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Experimental Study on Torsional Behavior of steel Fiber Reinforced Concrete Members under Pure Torsion

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Experimental Study on Torsional Behavior of steel Fiber Reinforced Concrete Members under Pure Torsion

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Abstract. An experimental study was conducted on ten steel fiber reinforced concrete specimens with low longitudinal reinforcement ratio to investigate the torsional behavior under pure torsion. The crack patterns, cracking torque, ultimate torsional strength, and torsional ductility, were discussed. The major parameters were the ratio and type of adding steel fiber. The obtained results showed that the cracks width of end hooked steel fiber specimens were wider than the corrugated steel fibers specimens, the cracks width decrease with increase the steel fiber ratio, and the number of cracks of end hooked steel fiber specimens were less than the corrugated steel fibers specimens. In the specimens of mix steel fiber, the width and the number of cracks less and more than other specimens, respectively. The higher percentage of the steel fiber, gives greatest torsional resistance. However, with an increase in the percentage of steel fiber the workability decreases.

Keywords*:* Fiber reinforcement, steel fiber, pure torsion, hollow section.

1. Introduction

Concrete contains a large numbers of micro cracks, especially, in the boundary of coarse aggregate which contacts with cement paste, even before stresses are applied. These cracks have significant effects on the concrete behavior under applied loading, since the micro crack propagation contributes during the loading to the nonlinear behavior of concrete mix at low applied loading, and causes the volume exchange near the failure. The widths of micro cracks perhaps exceed a few microns, but their other two dimensions often of higher magnitude. The development of such micro cracks is the major cause of inelastic deformation in concrete. The presence of cracks leads to weak resistance of concrete members to tension, and consequently failure occurs. There are many methods of control cracks, the most important of which is adding reinforcement and/or adding fibers. The addition of steel fibers to concrete used to enhance the main concrete characteristics such as toughness, stiffness, and ductility. Where the term of steel fibers reinforced concrete denotes to concrete reinforced by short, randomly oriented steel fiber. In the last decades, steel fibers consider the most commonly used of fiber type concrete. About in, the 1910s, steel fiber such chips metal and nails were used as reinforcement in concrete members [1]. Since 1960s, the experimental and theoretical studies about steel fibers introduced as an effective concrete reinforcement [2]. The American Code (ACI) [3], has recognized for the first time the fiber reinforced concrete as a structural material. Okay and Engin[4] experimentally tested 12 steel fiber reinforced concrete specimens under torsional moments. They stated that the torque capacity of beams is improved by the addition of steel fibers. Also the capacity of energy absorption is significantly affected. Nitesh et al. [5], experimentally studied self-compacting reinforced concrete with recycled coarse aggregate and end hooked steel fibers for constant ratio of 0.5 %. They observed that there is increase in ultimate torsional capacity, twist angle, stiffness, and toughness. Bhavani et al.[6], investigated the behavior of fiber reinforced concrete beams under pure torsion. Straight and crimpled fibers with varying volume ratios used. In both straight and crimpled steel fibers, the torque at first crack and failure indicated a continuous increase with increase in fibers volume for the varying volume fraction. Most studies on the fiber reinforcement concrete elements have been mostly limited to steel fibers opposite other types. This study investigates on the properties and structural applications of steel fibers. To ensure the bonding between steel fibers and surrounding concrete to prevent pulled out, the steel fibers typically produce as rough ends. Therefore, the end hooked and corrugated steel fibers will be used in this study as shown in Figure 1 (a & b).

