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Experimental Study on Tortional Shear Behaviour of High Strength Steel Fiber Reinforced Concrete with Varying Volume Fraction

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Abstract: *Behaviour of reinforced Concrete beams under pure torsion, torsional impact were studied experimentally using straight and crimpled fibers with varying volume fraction. Failures of the specimen , effects of the fiber content ,twist behaviour and torsion strain behaviour are carried out. In the first set of investigations, seven types of specimens having dimensions of 500 x 100 x 100mm, with 0%, 0.5%, 1.0% and 1.5% volume fraction of straight and crimpled steel fibers having aspect ratio 100, were used. During the investigations, cracking torque, ultimate torque, angle of twist and torsional stiffness were assessed.reinforcement with stirrups and torsion reinforcement with stirrups were used. During the investigations, cracking torque, ultimate torque, angle of twist and torsional stiffness were assessed. In the second set of investigations, six types of specimens having dimensions of 500 x 100 x 100mm, with and without 1.0% volume fraction of crimpled steel fibers, having aspect ratio 100 together with flexural reinforcement. In the tortion impact, seven types of specimens having dimensions of 500 x 100 x 100mm, with 0 %, 0.5%, 1.0% and 1.5% volume fraction of straight and crimpled steel fibers having aspect ratio 100, were used. These specimens were to be tested under torsional impact and the energy required to produce cracking and ultimate torque compared. In this investigation, six types of*

specimens, having dimensions of 500 x 100 x 100mm, with and without 1.0% volume fraction of crimpled steel fibers having aspect ratio 100, together with flexural reinforcement with stirrups and torsion reinforcement with stirrups were used. During the investigations, cracking torque, ultimate torque, angle of twist, and torsional stiffness were assessed.

1. Introduction

Till the 1960s the design engineers generally ignored torsion. It was assumed that torsion effects were minor and could be taken care of by the large safety factor used in flexural design. Torsion design began to arouse serious interest by the late 1950s because of three major stimuli. Firstly, ultimate strength design method was accepted as a replacement for the working stress design method. In the new ultimate strength design method, flexural analysis of reinforced concrete members was refined and safety factors were more accurately defined so that negligence of torsion effects was no longer acceptable. Secondly, the rapid advances in electronic computer application in structural analysis allowed engineers to consider many more design factors. Thirdly, in the post-world war II development, modern architectural concepts such as buildings, considered as three-dimensional structures rather than flat-plane objects, out of plane loading, curved beams, skew structures and irregular shapes were introduced. The new design often required structural members to resist large torsion moments. Post-Second world war design engineers neglected the effects of torsion but only considered bending, shear and axial forces. We may raise a question about the emphasis on analyzing torsion.

2. Principles of Design for Combined Bending, Shear and Torsion by IS 456

Bending shear and torsion are combined to an equivalent shear V_e. Similarly, the bending moment and torsional moment are combined to an equivalent bending moment M_e. The reinforced concrete section is then designed for V_e and M_e.

2.1. Calculation of Equivalent Shear and Design for Stirrups

$$V_e = V_u \frac{1.6\,T_u}{B} \qquad (1.3)$$

where,

V_e is equivalent shear
V_u is shear force
T_u is design torsional moment
b is breadth of beam

The equivalent bending moment M_t due to torsion T_u is given by

$$M_t = \frac{T_u \; 1 \frac{D}{b}}{1.7}$$

$M_{e=} M_{u+} M_t$

Where

T_u is design torsional moment
M_u is design-bending moment
D is overall depth of the beam
b is breadth of the beam
M_e is equivalent total bending moment
M_t is equivalent bending moment due to torsion

2.2. Design for Compression Steel

If $M_t > M_e$, then there can be reversal of moment, and longitudinal steel has to be provided on the flexural compression face also, so that the beam can withstand the equivalent moment

$M_{e2} = M_t - M_u$

2.3. Category-1: Investigation on Steel Fiber Reinforced Concrete Beams under Pure Torsion

In the first set of investigations, seven types of specimens having dimensions of 500 x 100 x 100mm, with 0%, 0.5%, 1.0% and 1.5% volume fraction of straight and crimpled steel fibers having aspect ratio 100, were used. During the investigations, cracking torque, ultimate torque, angle of twist and torsional stiffness were assessed.

2.4. Category-2: Investigation on Steel Fiber Reinforced Concrete Beams under Torsional Impact

In this investigation, seven types of specimens having dimensions of 500 x 100 x 100mm, with 0 %, 0.5%, 1.0% and 1.5% volume fraction of straight and crimpled steel fibers having aspect ratio 100, were used. These specimens were to be tested under torsional impact and the energy required producing cracking and ultimate torque compared.

