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Effect of stirrup, longitudinal reinforcement and steel fibers ratios on the torsional behavior of high strength concrete beams

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ABSTRACT

Many factors affect the torsional behavior of reinforced concrete beams, such as concrete strength, section dimensions, aspect ratio and concrete cover. Improvements in the torsional behavior of RC members had led researchers to investigate the effect of additional factors such as steel fibers, torsional reinforcement ratio and reinforcement arrangement. Based on the above, there is a gap in previous studies in taking effect of the distribution of stirrups with longitudinal reinforcement steel with steel fibers. Twenty-six reinforced concrete beams 250 mm wide, 250 mm high and 1150 mm long are investigated under pure torsion. Consider the effect of the steel fiber ratio, stirrup ratio and the longitudinal reinforcement ratio of high strength concrete. The results show the behavior of the concrete changing from brittle to ductile when increasing the ratio of the steel fiber registering the maximum torsional ductility index (3.98). The increase in the percentage of steel fiber to 6% caused a 105% increase in torque, but it was a slight increase in torque with respect to the percentage of steel fibers 2%. The optimum ratio of the steel fiber is 2% in terms of increased torque and workability, as it gave an increase in torque which reached 98.8%. Increasing the percentage of the stirrups to 2.5%, while the percentage of longitudinal reinforcement and the percentage of steel fiber was fixed, which led to an increase in torque which reached 130.4%. Increasing the percentage of the longitudinal reinforcement to 50%, while the percentage of stirrups and the percentage of steel fiber was fixed, which led to an increase in torque which reached 66.9%.

Keywords: Torsional Ductility Index, Stirrup, Ultimate Torque, Brittle Failure

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1. Introduction

Since 1960, the flexural behavior of reinforced concrete elements has been considered in theories [1]. Then the researchers started to study the behavior of R.C. elements under a combination of shear and torsion. In contrast, the use of high-strength concrete and the strengthening of R.C. members got popular. The effect of steel fibers and/or concrete cover on torsional behavior of hallow and/ or solid section was investigated by many research. Twelve hollow and solid square reinforced concrete sections were used by [2] to study the effect of steel fiber and concrete core on torsional behavior. They saw when increasing the steel fiber ratio to 2.5%, the torque increases by 98.2% for the solid section and by 91.3% for the hollow section. A model for the strength determination of steel fiber reinforced concrete beams was submitted by [3]. Their proposed model demonstrated good correlation with the test data collected. [4] were tested and compared the torsion behavior of conventional reinforced concrete beams with beams having steel fibers with 0.5%, 1%, 1.5% and 2%. [5] were investigated the torsional behavior of solid and hollow self-compacting reinforced concrete beams with 0%, 0.5%, and 1% steel fiber. In their results the torsional capacity was improved when the steel fiber ratio increased. [6] were introduced an alkali - activity concrete beams with fibers or conventionally reinforced. The fibers increase the cracking load of the beams by 20% in comparison with conventional reinforcement. The post-cracking ductility in the fiber beam was below the conventionally reinforced beam. [7] developed a twist moment cracking formula that takes into account the effect of steel fiber on lightweight concrete. They found that their formula was significantly better than the existing design codes.

[8] were studied on the torsional behavior of reinforced concrete with 0, 30, 60 kg/m3 of steel fiber for shearing, twisting and axial loading. Their results showed that the increase in the ratio of steel fibers resulted in an increase in the capacity of the torsional moment and a decrease in the shear capacity. Reinforced concrete with various types of fibers was examined by [9] to study torsion behavior. The results showed that it was possible to delimit the advances and gaps in the effect of the editing of reinforcement fibers in relation to the twisting of the structural elements. The impact of reinforcement ratios in longitudinal and transverse directions on the torsion behavior of reinforced concrete beams has been investigated by certain researchers. A method for estimating the ultimate strength of reinforced concrete beams under pure torsion was introduced in [10]. The quantity of transverse and longitudinal reinforcement was one of the characteristics selected. With 66 tests of the literature, they validated the method and discovered good agreement. An experimental investigation that looked at the torsional behavior of medium- and high-strength concrete beams with adjustable longitudinal and transverse reinforcing ratios was published in [11]. They observed that the longitudinal reinforcement ratio's impact was not as significant as the transverse reinforcement ratio. [12] investigated how reinforced concrete beams subjected to pure torsion were affected by the influence of two idealized shear zones. They discovered a 23.7 percent increase in torsional strength. [13] investigated the effects of longitudinal and transverse reinforcement on the torsional strength of reinforced concrete beams. They get to the conclusion that increasing torsional resistance with transverse reinforcement alone or longitudinal reinforcement alone is ineffective, but effective when increasing both at the same time. [14] By accounting for the torsional reinforcement ratio, the transverse-to-longitudinal reinforcement ratio, and the total reinforcement ratio, 18 high strength reinforced concrete beams were produced. They demonstrated that the required ratio of minimum torsional strength was insufficient to prevent a fast loss of strength. [15] examined the torsional behavior of reinforced concrete solid and hollow beams under various conditions. Torsional reinforcement ratio in comparison to ACI 318.19 codes was one of these variables. It was demonstrated that the torsional strength of the solid and hollow portions was comparable.

