Experimental Study on Torsional Behaviour of Hooked-End Steel Fiber Reinforced Beam

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Abstract— Steel fibers have been widely used in the construction industry for the erection of structural members such as beams, columns and slabs to improve their mechanical properties. This paper deals with the torsional behaviour of reinforced beams having steel fibers tested under pure torsion. A total of five beams consists of one conventional beam and four beams containing steel fiber. The steel fibers are added in a volume fraction of 0.5%, 1.0%, 1.5% and 2%. Hooked-end steel fibers were used with an aspect ratio of 66. The shape and aspect ratio was kept constant for all the beams. Test results include first cracking torque, ultimate torque and twist angles. The use of steel fibers in the volume fraction of 1.5% and 2% exhibited greater torque and twist angles. Therefore the results revealed that higher volume fraction of steel fibers improve the torsional performance of RC beams.

Key words: Steel fiber, Torsion, Hooked-end, Torque, Twist, Aspect ratio

I. Introduction

Structural members are more often to torsion. Torsion is a combination of bending moment and shear force. Usually beams are good in bending but not in torsion. From literature survey, torsional behaviour can be improved by using steel fibers. Steel fiber is not a new material that is being used in the construction industry. It has been used from the early 1960's. The inclusion of steel fiber improves the mechanical behaviour of concrete. Steel fiber reinforced concrete (SFRC) have special applications in seismic resistant structures and blast resisting structures.

Steel fiber properties are influenced by fiber shape, fiber aspect ratio, fiber volume fraction in the concrete. There are various shapes of steel fibers are available in market. More commonly used shapes are hooked-end, crimped and straight. Aspect ratio (lf/df) is the ratio between lengths of the fiber to the diameter of the fiber. Steel fibers are added in 0.5%, 1%, 1.5% and 2% volume fraction to the concrete. Workability of concrete will be affected by using higher volume fractions.

Many investigations and researches have been conducted for several years in this field of steel fiber. Several studies show that beams are subjected to combined flexure and torsion [1]. It revealed that under the presence of flexure, the torsional moment capacity is increased but flexural capacity does not increase in the presence of torsion. Ductility and energy dissipation capacity can be improved by steel fibers [2,3]. Compressive strength and ultimate strain of CFTTs increased with increase in fiber volume fraction [4]. Stirrup ratio improved the ultimate torsional strength and stiffness after initial cracking [5]. Single type of reinforcement i.e. longitudinal reinforcement or transverse reinforcement cannot improved the torsional strength [6]. Torsional strengthening can be done using Glass fiber reinforced polymer (GFRP) and Carbon fiber reinforced polymer sheets (CFS) [7,8,9]. Addition of steel fiber improved the energy absorption capacity [10], torsional moment capacity [11] and torsional toughness [12]. Aspect ratio influenced the cracking and ultimate torque [13].

The main objective of the study is experimenting and comparing the torsional behaviour of conventional reinforced beam with reinforced beams having steel fibers in the volume fraction 0.5%, 1%, 1.5% and 2%.

II. Experimental Program

A. Materials:

The mix design proposed for the beams is given in Table 1. Ordinary Portland cement of grade 43 was used as the binding material. Coarse aggregate as crushed stones in the size 20mm was used. River sand of size passing through 4.75mm was used as fine aggregate. Poly carboxylate as superplasticizers to improve the workability in steel fiber reinforced beams.

Reinforcement of the beam includes two types of steel reinforcement (i.e.) longitudinal and shear reinforcement. Longitudinal reinforcement having 4 nos. of 16mm diameter bars and shear reinforcement having 8mm diameter bars placed at a spacing of 200mm c/c.

Cement	504.15
Fine aggregate	602.615
Coarse aggregate	1087.09
Water	191.58
Polycarboxylate	76.5
W/C ratio	0.38

Table 1: Mix design of concrete (Kg/m3).

The shape of steel fiber used was hooked-end steel fibers with an aspect ratio (l/d) 66. The hooked-end steel fiber used is presented in Fig 1. Steel fibers were added in concrete in a volume fraction of 0.5%, 1%, 1.5% and 2%. The properties of steel fiber is given in Table 2.

Fig. 1: Hooked-end steel fiber

Tensile strength (KN/m^2)	400 – 1200
Young's modulus (GN/m^2)	200
Elongation at failure	< 4%

Table 2: Properties of steel fiber.

