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Enhancing the Behavior of Reinforced Concrete Beams Subjected to Pure Torsion Stresses Using Different Types of Steel Fiber in the Mix

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Abstract: **These days, the most popular method for enhancing the flexural, shear and torsional properties of concrete is steel fiber reinforced concrete (SFRC). This study examines the torsional behavior of steel-fiber reinforced concrete beams in pure torsion. Fiber ratio, fiber type and concrete strength were factors in this study.**

To cast the tested beams, six different concrete mixtures were chosen. The first group (1) consists of three rectangular beams split into a control beam with a compressive strength of 20 MPa and two rectangular beams with various steel fiber ratios and types. The second group (2) is made up of three beams, with one rectangular beam serving as a control beam with a compressive strength of 40 MPa and the other two rectangular beams having various steel fiber ratios and types. All beams were cast and put through a strict torsion test.

The objective of research is to study the crack pattern, crack torque, ultimate torque, torsion rigidity. The experimental study found that adding steel fibers to RC beams improved the ultimate torsion strength and decreased the angle of twist for beams when compared to control beams at the same load.

Keywords: **Steel fiber, reinforced concrete beams, torsional strength, angle of twist.**

1. INTRODUCTION

Torsion occurs in concrete structural members such as eccentrically loaded beams, spandrel beams, curved girders, space frame members, and spiral staircases. Torsion must be avoided by these members. Torsional failure of concrete members is caused by tensile stress generated by a state of pure shear caused by torsion. The addition of steel fiber to concrete improves its mechanical properties. According to the literature, steel fiber can improve torsional behavior.

The torsional moment capacity [1], torsional toughness [2], and energy absorption capacity [3] were all improved by the addition of steel fiber. Aspect ratio affected the ultimate torque and the cracking torque, respectively [4]. Steel fibers can increase ductility and the capacity to dissipate energy [5,6]. The fiber volume fraction increased along with the compressive strength and ultimate strain of CFTTs [7].

The laboratory results demonstrated that increasing the percentage of steel fiber increased both the ultimate and cracking torsional strength [8].

When RC beams were subjected to pure torsion, the experimental results demonstrated that adding steel fiber increased the torsional strength of the beams by up to 47.27% [9].

Steel fiber's real benefit is that it improves the mechanical characteristics of concrete and controls crack propagation. This quality, known as crack-bridging, is attributed to the steel fibers' ability to withstand tensile stress across crack surfaces. These fibers also offer resistance to shear across developed cracks.

The study's main objective is to determine whether adding steel fiber to RC beams increases the beams' torsional strength.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The concrete mix was made with ordinary Portland cement (Type 1), crushed gravel with a maximum aggregate size of 10 mm and fine river sand, and sika ViscoCrete as a superplasticizer to improve the workability of steel fiber reinforced concrete beams. The main steel of the beams was high tensile (36/52) steel. Deformed steel bars with a diameter of 12,10 mm were used at the bottom and top of the tested beams. Closed stirrups were made of mild smooth steel 8 mm in diameter in all specimens. Figure 1 depicts the shapes of the steel fibers used in the experiment. Table 1 displays the properties of the steel fibers used in the experiment.

Table (1): Properties of steel fiber

Type	l_f/d_f (mm)	Tensile strength (MPa)
End hooked	55/1	1500
Corrugated	50/0.7	1200

Figure (1): End hooked and Corrugated Steel Fiber.

2.2 Test program

1) 48 steel fiber cubes with dimensions of $15 \times 15 \times 15\ cm$ were casted and submerged in a tank of water until tested. Each steel fiber ratio had six specimens, half of which were tested after seven days of casting and the other half after 28 days of casting using a compression test machine to determine the best steel fiber ratio to be used in reinforced concrete beams under pure torsion. The compressive strength test results for cubes revealed that the best ratio of end hooked steel fiber was 1.5% by volume of concrete, and the best ratio of corrugated steel fiber was 1% by volume of concrete. The mix proportions for steel fiber cubes are shown in Table (2). Table (3) displays the compressive strength of steel fiber cubes after 7 days. Table (4) displays the compressive strength of steel fiber cubes after 28 days.

Table (2): The mix proportions for steel fiber cubes.

Cement	350 Kg/m^3
Aggregate	1120 Kg/m^3
Sand	680 Kg/m^3
Water	210 Kg/m^3
W/C	0.6
Plasticizer	4.5 Kg/m^3

Table (3): Compressive strength results for steel fiber cubes after 7 days.

Blend name	Type of steel fiber	% SF	Compressive strength (MPA)			Average compressive strength (MPA)
			C1	C2	C3	
1	End hooked	0.5	20.7	21	21.6	21.1
2		1	23.5	22.3	22.5	22.8
3		1.5	23.9	24.3	24	24.06
4		2	21.2	20.1	20.5	20.6
5	Corrugated	0.5	19	19.6	21.2	19.93
6		1	22.6	22.8	23.3	22.9
7		1.5	21.8	22	22.2	22
8		2	21.1	20.7	20.8	20.86

Table (4) Compressive strength results for steel fiber cubes after 28 days.