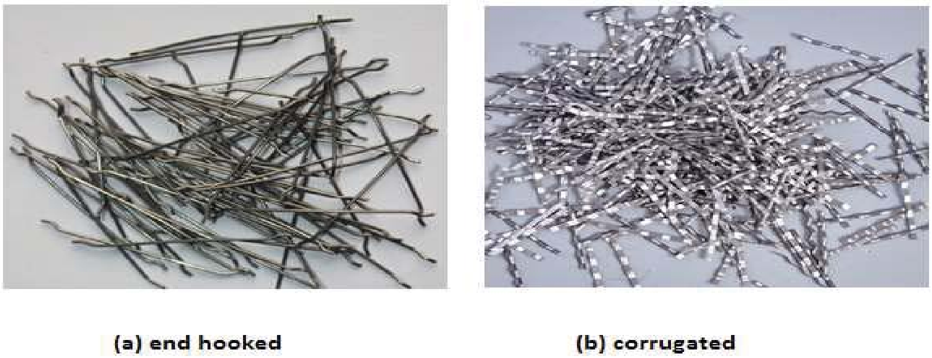

Figure 1. Typical steel fibers used in fiber reinforced concrete

1.1 Types of fibers
There are many types of fibers based on their material: glass fiber, synthetic fiber, natural fiber, and steel fiber. The addition of fiber could provide significant increase in tensile strength of concrete, but their main influence is to improve the concrete toughness. The addition of steel fiber would allow the concrete to continue to carrying a tensile load after the peak tensile strength has been reached.

1.2 Steel fiber
The most commonly fibers that which added to concrete is steel fibers. Where, the steel fiber addition could enhance the tensile strength of concrete. Steel fibers reinforced concrete has improvement resistance to crack propagation. The primarily researches in structural members on the use of fiber reinforcement have been limited to use of steel fiber, as opposed to other types, and used as shear reinforcement in beams. In 2008, the American Code (ACI)[3] allow for the first time to use the steel fibers as minimum shear reinforcement in concrete members.

2. Experimental study

2.1. Materials
The materials used in the experimental work were tested in Thi-Qar University laboratory according to the Iraqi specification requirements as follows:

2.1.1. Cement. Al-Doh Type I ordinary Portland cement was used. Results showed that the tested sample was within the Iraqi specification requirements, no.45, 1984[7].

2.1.2. Fine aggregate. AL-Zubair natural sand of max size 4.75 mm was used for this study. Table 1 shows the sieve analysis of fine aggregate. Results showed that the tested sample was within the requirements of the Iraqi specification no.45, 1984.

Table 1. Fine aggregate sieve analysis.

Sieve size (mm)	Cummlative passing (%)	Iraqi specification limits, no.45.1984
10	100	100
4.75	92.8	90-100
2.36	88.4	85-100
1.18	77.8	75-100
0.60	63.6	60-79
0.30	31.3	12-40
0.15	7.1	0-10

2.1.3. Coarse aggregate. AL-Zubair crushed gravel of max size 20 mm was used. The coarse aggregate gradient was given in Table2 corresponding to the Iraqi specification, no.45, 1984.

Table 2. Coarse aggregate sieve analysis

Sieve size (mm)	Cumulative passing (%)	Iraqi specification limits, no.45.1984
20	100	95-100
14	89	80-100
10	56	30-60
5	3.2	0-10

2.1.4. Steel reinforcement. Deformed reinforcing steel of 10 and 12 mm diameter were used for the longitudinal and stirrups reinforcement. The test results as shown in Table3 show that the used steel bars conformed to ASTM A615M-01[8].

Table 3. Properties of steel reinforcement

Nominal Dia. (mm)	Measured Dia. (mm)	Modulus of elasticity (GPa)	Yield strength (fy) (MPa)	Ultimate strength (fu) (MPa)
10	9.63	200	498	702
12	11.7	200	512	712

2.1.5. Water. For both concrete mixing and curing, the tap water was used.

2.1.6. Steel fiber. Table 4 shows the test results and material properties of steel fibers.

Table 4. Properties of steel fiber

No	Inspection items	Requirement	Test result	Evaluate
1	Tensile strength (MPa)	≥1100	1185	Qualified
2	Length (mm)	35±0.5%	35	Qualified
3	Diameter (mm)	0.55±0.5	0.55	Qualified
4	Aspect ratio(length/diameter)	65±5	65	Qualified
5	Qualified rate of shape %	≥90	98	Qualified
6	Impurity content %	≤1	0.1	Qualified

2.2. Concrete mixing

Several trial mixes were made to achieve the required strengths. The concrete mixtures were designed to reach the cube strengths to 30 MPa at 28 days. The mixtures were (1 cement: 2.19 sand: 3 gravel: 0.48 water, by weight). The slump test was about 100 mm. For testing the mix properties, 150 mm cubes, and 100φ*500 mm prisms, as shown in Figure 2 (a & b), respectively, prepared for concrete compressive strength, and splitting tensile strength tests, respectively. The mix samples were removed from the molds after 24 hrs. After that the samples were cured in tap water for 28 days until the testing day. The trail concrete mixtures that which used were consistent of uniform concrete mixing, acceptable workability, and without segregation. The compressive strengths were (average of 6 cubes at 28 days) were 30.6 MPa for mixture of 30MPa.