Adding steel fibers in concrete significantly reduced the workability of the concrete. In order to maintain the workability without affecting the water-cement ratio, superplasticizers were added to the concrete.

B. Test Specimen:

A total of five rectangular beams were casted. The dimension of the conventional beam was 200mm x 250mm x 1200mm. All the other four steel fiber reinforced beams had the dimension of 100mm x 150mm x 1200mm. The conventional beam was specified by CB and steel fiber reinforced beams were specified by HEVF0.5%, HEVF1.0%, HEVF1.5% and HEVF2%. HEVF1%% represents hooked-end steel fiber reinforced beam in the volume fraction 1% respectively.

C. Test Setup:

Test specimens were tested under pure torsion in a torsion setup shown in Fig 2. The specimens were placed on two roller supports on both ends 1.0 m apart. Roller supports enabled the specimen to twist freely while testing. The load was applied through steel spreader beam placed above the steel arms projecting from two ends of the beam. Steel arms are fixed to the beam using bolts.

Fig. 2: Torsion setup

The ends of the beams were over reinforced with high volume of stirrups and rubber sheets were provided at the junction of steel arm and beam to bear without cracking the impact torsional loading. The load was applied consistently and measured by load cell. Twist per metre were measured using two linear variable differential transducers (LVDTs) placed at 300 mm apart.

The beams were tested to its ultimate torsional strength and subsequently in increasing twist until the total failure of beam or the maximum twist capacity of the test apparatus.

III. TEST RESULTS

The first visible cracking torque, corresponding twist, and ultimate torque, corresponding twist of each beam tested were recorded. Torque versus twist response of each beam were presented below. The test results were tabulated in Table 3.

Specimen Name	First cracking torque (kN.m)	Twist at first crack (mm)	Ultimate cracking torque (kN.m)	Twist at ultimate crack (mm)
CB	3.0	0.0025	4.2	0.0035
HEVF0.5%	3.4	0.0028	4.6	0.0038
HEVF1%	4.0	0.0033	5.2	0.0044
HEVF1.5%	4.5	0.0038	6.0	0.0050
HEVF2%	4.8	0.0045	6.6	0.0064

Table 3: Experimental results of fibrous beams.