Blend name	Type of steel fiber	% SF	Compressive strength (MPA)			Average compressive strength (MPA)
			C4	C5	C6	
1	End hooked	0.5	29.4	29.8	30.3	29.8
2		1	31.9	31.4	31.7	31.66
3		1.5	33.5	34.4	34.2	34.03
4		2	29.6	28.7	30.1	29.46
5	Corrugated	0.5	28.08	28.31	28.53	28.31
6		1	31.48	32.61	32.16	32.08
7		1.5	30.8	30.57	30.35	30.57
8		2	30.57	30.12	29.44	30.04

2) To investigate the torsion behavior of steel fiber reinforced concrete beams, six concrete mixes were chosen for casting the tested beams. The beams that were tested were divided into two groups. The first group (1) is made up of three beams: one rectangular beam as a control beam with a compressive strength of 20MPa and two rectangular beams with different steel fiber ratios and types. The second group (2) consists of four beams, one rectangular beam as a control beam with a compressive strength of 40MPa and two rectangular beams with different steel fiber ratios and types. The beams were subjected to pure torsion testing. The effect of steel fiber type, steel fiber ratio, and concrete strength on beam torsion behavior was investigated.

2.3 Test specimens

The dimensions of the tested beams were 2000 mm long, 400 mm thick, and 120 mm wide. Both beams were designed to be forced to fail in torsion. 2T10 top reinforcement, 4T12 bottom reinforcement and 5Y8/m closed stirrups as shown in figure (2).

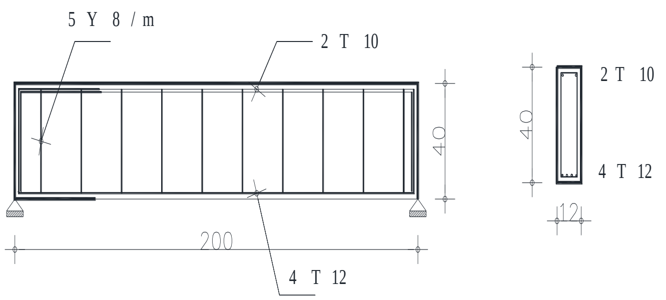

Figure (2): Details of Test Specimens

2.4 Concrete mix design

The mix proportions used in the beam tests are shown in Tables (5) and (6). Table (5) shows the mix proportions used to make the concrete mix for beams B1, B2, and B3. Table (6) shows the mix proportions used to make the concrete mix for beams B4, B5, and B6.

Table (5): The mix proportions for beams B1, B2 and B3

Specimen	Cement (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Sand (Kg/m^3)	Water (Kg/m^3)	W/C ratio	Super Plasticizer (Kg/m^3)	Steel Fiber (% vol concrete)	Type of Steel Fiber
B1	250	1100	800	162.5	0.65	3.75	-	-
B2							1.5 %	End hooked
B3							1 %	Corrugated

Table (6): The mix proportions for beams B4, B5 and B6

Specimen	Cement (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Sand (Kg/m^3)	Water (Kg/m^3)	W/C	Super Plasticizer (Kg/m^3)	Steel Fiber (%vol concrete)	Type of Steel Fiber
B4	450	1100	800	185	0.41	6	-	-
B5							1.5 %	End hooked
B6							1 %	Corrugated

2.5 Test setup and beam loading

Test specimens were subjected to pure torsion in the torsion setup depicted in Figure 3. The specimens were supported on both ends by two roller supports. The roller supports allowed the specimen to freely twist during testing. Figure 3 depicts the experimental test setup. A beam specimen was supported by a very rigid steel frame made of horizontal and vertical I-sections. The load was applied vertically with a 20-ton hydraulic jack in the middle of a steel spreader beam (I sec.) placed above steel arms projecting from the two ends of the tested beam. Bolts secure the steel arms to the beam. All beam specimens were painted white with lime to allow for easy tracing of crack propagation during testing. To keep the jack vertical, it was connected to S.I.B. 360. To measure the load equal increments, a load cell was directly underneath the jack.

Figure (3): Torsional Test Setup

2.6 Testing procedure

The steel strain gauges, and vertical dial gauges were reset to zero after preparing the test setup and before loading the specimens. Using the data acquisition system's testing software, the electrical instrumentation readings were reset to zero. The load was then gradually applied using hydraulic jacks at a constant rate. At each load increment, the readings of the various measurement devices were recorded on a piece of paper. Once the first visible crack was identified, the cracking load was recorded. After each load increment until the failure load, the crack propagation was marked.

2.7 Test measurement

The maximum torsion capacity and the angle of twist (α) were measured. The load was gradually applied. Manual readings were taken at each load increment (0.5 ton). Cracks were also recorded at each stage. Torsion force was gradually increased until the beam failed. Failure is defined as a decrease in loading capacity as the rotation of the beam increases.

2.7.1 The torsion force (Torque) can be obtained by equation.

$$T = P/2*d$$

Where:

T = The torsion, KN.m

P = The load applied, KN

d = The distance from load to the center of beam, m.

2.7.2 Angle of twist (α) measurement

The angle of twist was measured in two ways.

The first method for calculating the angle of twist for Beams B1, B2, and B3 is as follows: The specimens' deflection was measured using three dial gauges. One gauge was in the center of the specimen, and the others were about 65 cm to the left and right. The uplift and deflections of the end sections caused by the applied load were measured using dial gauges one and three. Dial gauges one and three were located 30 mm from the center of the beam's longitudinal axis.