2.5. Category-3: Investigation on Steel Fiber Reinforced Concrete Beams under Cyclic Tortion

In this investigation, six types of specimens, having dimensions of 500 x 100 x 100mm, with and without 1.0% volume fraction of crimpled steel fibers having aspect ratio 100, together with flexural reinforcement with stirrups and torsion reinforcement with stirrups were used. During the investigations, cracking torque, ultimate torque, angle of twist, and torsional stiffness were assessed.

Loading arrangement

Crimbled fibers

Table. *Details of mix design*

Sl. No.	Properties	Values adopted
1	Required cube strength (at 28 days)	25N/mm^2
2	Degree of quality control	Very good
3	Degree of workability	High
4	Type of cement	Ordinary Portland cement
5	Type of sand	Natural river sand
6	Type of coarse aggregate	Crushed granite (Angular)
7	Maximum size of coarse aggregate	10mm
8	Specific gravity of cement	3.15
9	Specific gravity of sand	2.61
10	Specific gravity of coarse aggregate	2.69
11	Water/cement ratio	0.45
12	Proportion of mix	1: 1.36: 2.32

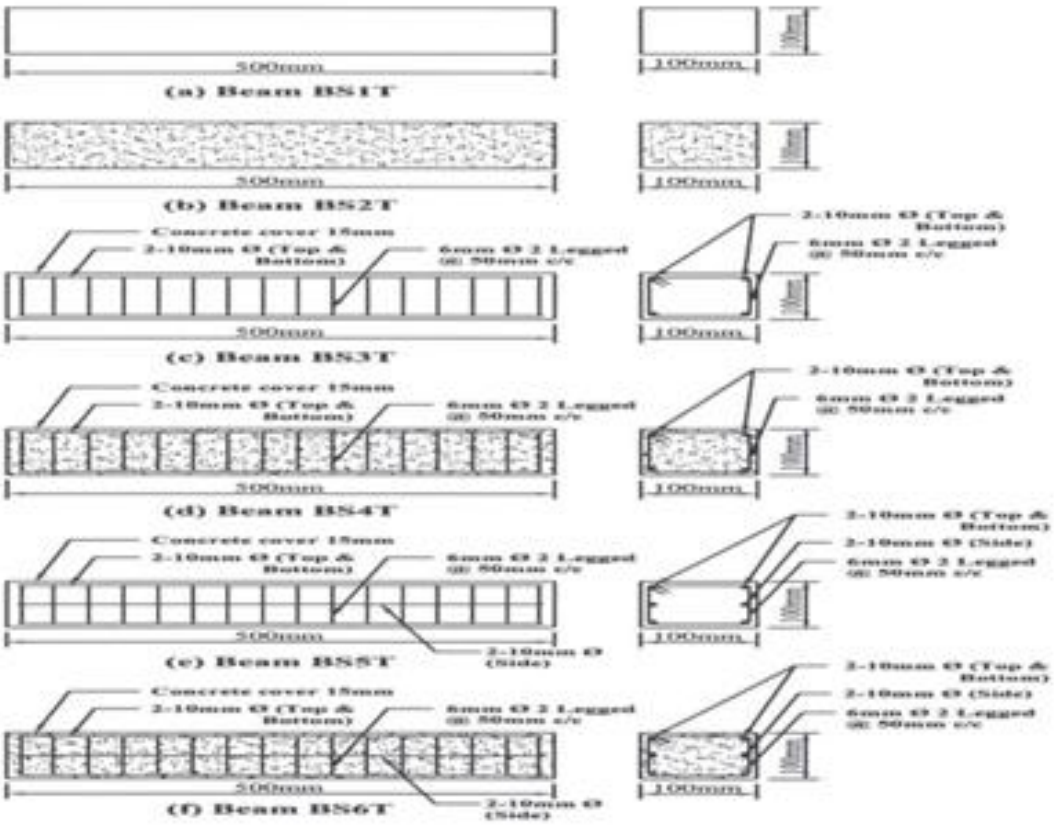
Details of steel fiber reinforced concrete

Sl. No.	Concrete strength N/mm^2	Type of fiber	Volume fraction of fiber	Dimension (l x b x d) Mm	Designation of specimen	No. of Specimen
1	25	Straight	0%	500x100x100	B1T	3
2			0.5%		B2T	3
3			1.0%		B3T	3
4			1.5%		B4T	3
5		Crimpled	0.5%		B5T	3
6			1.0%		B6T	3
7			1.5%		B7T	3
Total no. of specimens						21

Detailed experimental program for steel fiber reinforced concrete beams with reinforcement (2000 x 150 x 230mm)