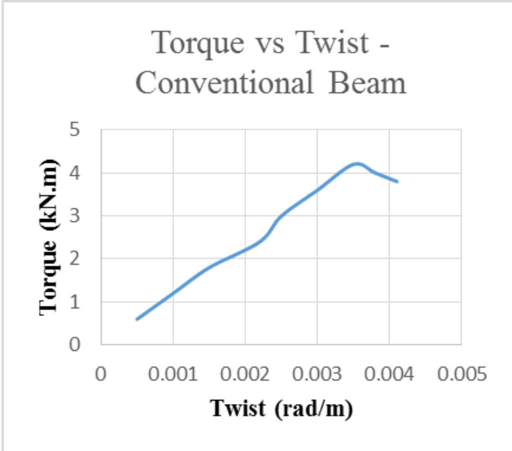

Fig. 3: Torque-Twist response of Conventional beam

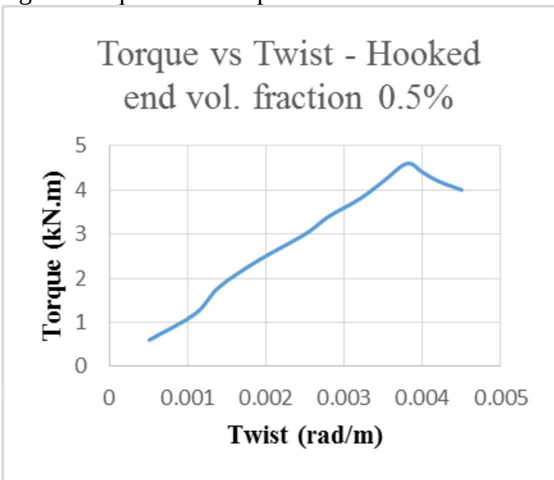

Fig. 4: Torque-Twist response of SFRC beam of volume fraction 0.5%

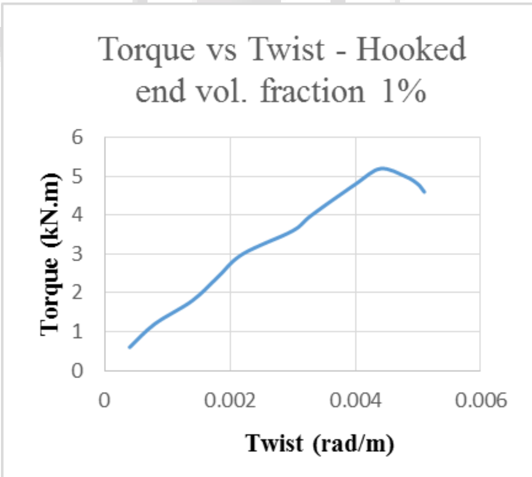

Fig. 5: Torque-Twist response of SFRC beam of volume fraction 1%

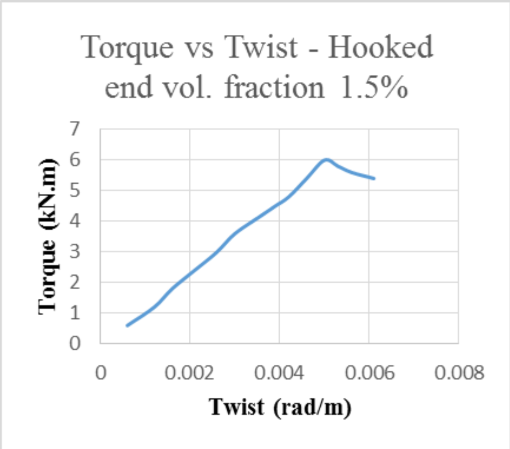

Fig. 6: Torque-Twist response of SFRC beam of volume fraction 1.5%

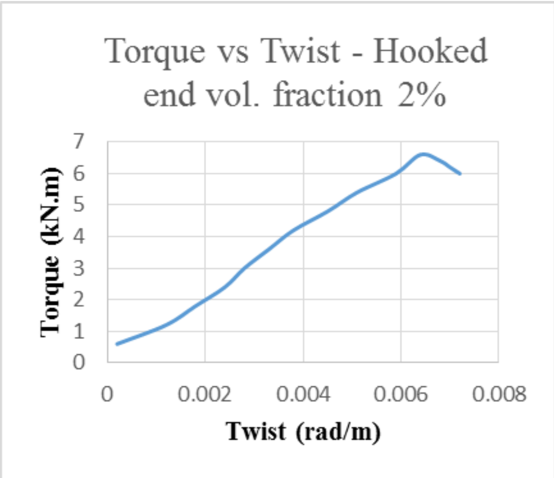

Fig. 7: Torque-Twist response of SFRC beam of volume fraction 2%

The results show that conventional beam exhibited a maximum torque of 4.2 kN.m which is lesser than the beams having hooked-end steel fiber of all volume fraction. Steel fibers of volume fraction 1.5% and 2% exhibited greater torque and twist than the other two volume fraction 0.5% and 1%. The failure pattern of beam were presented below.

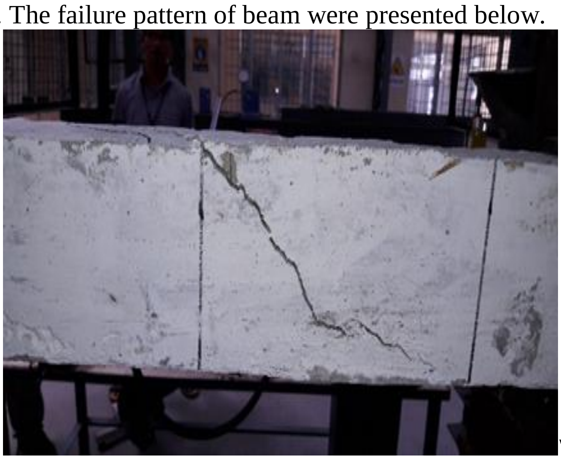
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Fig. 8: Failure pattern of SFRC beam

Fig. 9: Failure pattern of Conventional beam

IV. Conclusion

1) The torsional response of reinforced beam is improved by using steel fiber in the concrete.
2) Steel fibers used in volume fraction of 1.5% and 2% exhibited the increased torque carrying capacity and angle of twist.
3) Steel fibers improve the cracking torque of the members to a noticeable extent, which improves the performance of the member in aggressive environments.
4) Addition of steel fibers is more beneficial in high strength concretes as they are brittle in nature.

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