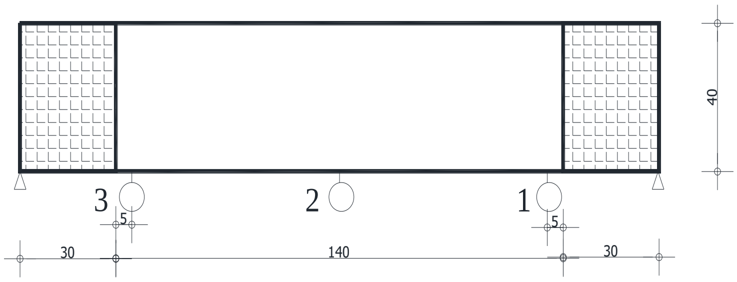

Figure (4): Dial Gauges for Deflection Measurements for Beams B1, B2 and B3

The second method for calculating the angle of twist for beams B4, B5, and B6 is as follows: The angle of twist (α) was calculated using two dial gauges located at the bottom of one end of the beam to the right and left, respectively, at each end of the beam, at a point 30 mm from the center of the longitudinal axis of the beam. The angle of twist (α) in radians is calculated by recording the uplift and down values.

$$\text{Angle of twist } \alpha = \tan^{-1}(\text{LVDT reading }/30)$$

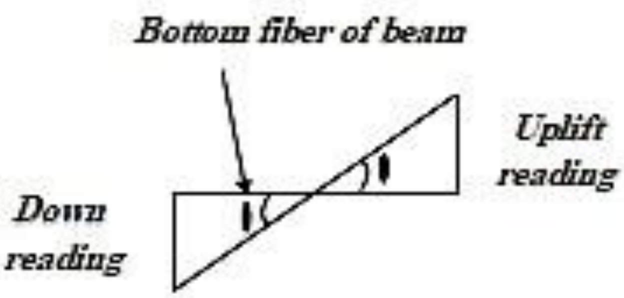

Figure (5): Angle of Twist Measurement

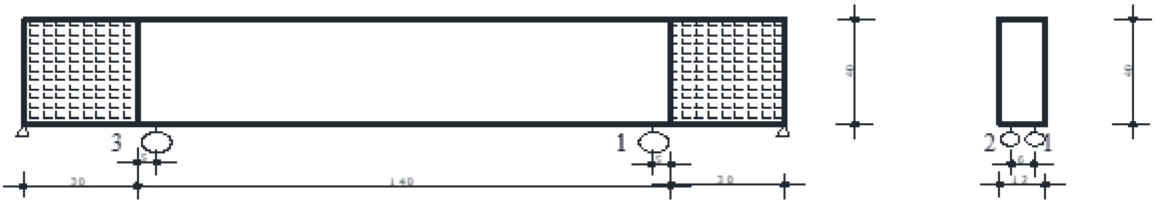

Figure (6): Dial Gauges for Deflection Measurements for Beams B4, B5 and B6

2.7.3 Strain measurements

Electrical strain gauges were used to measure the strain in the steel reinforcement. The strain gauges were attached to the steel reinforcement's softened surface with glue material and covered with a waterproof coating to prevent damage. The location of the strain gauge was in the center of the main steel reinforcement at the bottom of the beam. The strain gauges were attached to an accurate strain meter with a resolution of 1×10^{-6} and had a length of 60 mm and a resistance of 120 ohms.

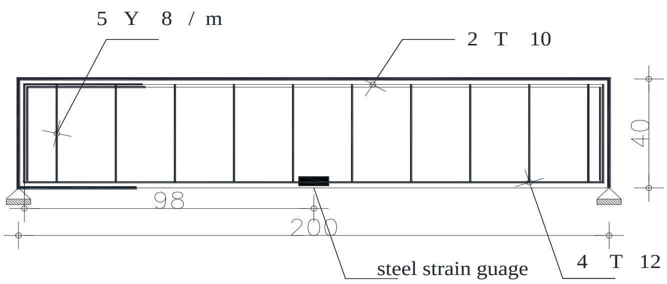

Figure (7) Position of Strain Gauges in Tested Beams

2.8 Test parameters

The main test parameters are steel fiber ratio (% vol concrete), steel fiber types, and concrete strength.

Table (7): Classification of test specimens

Group	Specimen No	f_{cu} (MPa)	Types of steel fiber	Ratio of steel fiber (% vol concrete)
1	B1	20	---	0.0
	B2		End hooked	1.5
	B3		Corrugated	1
2	B4	40	---	0.0
	B5		End hooked	1.5
	B6		Corrugated	1

3. TEST RESULTS

3.1 Torque-Twist Response

The first crack due to applied torque, ultimate torque and corresponding twist of each beam tested were recorded. Torque versus twist response of each beam was presented below. Tables 8, 9, 10, and 11 contain a summary of the test results. The torque-angle of twist diagram for the specimens B1, B2, and B3 under pure torsion is shown in Figure (8). The torque-angle of twist diagram for the specimens B4, B5, and B6 under pure torsion is shown in Figure (9).