The effect of transverse reinforcement, compressive strength, and concrete cover on the torsional behavior of the reinforced concrete beams were taken by [1]. The results showed that the concrete cover has a very large effect on the ultimate capacity and torsional behavior of the beams. [16] derived the proposed torsional reinforcement ratio in relation to the equilibrium and compatibility of the transverse and longitudinal direction to predict the failure modes of the torsional elements. The results were compared with 98 torsional beams found within the literature. This ratio was found to be higher than those suggested by other research and design codes. [17] investigated the torsional behavior of the solid, hollow rectangular cross-section with variable pitch, angled spiral stirrups. The results showed that the solid section increased the torsional strength by 16% and the hollow section increased by 18%. Variable distribution of longitudinal reinforcement was taken in the model proposed by [18] which was based on equilibrium conditions and the lower – bound theorem of plasticity. They found that the model was very good relative to more than 200 experimental data from the literature on pure torsion reinforced concrete elements. Recycled aggregates and the number of transverse reinforcements were the main parameters chosen by [19] for reinforced concrete beams. the percentage of recycled aggregates and the number of transverse reinforcements were examined. Torsional response and crack behavior were studied.

Strengthening reinforced concrete elements with different materials such as CFRP, GFRP, aramid fibers and ferrocement have been studied by many researchers. [20, 21] were examined the effect of the wrapped CFRP on the torsional behavior of the torsional reinforced concrete beams. They concluded that the U - wrapped were less effective than full wrapped and full stirrups. In addition, the post-peak strength, cracking behavior, and torsional stiffness were like those of the reinforced concrete beams. [22] tried to improve the torsion behavior of reinforced concrete beams by reinforcing with aramid fiber strips. The findings showed that the fiber increased the ultimate strength of the beams by 140%. [23] carried out a comprehensive review and evaluation of the torsional strength of FRP reinforced concrete beams. Reinforced concrete beam reinforcement with CFRP was tested under shear and torsion by [24]. The torsional behavior of box section was examined. The results showed that the U-shape reinforcement - was the best to improve the torsion capacity of the beams. High strength concrete has also been studied extensively on torsion reinforced concrete beams.[25] showed different types of behavior of pure torsional high strength hollow sections. The results showed an unexpected failure which did not allow the beams to achieve maximum resistance. To investigate the torsional behavior of the torsional beams, [11] transported medium and high strength concrete beams. In the current study, 26 high strength reinforced concrete beams with solid sections were subjected to pure torsion, and their torsion behavior was examined in relation to the volume fraction of steel fibers (VF) and the ratio of longitudinal and transverse steel reinforcement.

2. Research method

The study included three groups of reinforced concrete beams with the dimensions and details indicated in Table 1 and Figure (1), to study the torsional behavior of concrete beams under pure torsion. All beams have the same dimensions (250 mm wide, 250 mm high, and 1150 mm long). The same concrete cover (20 mm) is used for all specimens. The first group consisted of 12 beams with 4 Ø 12 mm longitudinal reinforcement and Ø8 mm@100 mm stirrup, the steel fiber ratios of this group are (0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.5, 4.0, and 6.0%).