(a) **(b)**

Figure 2. Concrete mixing properties

2.3. Test methodology

The aim of the experimental study was to choose the type and quantity of steel fiber that give the highest torsional resistance under pure torsion behavior with acceptable workability and without segregation. Ten hollow cross section specimens (outer dimensions: 250 mm*250 mm, and hollow dimensions 150 mm*150 mm) with (1000 mm) long as shown in Figure 3, were casting with different types and quantity of steel fibers as shown in Table 5. To prevent the cracking failure of the specimens at the cracking torsional load, all beams were designed to have 4#10 mm longitudinal reinforcement. Also, to prevent the ends collapse during the testing, three closed transverse (#12 mm stirrups) at each end were used. The percentage of longitudinal reinforcement was slightly higher than the minimum American Code (ACI)[3] requirement sustaining the continuity of the beams beyond cracking stage. Also, this will consider the case of deficient beams in terms of reinforcing[9].

Table 5. Specimens properties

Specimens symbol	No. of specimen	Steel fiber ratio	Steel fiber type
B0	1	0%	No
BE0.5	1	0.5%	End hooked
BE1	1	1%	End hooked
BE1.5	1	1.5%	End hooked
BC0.5	1	0.5%	Corrugated
BC1	1	1%	Corrugated
BC1.5	1	1.5%	Corrugated
BM0.5	1	0.5%	Mix (50% end hooked and 50% corrugated)
BM1	1	1%	Mix (50% end hooked and 50% corrugated)
BM1.5	1	1.5%	Mix (50% end hooked and 50% corrugated)

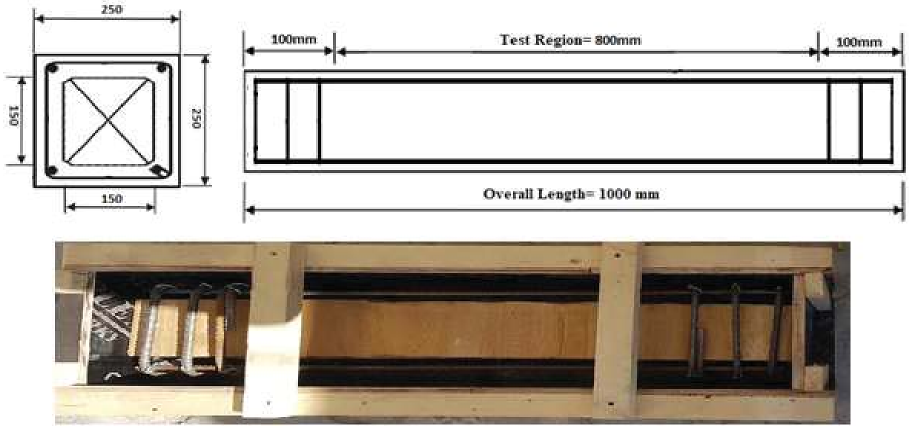

Figure 3. Geometry of the specimens

2.4. Testing procedure
The details of the test system are shown in Figure 4. The ends of the test beams were clamped with I section steel arms (750 mm), which were loaded through I section steel beam by the universal testing machine to create a pure torsional moment. The supports at each end were placed on roller support to ensure free rotate, extension or contraction during the testing. At both ends of the specimen, electronic angle measures gages were tight to the surface of each beam to measure the twist angle of its ends cross section. The beam is hinged to the upper I section arms and plates, which are fixed by the roller supports with help bolts. The torque is produced by applying a point load to the center of the transmitter I section girder. In order to obtain pure torsion, the girder was used to transfer the concentrated load of the hydraulic testing machine to the ends of the lever arms. The I section girder was attached to the hydraulic testing machine piston. Reinforced fiber concrete specimens were tested under increasing monotonically torsional loads up to failure stage. During the test, the applied load was in a controlling manner until visible cracks appeared on the surface of the beams. The torsional cracking T_{cr} and the associated twist angle θ_{cr} were recorded, and then the load was applied gradually 5kN at each step. Readings were recording manually at each load step after first cracking.

