NJ-5

A Study of the Behaviour of Fiber Reinforced Concrete beams under Pure Torsion

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In addition to shear and flexure, torsion occurs in many reinforced concrete structures. It occurs mainly in curved beams, balcony girders supporting cantilever slabs, spiral stairs and spandrel beams, whose torsional reinforcement is to be specially designed and provided for. Yet torsion was consideredd secondary, till now in may structures. The safety factor provide for flexure takes care of torsion indirectly. But in the recent times the use of thin sections has made the problem of torsion very important.

Fiber Reinforced Concrete (FRC) is a two phase composite consisting of discontinous discrete fibers and cement mortar with or without coarse aggregate which will have improved properties over the Plain Cement Concrete (PCC). The basic concept of steel fiber reinforced concrete proposed by Romualdi was to assume a different mode of action of steel from that of conventional reinforcement. Fibers in the concrete serve as crack arresters by applying pinching forces at crack tips, thus delaying the appearance of cracks and leading to slow crack propagation (1-2). The ductility of the composite increase by many folds, compared to the unreinforced matrix, with a corresponding increase in strength. Among the various types of fibers currently available, steel fibers are most widely used.

Recently, research interest has been directed towards understanding the benefits that accrue in torsional behaviour as well. Several reports (4) of investigations have appeared describing the improvement in strength under pure torsion of concrete when fibers are included with certain volume percentage. However, very few investigations have reported on pure torsional behaviour of FRC under different volume percentages of fiber with different grades of concrete.

This paper presents an experimental investigation on the bahaviour of Steel Fiber Reinforced Concrete (SFRC) with and without main reinforcement, under pure torsion.

Experimental Investigation

Outline of Experimental Programme

The experimental programme consisted of casting and testing of 20 concrete rectangular beams of overall size 100 x 200 x 2200mm. The 20 beams were divided into two groups, 10 in each group, representing M15 and M20 grade concrete. In each group there are two sets of beams (5 in each set) the first set representing plain concrete beams(P) and other representing reinforced concrete beams (R). In each set of beams the percentage of fiber by volume of concrete was varied from 0 to 1% in intervals of (0.25% fiber), C (0.50% fiber) D (0.75% fiber) and E (1.0% fiber) respectively. Each specimen was designated by the set of the beam (P or R), Type of mix (A, B, C, D or E) and the grade of concrete (M15 or M20). Thus the specimen with designation RB15 stands for reinforced concrete beam with 0.25% fiber content in the M15 grade concrete mix.

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Materials Used

Cement: The cement used was 43-grade ordinary Portland cement.

Fine Agggregate: River sand procured locally confirming to zero- II as per IS 383.

Coarse Aggregate: Machine crushed granite chips having maximum size of 12.5 mm were used throughout the investigation.

Fiber: The fibers were obtained by cutting the G.I binding wire of diameter 0.5 mm, into the length which gave the fiber an aspect ratio of 75.

Reinforcement: In reinforced concrete beams, the longitudinal reinforcement consists of 4-10 mm diameter steel bars (two at top and two at bottom). The shear reinforcement consists of 6 mm diameter steel bars at 55 mm centre to centre. The reinforced concrete beams were designed as under reinforced beam.

Moulds: Rolled steel channel moulds were used for casting the beams.

Mix Proportion: The design mix proportions adopted in the study were 1:2.4:4.1 with w/c ratio of 0.6 for M15 grade, and 1:1.68:3.2 with w/c ratio of 0.55 for M20 grade concrete respectively.

Testing

All the beams were tested under pure torsion by mounting the beams on the wing table of Tinious Olsen Testing Machine. To enable the application of torque, twisting arms were attached at both the ends of the beam. The torque was applied by means of a screw jack through a proving ring, which records the load applied at the twisting end of the beam, at a perpendicular distance of 146 cm form the longitudinal axis of the beam. The load read at any stage of loading from the proving ring multiplied by the lever arm (146 cm) gave the torque applied at that stage of loading. At the restraining end, the restraint was offered by the reaction at a distance of 146 cm from the longitudinal axis of the beam, from a loading frame at the end of twisting arm. Thus the beam was subjected to uniform torsion (pure torsion) throughout its length. Specially fabricatedd twist meters were usedd to measure the twist of the beam. The twist meters consisted of a steel U-frame with a horizontal Aluminum flat hinged to the top of one of the vertical of the frame. The flat extendc beyond the other vertical of the frame. A sensitive bubble tube was attached to the flat. The entire frame was attached to the beam by means of transverse screws. Near the free end of the flat a vertical screw was provided, the operation of which, bought the bubble in the level to the centre of its run. As the torque applied, the beam and hence the twist meter rotate displacing the bubble from its centre of run initially adjusted. The vertical movement of the screw, which was measured by a dial gauge of least count 0.01 mm attached to the U-frame, brought the bubble to the centre of its run. Knowing the vertical displacement of the screw, the rotation of the flat and hence the twist of the beam was calculated. Two twist meters were provided, one at the either end of the gauge length (200 mm), to measure the twist per unit length of the beam. Figure-1 shows the schematic outline of the test set up for applying the torque.