The second group included six beams with 4 Ø 12 mm longitudinal reinforcement and stirrups of Ø 8@ 150 mm, with the steel fiber with ratios of (0, 0.5, 1.0, 1.5, 2.0, and 6.0%). The third group with six beams has 2Ø12 mm longitudinal strengthening and stirrups of Ø8@ 100 mm, the steel fiber ratios used in this group are (0, 0.5, 1.0, 1.5, 2.0, and 6.0%). The beams (B1, B13, and B19) with steel fiber of (0%) represent the reference beams in each group. An additional beam is used to study the effect of the stirrups. Beam B25 reinforcement include 4 Ø 12mm longitudinal and stirrups Ø 8@ 60mm, while beam B26 reinforcement contain 2 Ø 12mm longitudinal at the top and 3 Ø 12mm longitudinal at the bottom with stirrups of Ø 8@ 100mm.

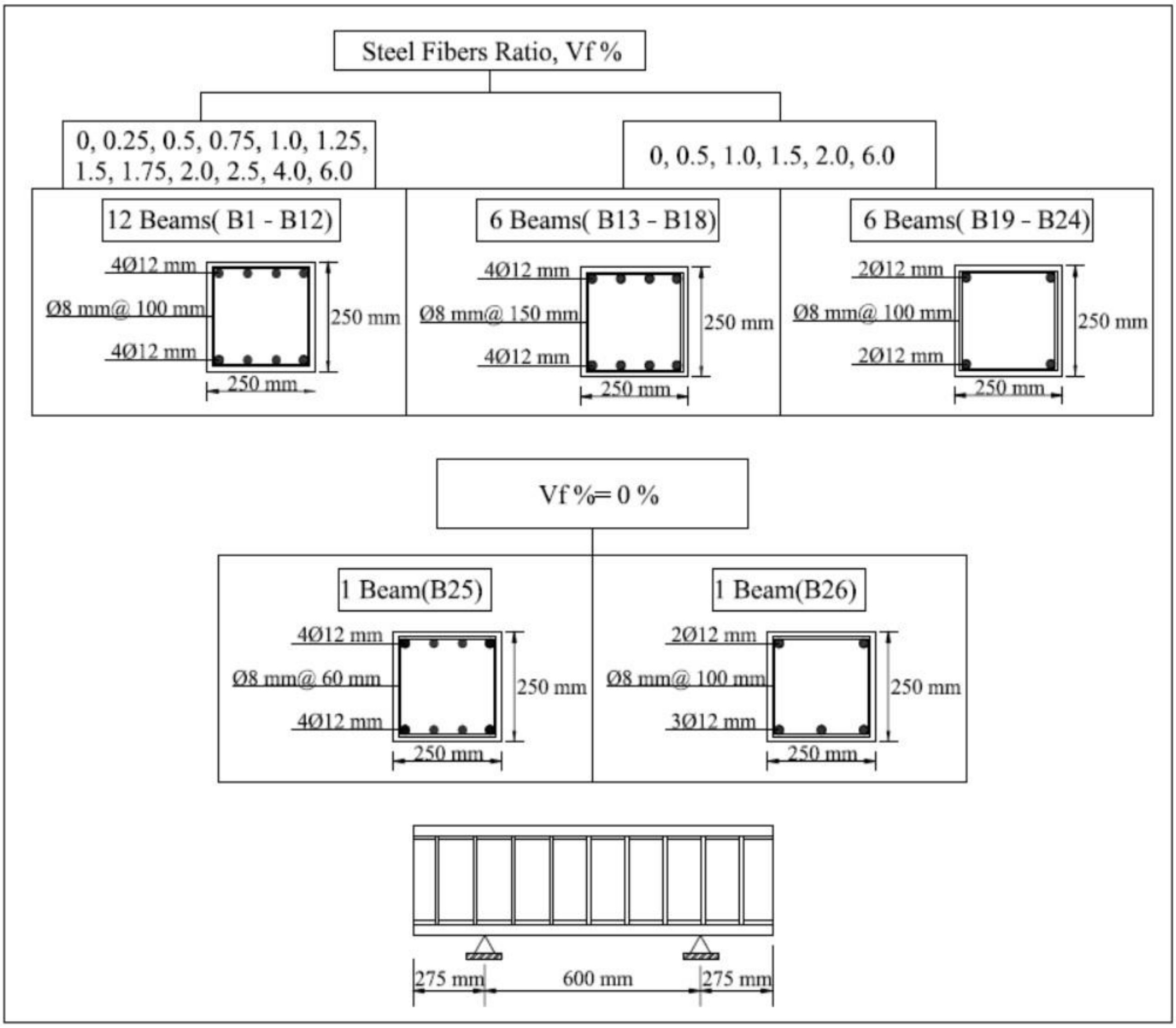


Figure 1. Details of experimental work

Table 1. Details of the specimens

Group No.	Beam No.	Vf %	Top reinforcement	Bottom reinforcement	Stirrup
1	**B1**	0	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B2	0.25	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B3	0.5	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B4	0.75	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B5	1	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B6	1.25	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B7	1.5	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B8	1.75	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B9	2	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B10	2.5	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B11	4	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
	B12	6	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 100 mm
2	**B13**	0	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 150 mm
	B14	0.5	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 150 mm
	B15	1	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 150 mm
	B16	1.5	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 150 mm
	B17	2	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 150 mm
	B18	6	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 150 mm
3	**B19**	0	2 Ø 12 mm	2 Ø 12 mm	Ø 8 mm @ 100 mm
	B20	0.5	2 Ø 12 mm	2 Ø 12 mm	Ø 8 mm @ 100 mm
	B21	1	2 Ø 12 mm	2 Ø 12 mm	Ø 8 mm @ 100 mm
	B22	1.5	2 Ø 12 mm	2 Ø 12 mm	Ø 8 mm @ 100 mm