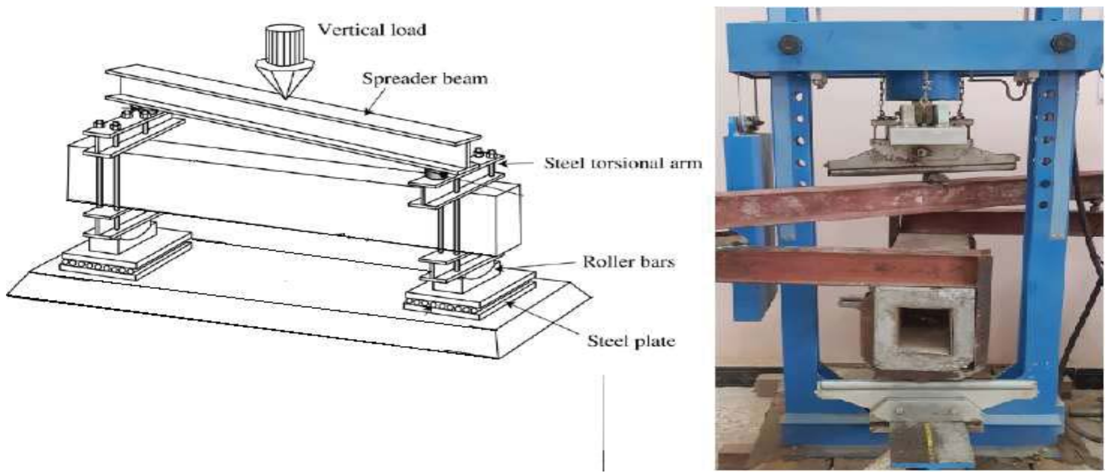

Figure 4. Testing setup

3. Test results and discussion

The results of this experimental study are shown in Table6. The variables of the obtained results of this study are discussed below.

Table 6. Experimental Results

Specimen symbol	$T_{Cracking}$(Spec.) (kN.m)	$T_{Ultimate}$(Spec.) (kN.m)	$\frac{T_U(Spec.)}{T_{Cr}(Spec.)}$	$\frac{T_{Cr}(Spec.)}{T_{Cr}(B0)}$	$\frac{T_U(Spec.)}{T_U(B0)}$	$\theta_{Cracking}$ (rad/m)	$\theta_{Ultimate}$ (rad/m)
B0	4.25	6.1	1.4	1.00	1.00	0.0015	0.033
BE0.5	4.65	9.95	2.09	1.09	1.63	0.00155	0.045
BE1	5.5	10.95	1.99	1.29	1.79	0.0016	0.062
BE1.5	6.4	12.2	1.9	1.5	2.00	0.0018	0.068
BC0.5	4.45	9.63	2.08	1.05	1.58	0.0015	0.045
BC1	5.3	10.75	2.03	1.25	1.76	0.0016	0.058
BC1.5	6.1	12	1.96	1.43	1.96	0.00175	0.065
BM0.5	4.85	10.35	2.13	1.14	1.70	0.0014	0.049
BM1	5.65	11.75	2.08	1.33	1.93	0.0017	0.068
BM1.5	6.55	13.5	2.06	1.54	2.21	0.0018	0.079

3.1. Crack patterns

When the members are subjected to a pure torsional moment, shear stresses develop on the top and front face [3], as shown in Figure 5(a-c). The principal tensile stresses are equals the principal compressive stresses, and both are equals to the shearing stresses. Where, the principal tensile stresses mainly caused spiral cracking around the member. During the testing, the pattern of the cracks in plain concrete B0 was one major spiral crack initiated on the side and at the top of the tested beam. After that, the crack initiated on the back side and the bottom with approximately twist angle 45º as shown in Figure 6. The crack patterns of experimental specimens are approximately corresponding to that assumed in the skewing bending theory [10]. On the other side, in the specimens of fiber reinforced concrete the smeared inclined cracks were distributed on the surfaces as shown in Figure 7. Where, the steel fibers developed to resist the applied torque after the first crack stage depending on the shape of steel fiber and coherence between it and concrete. According to the elasticity theory, when the member is under a pure torsion, the first cracking generally initiates inclined on the face of the wider side of the specimen cross section [11]. The obtained results show that the cracks width in the specimens that contained end hooked steel fiber more than corrugated steel fiber. When using a mixture of steel fiber (50% end hooked and 50% corrugated), the results show that the number of smeared cracks increased and their width were decreased.