The beams were gradually loaded beyond the maximum torque until the torque dropped to about 0.85 times the ultimate value. From the observed values to torque twist diagram were drawn for each set of beams. Such diagrams are shown in Figure 2 - 5. The angle ( ) between the tensile crack on the wider face and longitudinal axis of the beam were also meausred. The experimental values of ultimate and cracking torque and crack angle are tabulated in Table 1.

Torsional Behaviour of Test Specimens

Plain Concrete Beams

The torque twist diagrams presented in Figures 2 and 3 demonstrate the torsional behaviour of plain concrete beams. An examination of these diagrams indicates that the behaviour of plain fiber concrete beam is almost similar to the behaviour of ordinary concrete beam in pure torsion except in initial stages. The failure in plain concrete beams without fibers is brittle and sudden. There is some linearity in the initial stages of torque twist diagrams of plain fiber concrete beams, and this linearity increased by increasing the volume percentage of fiber content. This can be attributed to the delay in widening of micro cracks in concrete due to presence of fibers. But in case of plain concrete beam, without fiber, the torque-twist diagram is continuously non-linear right from the initial stages.

But once the crack is formed, the beams have failed suddenly and in brittle manner irrespective of the fiber

Table 1 - Cracking, Ultimate Torque and Crack angle of tested specimens

Sl. No.	Designation	% of fiber by volume of concrete	Cracking torque (kN-m) T_{cr}	Ultimate Torque (kN-m) T_u	T_{cr}, FRC/T_{cr}, Plain	T_u, FRC/T_u, Plain	Crack angle at failure (τ) (degrees)
1	PA15	0.00	2.212	2.212	1.000	1.000	37
2	PB15	0.25	2.550	2.550	1,152	1.152	34
3	PC15	0.50	2.654	2.654	1.199	1.199	36
4	PD15	0.75	2.986	2.986	1,349	1.349	45
5	PE15	1.00	3.429	3.429	1,550	1.550	27
6	RA15	0.00	2.656	3.720	1.000	1.000	46
7	RB15	0.25	3.098	4.200	1,166	1.129	31
8	RC15	0.50	3.328	4.640	1,253	1.247	45
9	RD15	0.75	3.540	5.090	1.332	1.368	39
10	RE15	1.00	3.980	5.530	1.498	1.486	33
11	PA20	0.00	3.097	3.097	1.000	1.000	40
12	PB20	0.25	3.539	3.539	1.142	1.142	38
13	PC20	0.50	3.649	3.649	1.178	1.178	31
14	PD20	0.75	3.990	3.990	1.288	1.288	29
15	PE20	1.00	4.551	4.551	1.469	1.469	40
16	RA20	0.00	3.098	4.200	1.000	1.000	45
17	RB20	0.25	3.430	4.550	1.100	1.083	40
18	RC20	0.50	1.890	4.760	1.255	1.133	31
19	RD20	0.75	4.170	5.310	1.346	1.264	34
20	RE20	1.00	4.650	6.420	1.501	1.528	34

Note:

1. For plain concrete beams with and without fiber, the ultimate torque and cracking torque are same due to sudden and brittle failure.
2. The 28 days cube strength for M15 grade concrete is 33 Mpa and for M20 grade concrete is 43.4 Mpa.