Sl. No.	Concrete strength N/mm^2	Dimension (l x b x d) mm	Type of reinforcement	Designation of specimen	No. of Specimen
1	25	200x150x230	Flexural reinforcement with shear reinforcement	BL1T	3
2			Flexural reinforcement with shear reinforcement and with 1.0% crimpled fiber content	BL2T	3
3			Torsion reinforcement with shear reinforcement	BL3T	3
4			Torsion reinforcement with shear reinforcement and with 1.0% crimpled fiber content	BL4T	3
5			Flexural reinforcement with welded mesh as shear reinforcement	BL5T	3
6			Flexural reinforcement with welded mesh as shear reinforcement and with 1.0% crimpled fiber content	BL6T	3

7			Torsion reinforcement with welded mesh as shear reinforcement	BL7T	3
8			Torsion reinforcement with welded mesh as shear reinforcement and with 1.0% crimpled fiber content	BL8T	3
Total no. of specimens					24



Detailment of reinforced concrete beam

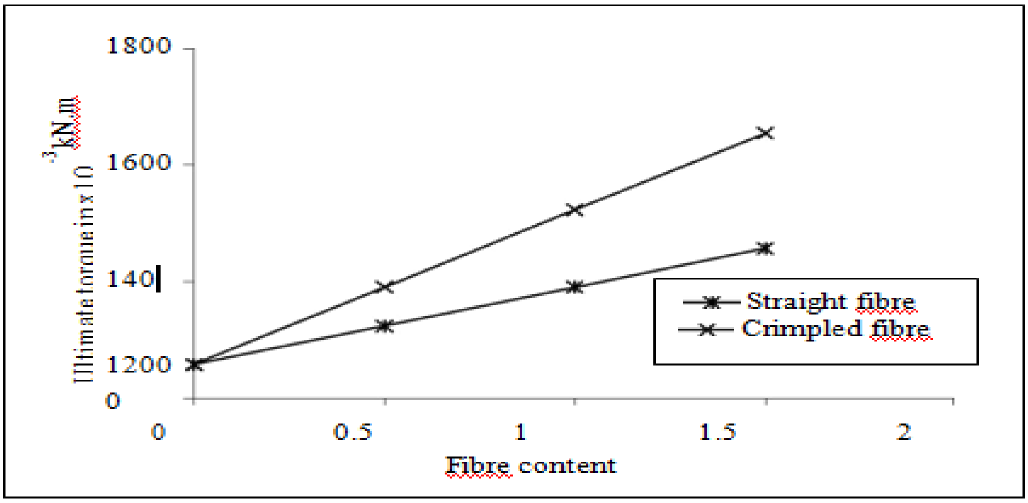
Comparisons of cracking torque and ultimate torque

Test Specimen	Type of fiber	Volume fraction of fiber	Cracking Torque x 10^{-3}kN.m	Ultimate Torque x 10^{-3}kN.m
B1T	Straight	0%	1059	1258
B2T		0.5%	1192	1324
B3T		1.0%	1258	1391
B4T		1.5%	1324	1457
B5T	Crimpled	0.5%	1258	1391
B6T		1.0%	1391	1523
B7T		1.5%	1523	1655

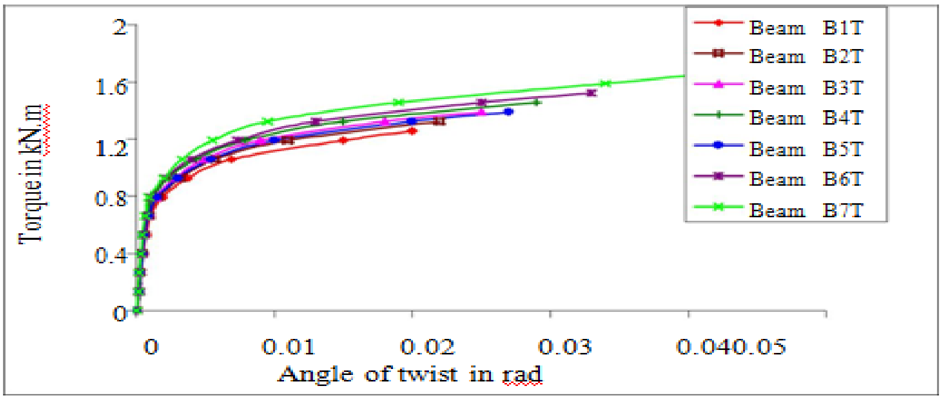
The torque at first crack of fiber reinforced concrete beam with 0.5%, 1.0% and 1.5% crimpled fiber content was found to be 19%, 31% and 44% more when compared with plain concrete beam. Similarly the torque at failure of fiber reinforced concrete beam with 0.5%, 1.0% and 1.5% crimpled fiber content was found to be 11%, 21% and 32% more when compared with plain concrete beam.

2.6. Effect of Fiber Content

The torque at first crack and failure showed a continuous increase with increase in fiber volume in both straight and crimpled fiber for the three-volume fraction as shown in Figure 4.5 and Figure 4.6. The increase in torque atcrack and failure was not appreciable in the case of straight fiber but, in the case of crimpled fiber, there was substantial increase in torque at both first crack and failure.