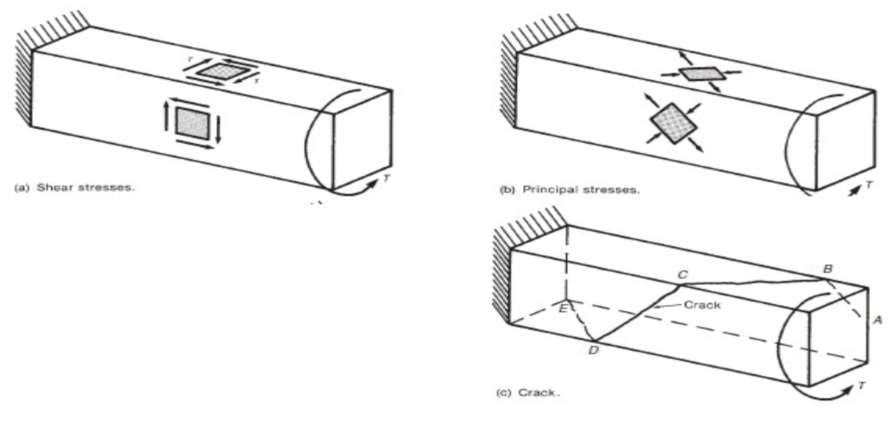

Figure 5. Principal stresses and cracking patterns due to pure torsion.

Figure 6. Crack pattern of specimen B0.

Figure 7. Crack pattern of fiber specimens.

3.2. Effect of fiber content

The obtained results show the first cracking and ultimate torsional resistance continuous increase with increase of steel fiber ratio in both the end hooked and corrugated fiber for the (0.5%, 1% and 1.5%) ratios as shown in Figures 8-10. respectively. At higher applied torque appreciable magnitudes of twist angle were observed showing the ductility of the specimen increases with the increase of steel fiber ratio. The Figures show that the end hooked steel fiber concrete members gives an ultimate torsional strength and torsional ductility slightly higher the corrugated steel fiber concrete members. Figure 10 shows the mix steel fiber concrete members (50% end hooked and 50% corrugated) give higher first cracking, ultimate torsional strength and torsional ductility than both end hooked and corrugated if separately used. The cracking torque of fiber reinforced concrete members BE0.5, BE1, BE1.5, BC0.5, BC1, BC1.5, BM0.5, BM1 and BM1.5 was found to be 32%, 52%, 97%, 29%, 48%, 88%, 37%, 56% and 100% more when compared with B0 plain concrete member. Similarly the ultimate applied torque of concrete members BE0.5, BE1, BE1.5, BC0.5, BC1, BC1.5, BM0.5, BM1 and BM1.5 was found to be 43%, 79%, 124%, 36% 76%, 113%, 53%, 92% and 137% more when compared with plain concrete member B0. The ultimate applied torque of members BE0.5, BE1, BE1.5, BC0.5, BC1, BC1.5, BM0.5, BM1 and BM1.5 was found to be 54%, 68%, 63%, 51%, 70%, 61%, 59%, 76% and 70%

more when compared with them cracking torque. From the previous results, noticed that the higher percentage of the steel fiber gives a great torsional resistance. Also, the ratio of 1% of steel fiber gives the highest values of ultimate torsional strength when compared with the first cracking torsional strength, with acceptable workability and without segregation.