	B23	2	2 Ø 12 mm	2 Ø 12 mm	Ø 8 mm @ 100 mm
	B24	6	2 Ø 12 mm	2 Ø 12 mm	Ø 8 mm @ 100 mm
	B25	0	4 Ø 12 mm	4 Ø 12 mm	Ø 8 mm @ 60 mm
	B26	0	2 Ø 12 mm	3 Ø 12 mm	Ø 8 mm @ 100 mm

2.1. Specimen's material

High strength concrete HSC with compressive strength of (77.84 MPa) is used to cast the specimens with ordinary Portland cement, sand and gravel to meet the ASTM C150 and C33[19, 20]. Table 2 illustrates the selected mix design. Table 3 shows the chemical and physical parameters of the sand and gravel utilized in this study. A superplasticizer (Viscocrete Pc20) with qualities listed in Table 5 (as specified in the manufacturer's sheet) is employed at a percentage of 1.2. As longitudinal and transverse reinforcement, deformed bars of various diameters (12 mm and 8 mm) are utilized. Table 6 and Figure 2 show the characteristics and the shape of the hooked steel fibers used in the experiment.

Table 2. Mix properties of the HSC

Mix number	Super plasticize%	Cement content (Kg/m3)	Mix proportion (By weight)	Water cement ratio (By weight)	Slump (mm)	f'c 7-day (MPa)	f'c 28-day (MPa)
Mix 1	0.7	540	1:1:2.1	0.3	150	44	70.3.4
Mix 2	1.2	548	1:1:2.1	0.28	150	48	77.84

Table 3. Chemical and physical properties of cement

Composition	(%)	Limit of ASTM	Physical property	Test result	Limit of ASTM
(CaO)	64.83		**Setting time Vicat apparatus, hr.: min**		
AL2O3	5.4	6.0 (max.)			
SiO2	23.54				
Fe2O3	2.62	6.0 (max.)	**Initial**	00:59	00:45
SO3	2.15	3.0 (max.)	**Final**	05:10	06:25
MgO	3.21	6.0 (max.)			
(K2O)	0.61		**Compressive strength (70.7mm cube), MPa**		
(Na2O)	0.25				
(L.O.I)	0.74	3.0 (max.)			
(I.R)	0.55	0.75 (max.)			
(L.S.F)	0.93		**3-day**	20.7	7 (min.)
Compound of Cement			**7-day**	29.3	12 (min.)
C3S	38.52				
C2S	33.62				
C3A	7.23	8.0 (max.)			
C4AF	7.93				

Table 4. Specifications of sand and gravel

Sand			Gravel		
Sieve size	**Passing %**	**Limit of ASTM C33[27]**	**Sieve size, in. In**	**Passing % %**	**Limit of ASTM C33[27]**
No. 8	100	100	**2**	100	100
No. 4	95	95-100	**1.5**	98	90-100
No. 8	83	80-100	**3/4**	63	40-70
No.16	64	50-85	**3/8**	12	0-15
No. 30	44	25-60	**3/16**	2	0-5
No. 50	16	5-30	**Pan**	0	
No. 100	6	0-10	**F.M.**	7.1	
F.M.	2.7		**M.A.S**	1.5 in.	
A.S.S.	**No.30**				