Table (8): Comparison of tested beams results at cracking torque for group (1)

Specimens	Type and ratio of steel fiber	First crack torque (KN.m)	Increasing in first crack torque (%)
B1	-	4.53	-
B2	End hooked (1.5%)	5.96	31.5
B3	Corrugated (1%)	5.45	20.4

Table (9): Comparison of tested beams results at ultimate torque for group (1)

Specimens	Type and ratio of steel fiber	Ultimate torque (KN.m)	Increasing in ultimate torque (%)	Angle of twist (Degree)
B1	-	8.64	-	3.09
B2	End hooked (1.5%)	15.13	75	5.20
B3	Corrugated (1%)	11.93	38	5

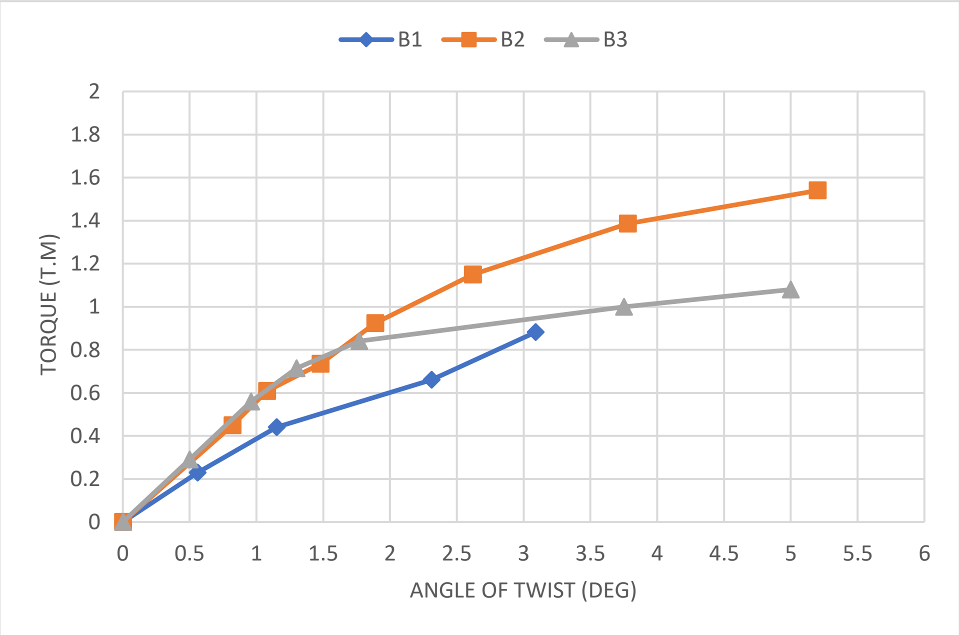

Figure (8): The influence of steel fiber on twisting angle for beams B2, and B3

Table (10): Comparison of tested beams results at cracking torque for group (2)

Specimens	Type and ratio of steel fiber	First crack torque (KN.m)	Increasing in first crack torque (%)
B4	-	6.5	-
B5	End hooked (1.5%)	8.70	33.8
B6	Corrugated (1%)	8.60	32

Table (11): Comparison of tested beams results at ultimate torque for group (2)

Specimens	Type and ratio of steel fiber	Ultimate torque (KN.m)	Increasing in ultimate torque (%)	Angle of twist (Degree)
B4	-	10.50	-	3.40
B5	End hooked (1.5%)	18.11	72.5	5.56
B6	Corrugated (1%)	15.23	45	5.42

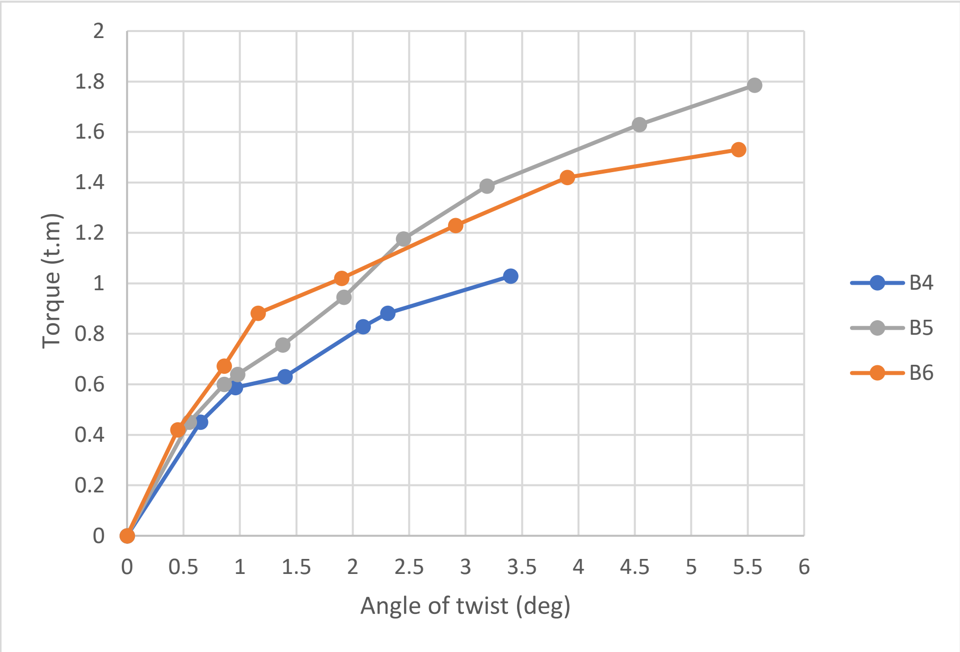

Figure (9) The influence of steel fiber on twisting angle for beams B5, and B6

3.2 Crack and Failure Loads

The crack and failure load for specimens B1, B2, and B3 are depicted in Figure (10). Figure (11) depicts the crack pattern for specimens B1, B2, and B3 at failure. The crack and failure load for specimens B4, B5, and B6 are shown in Figure (12). The crack pattern at failure for specimens B4, B5, and B6 is shown in Figure (13).