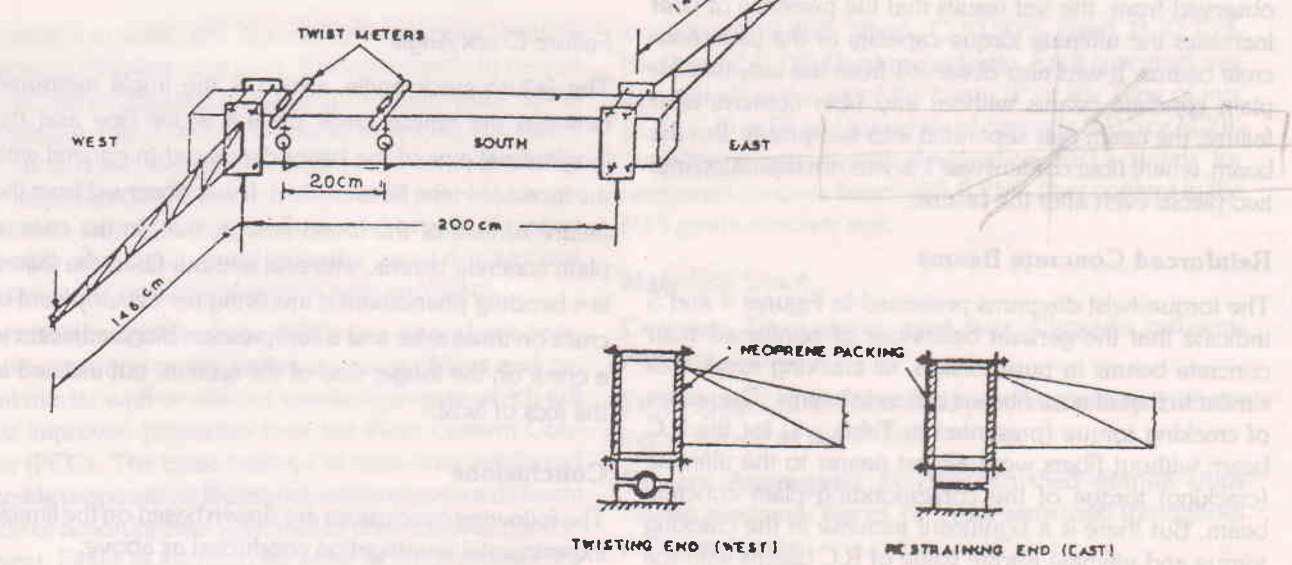
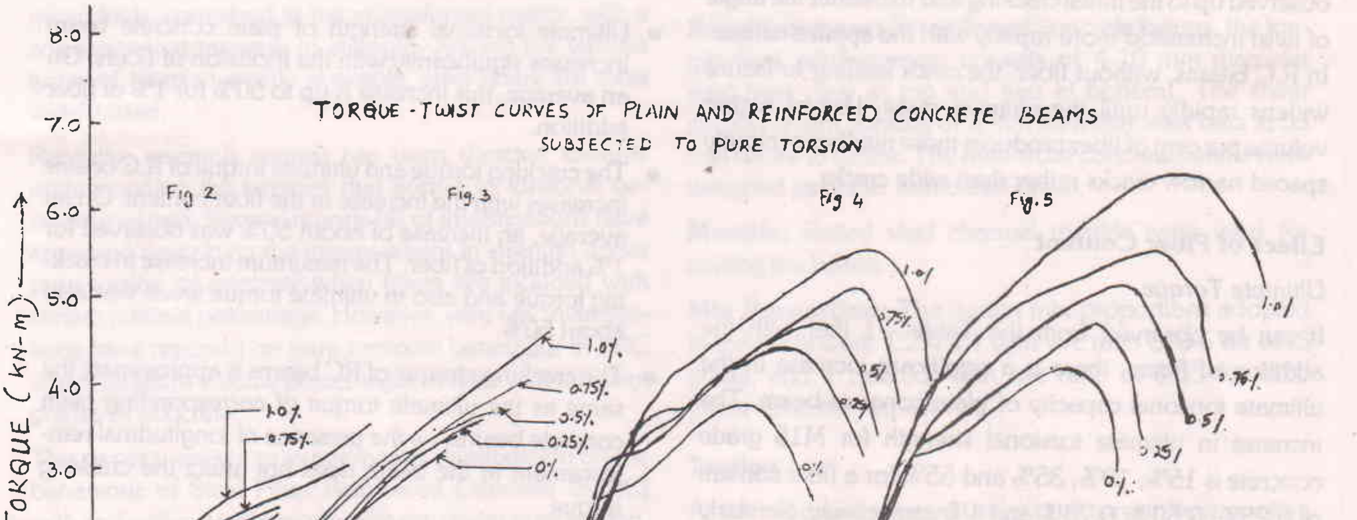