Table 5. Viscocrete Pc20 properties

Viscous liquid	**Form**
Appearance/Colors	Light brownish liquid
Chemical Base	Modified polycarboxylates based polymer
Density	1.09-1.13kg/l, at 20oC
pH Value	3-7
Soluble in Water Chloride Ion Content % w/w	Max 0.1% Chloride-free
Effect on Setting	Non-retarding
Effect of Overdosing	Bleeding may occur

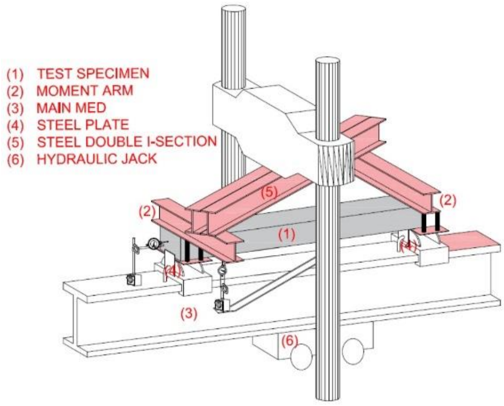
Table 6. Properties of steel fibers

Fiber Type	**Shape**	**Length, mm**	**Diameter, mm**	**Aspect Ratio, mm**	**Tensile Strength, MPa**
Hooked Steel Fiber	Hooked	30	0.5	60	> 1000

Figure 2. Hooked steel fibers

2.2. Experimental setup

A torsional test setup was installed and attached to the test equipment, as shown in Figure (3), to conduct the torsional test. A steel I-section is attached to the specimen using bolts. A moment arm made of steel I-section creates the twisting moment. The reinforced concrete (RC) Beam is simply supported at both ends. linear variable differential transformers (LVDT) were attached to both ends of the steel I-section to estimate the twist angle. As illustrated in Figure (3b), these gages are positioned on the bottom sides of the steel I-section (90 mm from the start of the specimen). The average is used to measure the twist angle. In addition, two LVDT are attached horizontally at either end of the sample to detect axial displacement, as illustrated in Figure (3b).



a

b

Figure 3. Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

3. Results discussion

The effect of steel fiber and reinforcing ratio in longitudinal and transverse directions on the torsion behavior of RC beams is examined using 26 beams. 11 steel fiber ratios are used to reinforce 11 beams (B2-B12), and they are compared to the reference beam B1. Five beams (B14–B18) that have five percentages of steel fiber added to them are compared to reference beam B13. The final step involves strengthening five beams (B20-B24) in five steel fiber ratios and comparing them to reference beam B19. Beam B25 strengthened with longitudinal reinforcement of 4 12 mm and stirrup of 8 mm @ 60 mm, both of which contain zero percent steel fiber. Additionally, Beam B26 with no steel fiber, but reinforced with 2 Ø 12 mm at top and 3 Ø 12 mm at bottom as a longitudinal reinforcement and Ø 8 mm @ 100 mm as stirrup. Results for all groups are shown in Table 7.

Table 7. Result of the test

Group No.	Beam No.	Vf%	Ty, kN.m	Øy, deg.	Tu, kN.m	Øu, deg.	Ductility* Index	increase in ductility %	increase in Ty %	increase in Tu %
1	**B1**	0	11	3.5	23.7	11.5	3.3	0	0	0
	B2	0.25	14	3.65	24	12.6	3.45	5.06	27.3	1.3
	B3	0.5	15	3.75	25	13.6	3.63	10.38	36.4	5.5
	B4	0.75	17.2	4.24	28.9	15.5	3.66	11.26	56.4	21.9
	B5	1	20.7	4.38	29.6	16.1	3.68	11.87	88.2	24.9
	B6	1.25	21.9	4.51	30.1	16.8	3.73	13.37	99.1	27.0
	B7	1.5	23.9	4.64	31	17.4	3.75	14.13	117.3	30.8
	B8	1.75	25.3	4.69	31.28	17.7	3.77	14.86	130.0	32.0
	B9	2	25.6	4.84	32.7	18.4	3.80	15.58	132.7	38.0
	B10	2.5	25.9	4.85	33.6	18.6	3.84	16.72	135.5	41.8
	B11	4	28	4.95	34.1	19.4	3.92	19.28	154.5	43.9
	B12	6	28.6	5.00	34.15	19.9	3.98	21.13	160.0	44.1
2	**B13**	0	8.7	3.7	16.1	10.8	2.92	0	0	0
	B14	0.5	11.9	3.85	22.08	11.7	3.04	4.11	36.8	37.1
	B15	1	17.9	3.95	26.99	12.9	3.27	11.88	105.7	67.6
	B16	1.5	18.2	4.05	29.49	13.6	3.36	15.04	109.2	83.2

