. The ultimate load was found to increase with the addition of steel fibre and it increased with the increment in the percentage of steel fibre and then decreases. And also the specimens with 0.75 % steel fibre undergoes large deflection prior to failure.

3.3 Fracture Parameters

The fracture parameters such as fracture toughness, fracture energy and also the ductility and stiffness were determined. Table 6 shows the Fracture energy and Fracture toughness.

Table 6 Fracture energy and Fracture toughness of beam specimens

Specimen designation	Fracture Energy (N/m)	Fracture Toughness K_{IC} (MPa√m)
CFV0	60.37	-
CF0	80.34	1.52
CF1	126.96	1.61
CF2	198.28	1.75
CF3	319.28	2.09
CF4	202.93	1.77

The Fracture energy and Fracture toughness increased with the fibre content and attained a maximum value for 0.75% fibre content and then decreased. The values of ductility factor and stiffness obtained are shown in Table 7.

Table 7. Ductility factor and Stiffness

Mix	Ultimate load W(N)	Deflection at yield load δy in mm	Deflection at ultimate load δu in mm	Ductility Factor $\frac{\delta u}{\delta y}$	Stiffness ,kN/m
CF0	4330	0.09	0.27	3	16.03
CF1	4600	0.09	0.39	4.33	11.79
CF2	5000	0.11	0.51	4.63	9.80
CF3	6000	0.1	0.62	6.2	9.67
CF4	5066	0.11	0.54	4.9	9.38

The ductility was found to be increased with the addition of steel fibres and CF3 was found to be more ductile. The increase in ductility was due to the effective bond and confinement between the particles. The stiffness was found to be decreased with the addition of steel fibres. The failure pattern observed was flexural failure. Plain concrete beams failed by splitting in to two halves while SFRC beams exhibited only narrow cracks and no splitting. The results indicated that there was a substantial increase in the ultimate load and fracture parameters of SFRC beams compared to plain concrete beams.

IV. Conclusion

The concrete mix of M25 grade was designed with a maximum aggregate size of 20 mm. The effect of fibre content on the fresh properties of concrete was studied. The main objective of the study was to explore the influence of steel fibres on fracture behaviour of concrete beams. From the results obtained following conclusions were arrived.

- Steel fibre addition in concrete mix affects the fresh properties of concrete and demanded dosage of 0.3%-0.5% superplasticizer to maintain the fresh properties within workable limits.
- For a fibre content of 0.75 percent, an increase of 37.8% in the ultimate load, 74.8% in fracture energy and 37.5% in fracture toughness was observed compared to that of plain concrete beams.
- There was a substantial increase in the ultimate load and the fracture parameters of SFRC beams compared to plain concrete beams. Fibre bridging action and crack arresting property increased the load carrying capacity of SFRC specimens.
- The reduction in fracture parameters in the specimens CF4 may be attributed to the unexpected decrease in ductility of beams with reduction in stiffness and load carrying capacity.
- Mode of failure was changed from brittle to a ductile flexural mechanism by the inclusion of steel fibres.

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