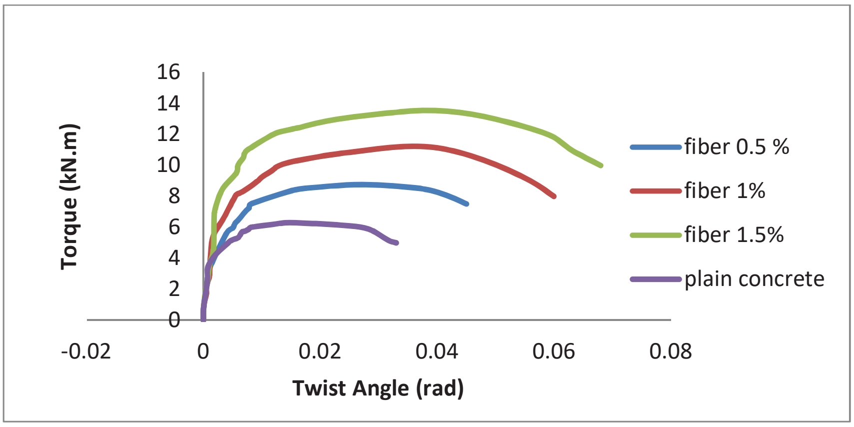

Figure 8. Torque-Twist Angle Relationship of End Hooked Steel Fiber

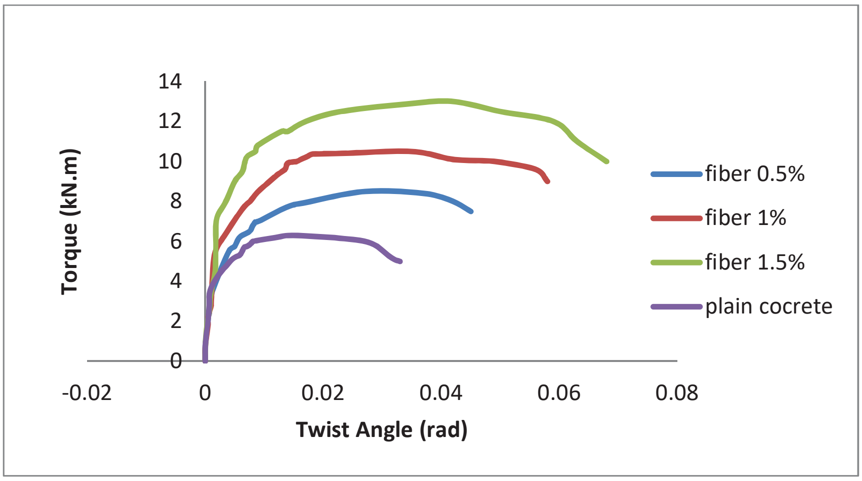

Figure 9. Torque-Twist Angle Relationship of Corrugated Steel Fiber

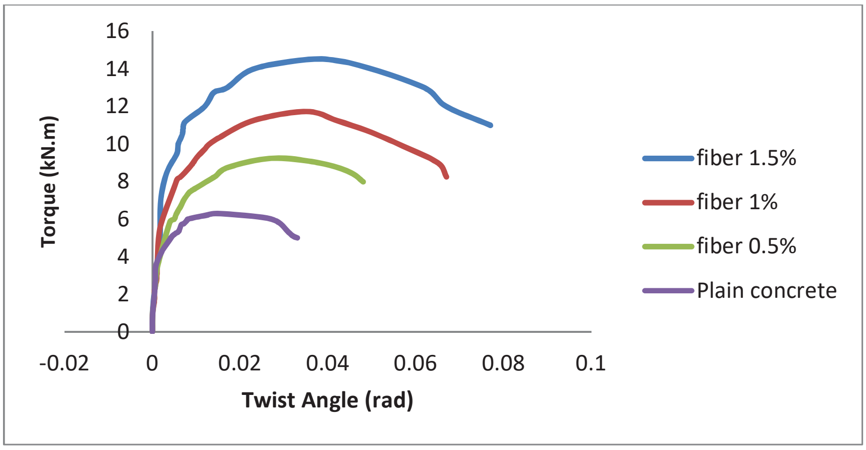

Figure 10. Torque-Twist Angle Relationship of Mix Steel Fiber

4. Conclusions:

1. Use of steel fibers has found to be very advantageous to increase the cracking and ultimate torsional strength of reinforced concrete members which subjected to pure torsion.
2. The higher percentage of the steel fiber, gives greatest torsional resistance. Also, the ratio of 1% of steel fiber gives the highest ultimate torsional strength values when compare with the first cracking torque with acceptable workability and without segregation, and through that it can be indicated that the ratio over 1% of steel fiber is caused problems during implementation.
3. End hooked steel fibers give relatively higher torsional resistance than corrugated ones. On the other hand, the mixture of fibers (50% end hooked and 50% corrugated) gives significantly higher results than the other two types if used separately.
4. For 1.5% mix fiber reinforced concrete specimens, the cracking and ultimate torsional strength were increased up to 100% and 137%, respectively, which was very significant increase in the torsional strength of reinforced concrete members compared with control beam.
5. The adding of steel fiber to concrete has succeeded to improve the ductility of the members by increase the twist angle of strengthened members as compared with the control beam.

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