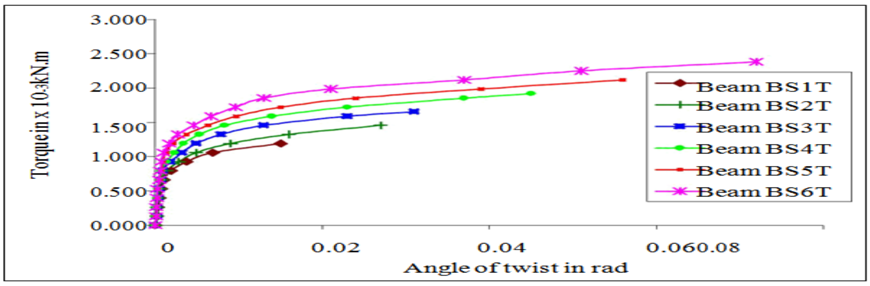


Torque versus angle of twist behavior without reinforcement



Relationship between torque and angle of twist

At higher loads appreciable magnitudes of twist were observed showing the ductility of the beams. The torque–twist curves of the beams are linear up to about 80% of their torsional strength after which they become non-linear



Torque versus angle of twist behaviour with reinforcement

Table. *Comparisons of cracking torque and ultimate torque*

Test specimen	Type of fiber	Volume fraction of fiber	Cracking torque x 10^{-3} kN.m	Ultimate torque x 10^{-3} kN.m
BS1T	Crimpled	0%	1059	1258
BS2T		1.0%	1324	1589
BS3T		0%	1655	2053
BS4T		1.0%	1854	2318
BS5T		0%	2053	2516
BS6T		1.0%	2318	2847

Table. *Details of average energy absorption due to torsional impact*

Test specimen	Type of fiber	Volume fraction of fiber	Average energy absorption in N.m at cracking torque	Average energy absorption in N.m at ultimate torque
B1TI	Straight	0%	80.8	121.2
B2TI		0.5%	303	484.8
B3TI		1.0%	363.6	565.6
B4TI		1.5%	424.2	626.2
B5TI	Crimpled	0.5%	343.4	787.8
B6TI		1.0%	565.6	888.8
B7TI		1.5%	828.2	1151.4

The average energy absorption required at first crack of fiber reinforced concrete beams with 0.5%, 1.0% and 1.5% crimpled fiber content was found to be 4.25, 7 and 10.25 times more when compared with plain concrete beam. Similarly the energy absorption required at failure of fiber reinforced concrete beam with 0.5%, 1.0% and 1.5% crimpled fiber content was found to be 6.5, 7.3 and 9.5 times more when compared with plain concrete beam. Histograms showing

Details of Cracking Torque and Ultimate Torque

Test specimen	Volume fraction of fiber	Cracking torque x 10^{-3} kN.m	Ultimate torque x 10^{-3} kN.m
B1TC	0%	795	1059
B2TC	1.0 %(Crimpled)	927	1258
B3TC	0%	1192	1589
B4TC	1.0 %(Crimpled)	1324	1788
B5TC	0%	1589	2119
B6TC	1.0 %(Crimpled)	1722	2384

The cracking torque of concrete beams B2TC, B3TC, B4TC, B5TC and B6TC was found to be 17%, 50%, 67%, 100% and 117% more when compared with plain concrete beam. Similarly the ultimate torque of concrete beams B2TC, B3TC, B4TC, B5TC and B6TC was found to be 19%, 50%, 69%, 100% and 125% more when compared with plain concrete beam B1TC. The ultimate torque of beams B1TC, B2TC, B3TC, B4TC, B5TC and B6TC was found to be 33%, 36%, 33%, 35%, 33% and 38% more when compared with the cracking torque.

3. Conclusion

- Use of fiber reinforcement in concrete along with conventional shear and flexural reinforcement makes it more ductile and therefore more suitable for torsion resistant structures.
- When the theoretical and the observed values of the cracking torque and the ultimate torque are compared, it is observed that the values are within the acceptable range of variation from experimental observations in the case of all the specimens. Therefore, it may be concluded that the results obtained from these tests may be relied upon and may be used in further investigations.
- The torque at failure of fiber reinforced concrete beam with 0.5%, 1.0% and 1.5% straight fiber content was found to be 5%, 11% and 16% more when compared with plain concrete beam.
- Appreciable crack width was noticed because of torsional impact. The failure of the plain concrete beams was sudden and with low energy absorption. But in fiber reinforced concrete beams, the failure was not sudden and it took increased number of blows.
- Due to cyclic torsion initially, the cracks widened and closed as the load was applied and released. Eventually, at the failure stage the crack kept on widening and the concrete failed.

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