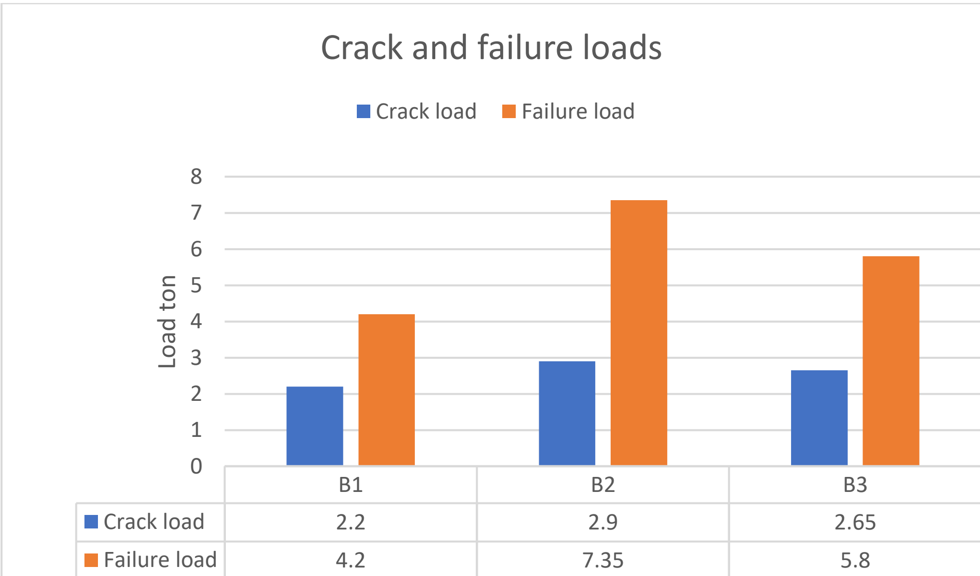

Figure (10): Crack and failure load for B1, B2 and B3

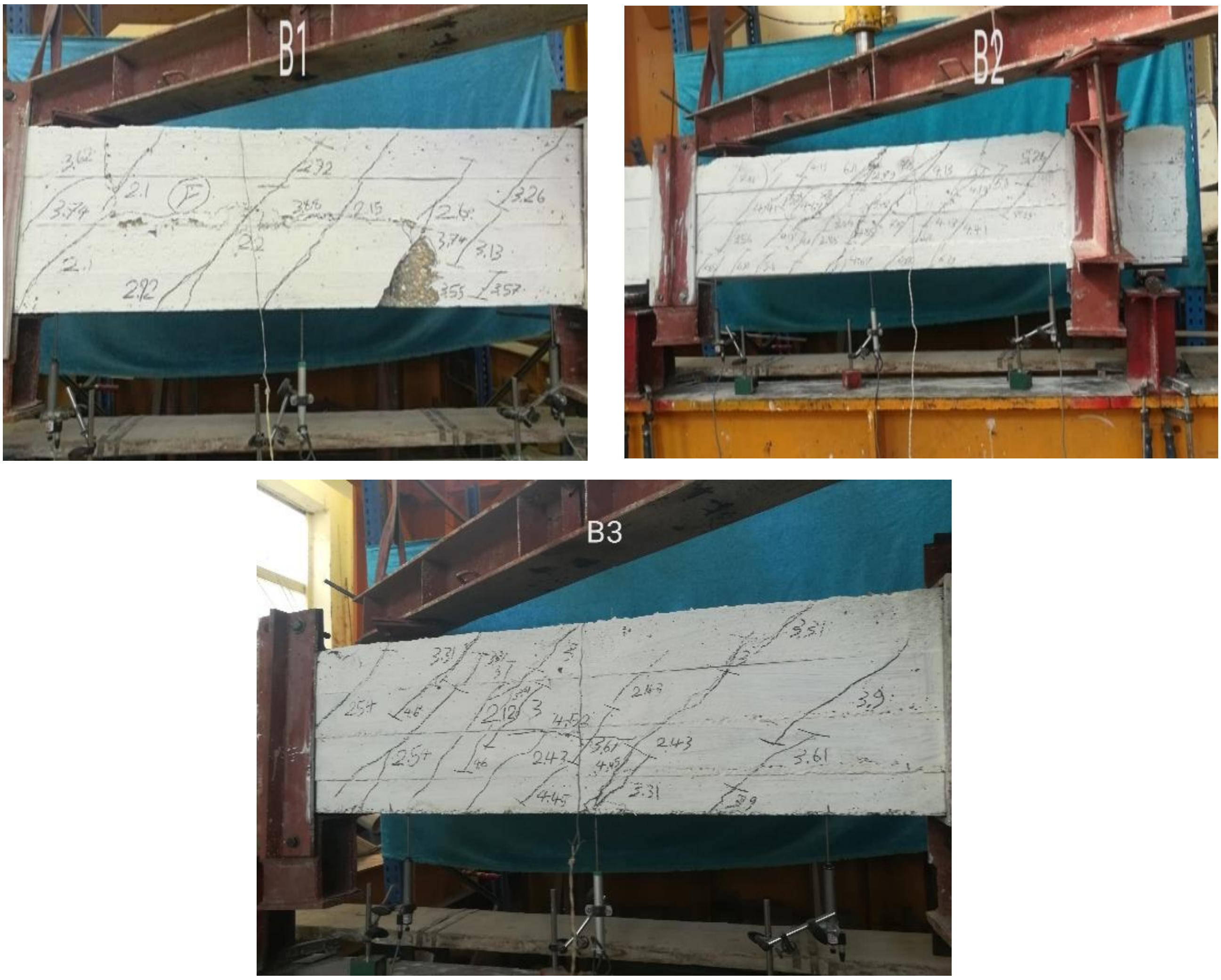

Figure (11): Tested beams at failure: B1, B2 and B3

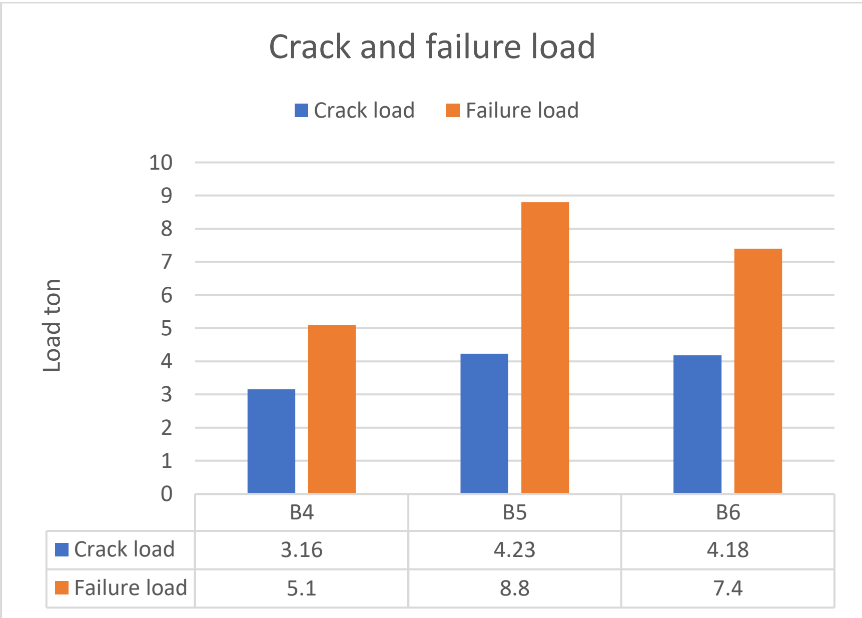

Figure (12): Crack and failure load for B4, B5 and B6

Figure (13): Tested beams at failure: B4, B5 and B6

3.3 Load-Strain

Figure (14) shows strain for bottom steel for B1, From the figure maximum strain in longitudinal bars was 1586×10^{-6} at a load of 40 KN. Figure (15) shows strain for bottom steel for B2, From the figure maximum strain in longitudinal bars was 2240×10^{-6} at a load of 71.7 KN. Figure (16) shows strain for bottom steel for B3, From the figure maximum strain in longitudinal bars was 2080×10^{-6} at a load of 56.8 KN. Figure (17) shows strain for bottom steel for B4, From the figure maximum strain in longitudinal bars was 970×10^{-6} at a load of 50 KN. Figure (18) shows strain for bottom steel for B5, From the figure maximum strain in longitudinal bars was 1580×10^{-6} at a load of 86.2 KN. Figure (19) shows strain for bottom steel for B6, From the figure maximum strain in longitudinal bars was 1090×10^{-6} at a load of 72.5 KN.