FIG. 1. SCHEMATIC OUTLINE OF TORSION TEST SETUP



7th September 1999 - Concrete Day

Concrete Day celebrations have been held in various places like Chennai, Imphal, Madurai, Nagpur, Pondicherry, Hyderabad etc. Reports from Chennai and Pondicherry are covered in this issue. Reports from other centres will follow.

content or the grade of concrete, i.e the respective cracking torque capacity of the plain concrete beams with and without fiber, is also the respective ultimate torque. It was observed from the test results that the presence of fiber increases the ultimate torque capacity of the plain concrete beams. It was also observed from the test, that for plain concrete beams without any fiber content, after failure, the beam gets separated into two pieces. But the beam, where fiber content was 1% was not separated into two pieces even after the failure.

Reinforced Concrete Beams

The torque-twist diagrams presented in Figures 4 and 5 indicate that the general behaviour of reinforced fiber concrete beams in pure torsion, till cracking stage, was similar to that of non- fibrous concrete beams. The values of cracking torque (presented in Table - 1) for the R.C beam without fibers were almost nearer to the ultimate (cracking) torque of the corresponding plain concrete beam. But there is a significant increase in the cracking torque and ultimate torque value of R.C beams with the inclusion of fibers.

A steady increase in the angle of twist per unit length was observed up to the initial cracking and thereafter the angle of twist increasedd more rapidly with the applied torque. In R.C beams, without fiber, the crack leading to failure widens rapidly until the ultimate stage. Use of higher volume per cent of fiber produces more number of closely spaced narrow cracks rather than wide cracks.

Effect of Fiber Content

Ultimate Torque

It can be observed from the Table - 1 that with the addition of fibers, there is a significant increase in the ultimate torsional capacity of plain concrete beam. The increase in ultimate torsional strength for M15 grade concrete is 15%, 19%, 35% and 55% for a fiber content of 0.25%, 0.50%, 0.75% and 1% respectively. Similarly for plain concrete beams of M20 grade, the increase in torsional capacity is in the order of 14%, 18%, 29% and 47% for fiber content of 0.25%, 0.50%, 0.75 and 1% respectively.

In the R.C. beams made with M15 grade concrete the ultimate torsional strength increases by 13%, 24.7%, 37% and 48% for the fiber content of 0.25%, 0.50%, 0.75% and 1% respectively. For M20 grade concrete, the increase is n the order of 8%, 13.3%, 26.4% and 52.8%, respectively.

Cracking Torque

The cracking torque and utlimate torque capacities are almost the same in plain concrete beams due to sudden and brittle type of failure. In the case of R.C. beams, the cracking torque increased with the increase of fiber content. The cracking torque is increased by 16.6%, 25.3%, 33.2% and 50% for M15 grade, and 10.7%, 25.5%, 34.6% and 50% for M20 grade concrete for fiber content of 0.25%, 0.50%, 0.75% and 1% respectively.

Failure Crack Angle

The failure crack angle, which is the angle measured between the tensile crack on the wider face and the longitudinal axis of the beam decreased in general with the increase in the fiber content. It was observed from the failure surface of the tested beams, that, in the case of plain concrete beams, with and without fiber, the failure is a bending phenomenon involving the development of crack on three sides and a compression hinge adjacent to a crack on the longer side of the section, but inclined to the axis of twist.

Conclusions

The following conclusions are drawn based on the limited experimental investigation conducted as above:

- Increase in the fiber content does not have any influence on the failure pattern of unreinforced and reinforced beams.
- Ultimate torsional strength of plain concrete beam increases significantly with the inclusion of fibers. On an average, this increase is up to 50% for 1% of fiber addition.
- The cracking torque and ultimate torque of R.C beams increases with the increase in the fiber content. On an average, an increase of about 50% was observed for 1% addition of fiber. The maximum increase in cracking torque and also in ultimate torque levels was also about 50%.
- The crackingg torque of RC beams is approximate the same as the ultimate torque of corresponding plain concrete beams, i.e the presence of longitudinal reinforcement in the beam does not affect the cracking torque.
- The inclination of failure crack decreases with an increase in the fiber content.

Acknowledgment

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