Group No.	Beam No.	Vf%	Ty, kN.m	Øy, deg.	Tu, kN.m	Øu, deg.	Ductility* Index	increase in ductility %	increase in Ty %	increase in Tu %
	B17	2	19.9	4.25	32	14.7	3.46	18.50	128.7	98.8
	B18	6	23.7	4.35	33	16.1	3.70	26.80	172.4	105.0
3	**B19**	0	6.4	3.95	14.2	10.8	2.73	0	0	0
	B20	0.5	11.1	4.1	20.2	11.9	2.90	6.15	73.4	42.3
	B21	1	12.9	4.25	24.1	12.9	3.04	11.01	101.6	69.7
	B22	1.5	15.9	4.28	27.5	13.3	3.11	13.65	148.4	93.7
	B23	2	21.9	4.55	28.1	14.7	3.23	18.16	242.2	97.9
	B24	6	22.8	4.75	28.9	16	3.37	23.20	256.3	103.5
	B25	0	21.1	5.4	37.1	19.6	3.62	10.47†	91.8†	56.5†
								24.35‡	142.5‡	130.4‡
	B26	0	11.6	4.1	18.2	10.9	2.69	-19.09†	5.5†	-23.2†
								-21.93⁑	81.3⁑	28.2⁑

* Torsional Ductility Index equal to Ultimate Twist Angle / Yielding Twist Angle [28]
† Increase with respect to B1,
‡ Increase with respect to B13,
⁑ Increase with respect to B19

3.1. Effect of steel fiber

Figures 4, 5, and 6 show the effect of steel fibers as a relation between the twist angle and applied torque for groups 1, 2, and 3, respectively. In terms of the presence of steel fibers, all beams behaved similarly. In contrast, raising the steel fiber ratio from 0% to 6% increases the torque and angle of rotation. As shown in Table 7, for groups 1, 2, and 3 the maximum increase in yielding torque was 160%, 172.4%, and 256.3%, respectively. At the same time, the maximum increase in ultimate torque was 44.1%, 105%, and 103.5% for groups 1, 2, and 3, respectively. The increase in the ratio of steel fibers caused the concrete to transform from brittle to ductile behavior. Figure 7 illustrates the relationship between steel fibers' ratio to the groups' cracking torque. The cracked torque increases as the ratio of steel fibers increases. As demonstrated in Figure 7, group 1 has the best behavior compared to groups 2 and 3, with a cracking torque of 18.28 kN.m at a steel fiber ratio of 6%. It was also noticed that when the percentage of steel fibers increased, the cracks changed from single cracks to branching cracks. Figures 8, 9 and 10 illustrate the crack propagation within groups. The increase in the steel fibers ratio increases the concrete compounds' cohesiveness.