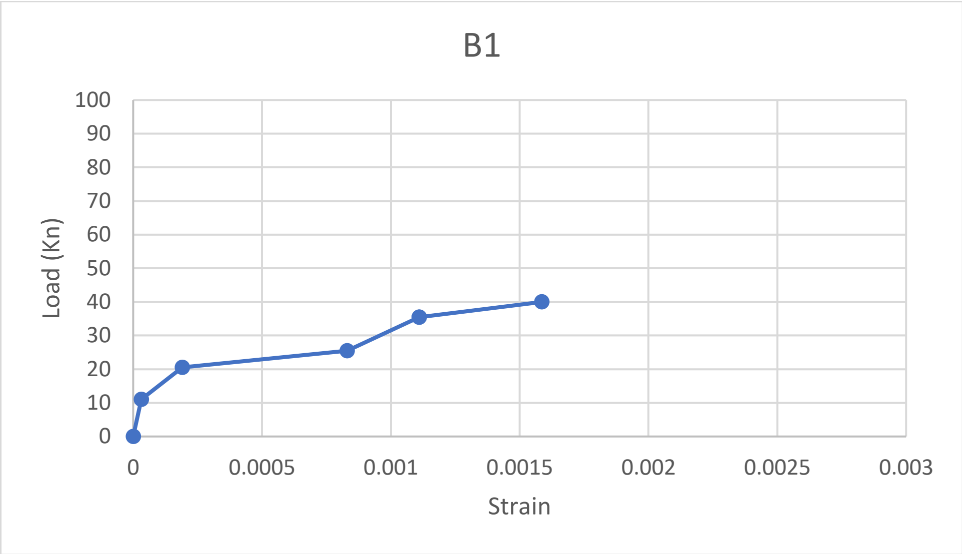

Figure (14): Load-Strain Curve for Bottom steel for B1

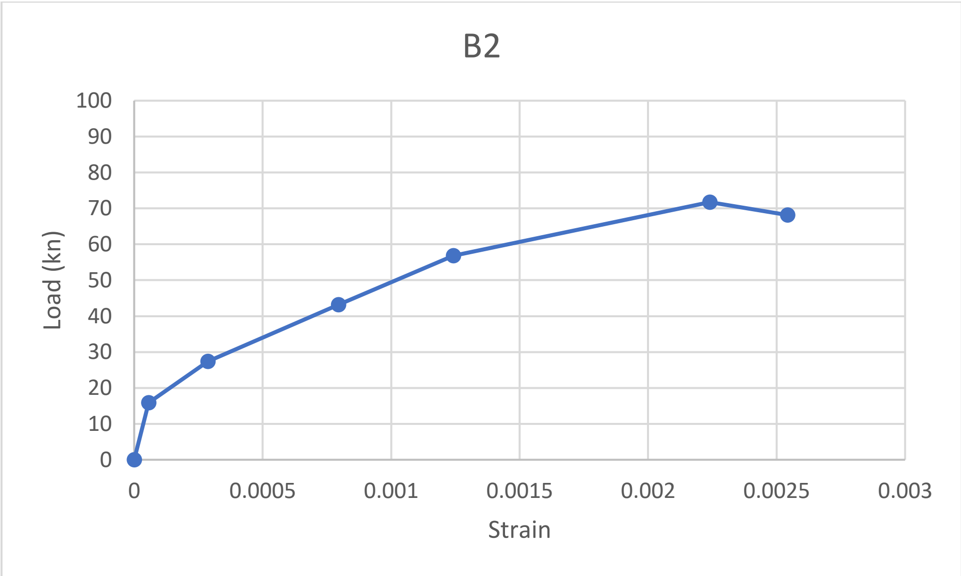

Figure (15): Load-Strain Curve for Bottom steel for B2

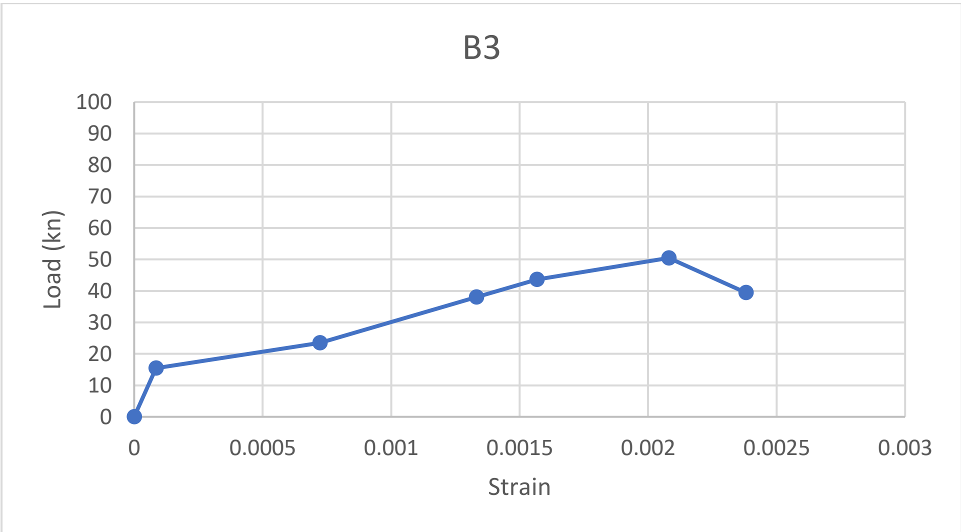

Figure (16): Load-Strain Curve for Bottom steel for B3

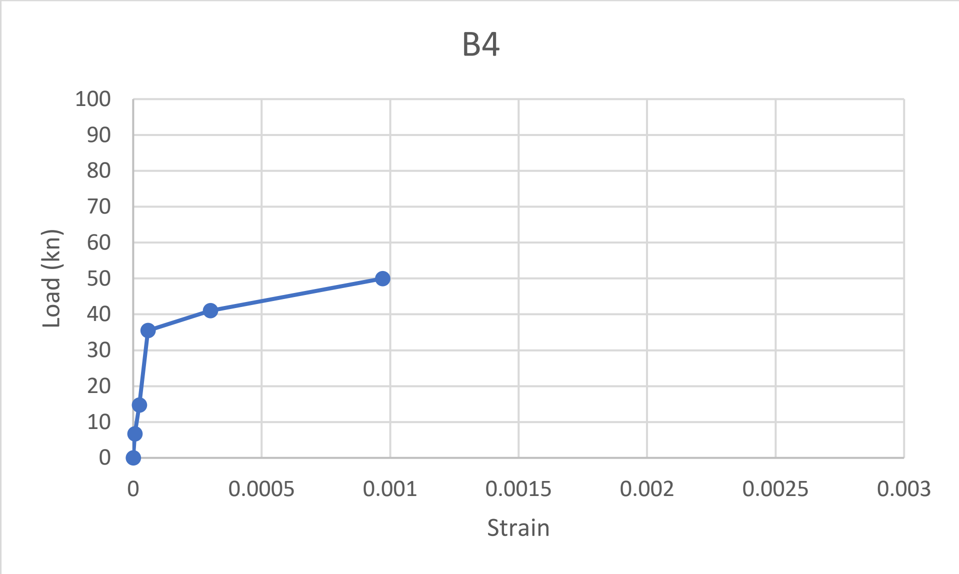

Figure (17): Load-Strain Curve for Bottom steel for B4

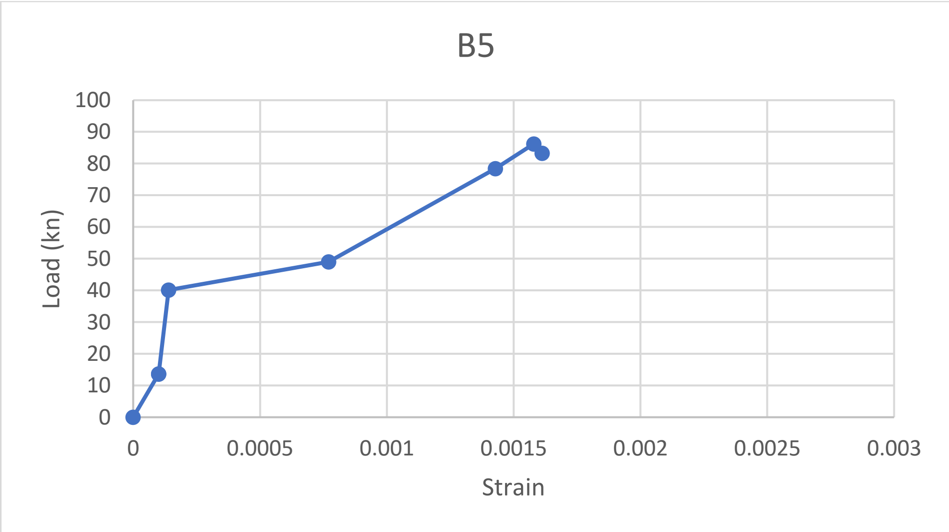

Figure (18): Load-Strain Curve for Bottom steel for B5

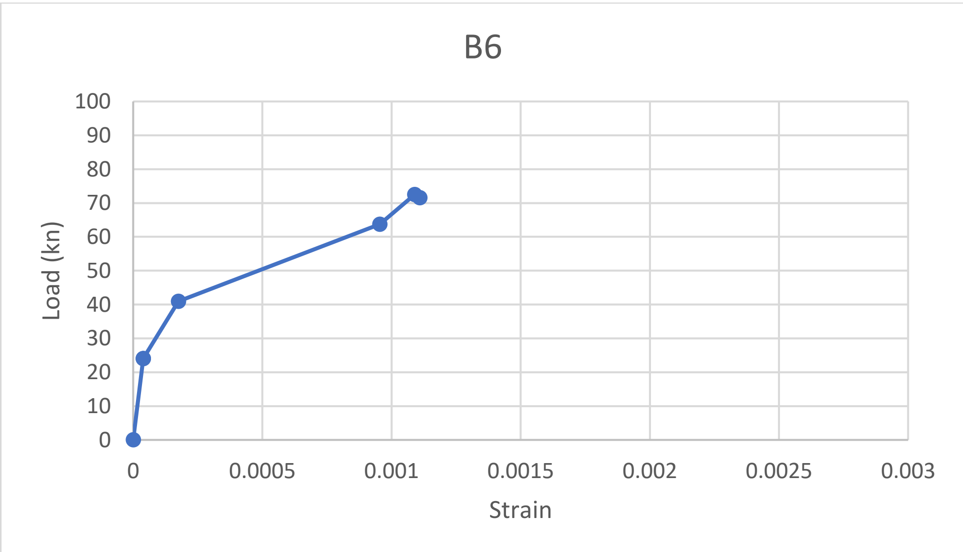

Figure (19): Load-Strain Curve for Bottom steel for B6

4. CONCLUSIONS

1. In a pure torsion test, adding steel fibers to RC beams increased the ultimate torsion strength of the specimens (B2), (B3), (B5), and (B6) by up to (75%), (38%), (72.5 %), and (45%), respectively.

2. In specimens subjected to torque force, the use of steel fiber reduces the angle of twist for beams (B2) and (B3) when compared to control beam ((B1) at the same load and decreases the angle of twist for beams (B5) and (B6) when compared to control beam (B4) at the same load.

3. Due to the steel fibers' ability to bridge cracks, the steel fiber-reinforced beams display various cracking mechanisms.

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