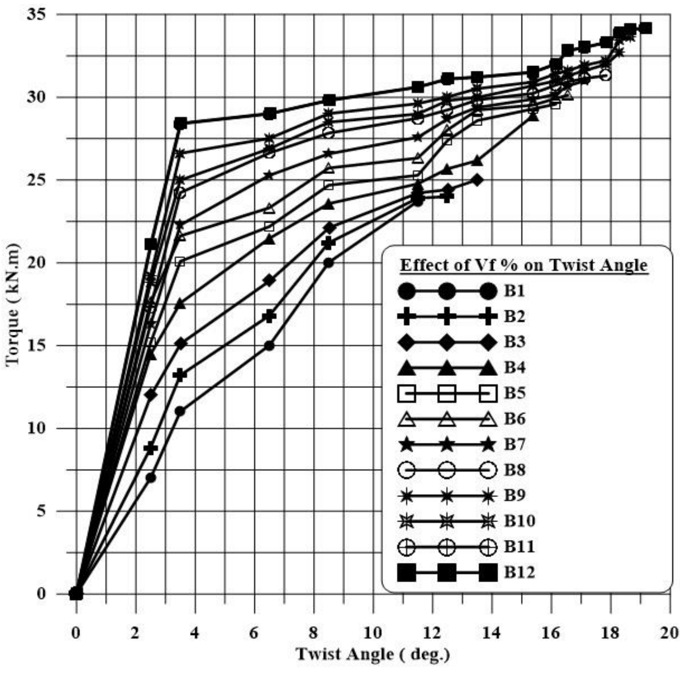


Figure 4. Twist angle verse torque of group 1

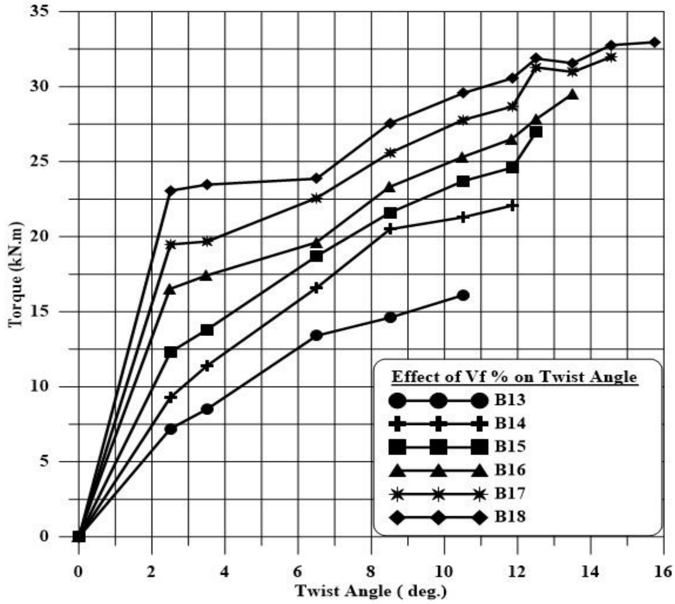


Figure 5. Twist angle verse torque of group 2

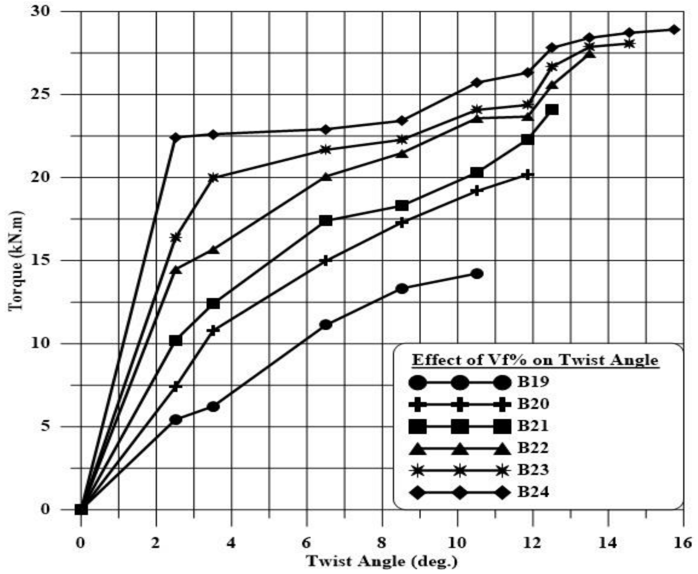


Figure 6. Twist angle verse torque of group 3

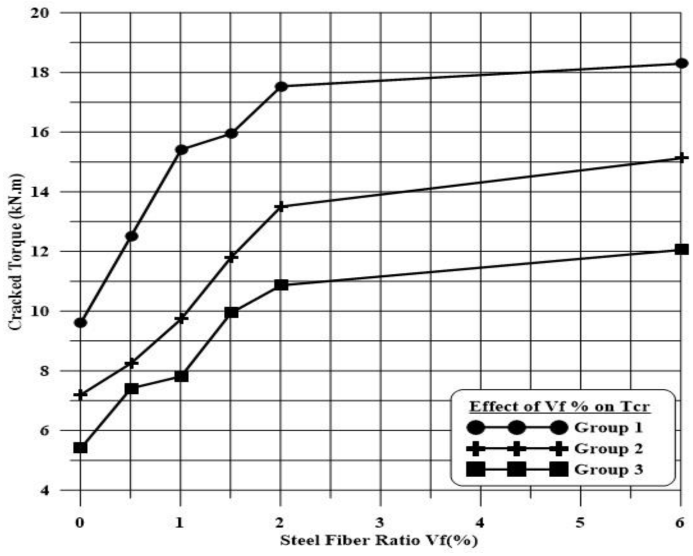


Figure 7. Twist angle verse cracked torque

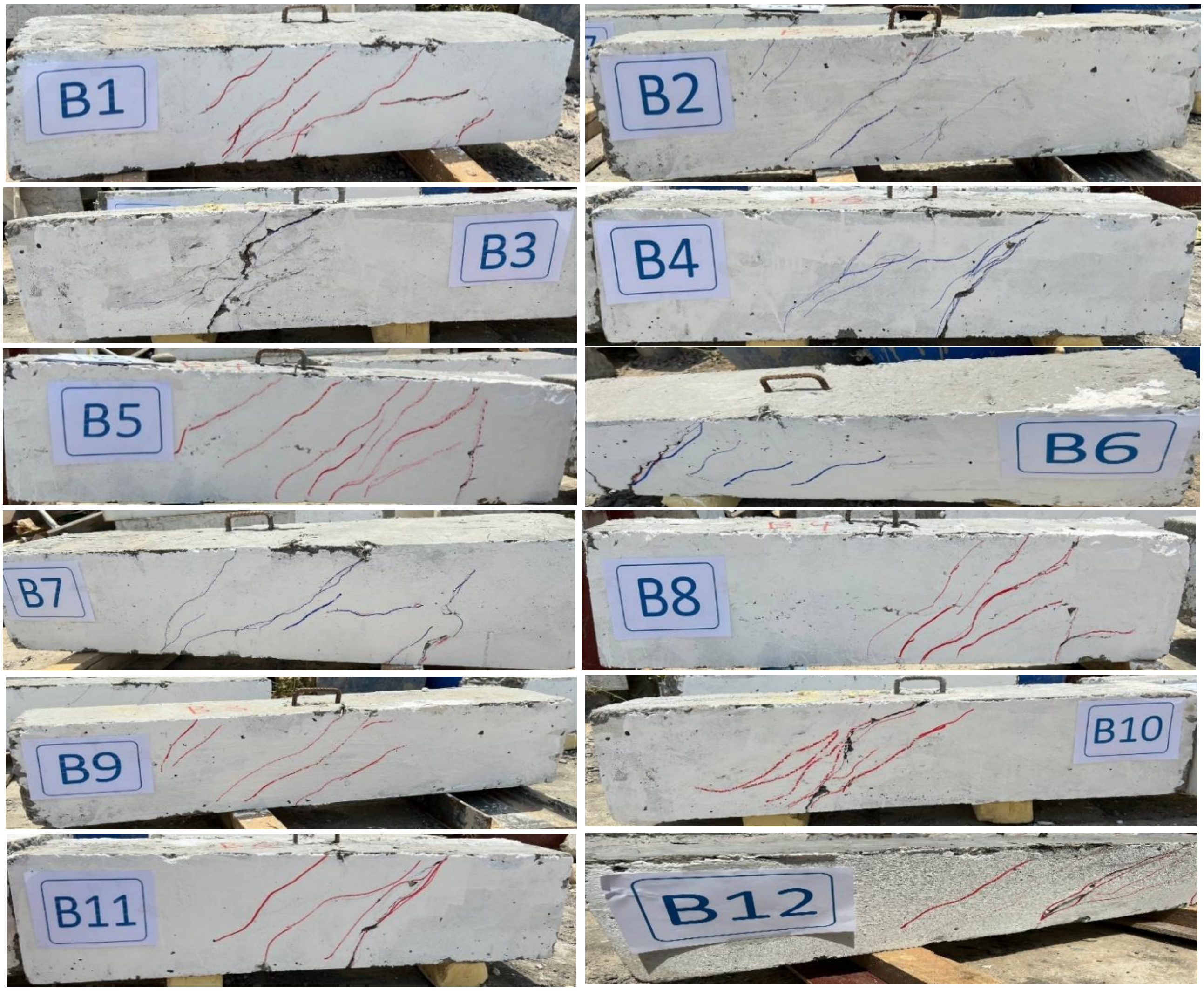


Figure 8. Crack pattern for group 1

Figure 9. Crack pattern for group 2

Figure 10. Crack pattern for group 3

3.2. Transverse and longitudinal reinforcement effect

Figures 11 and 12 show the effects of reinforcement on the longitudinal and transverse directions. Beams B1, B13, and B25 highlight the stirrups effect. These beams have the same longitudinal reinforcement (4Ø12mm) at the top and the bottom while changing the stirrups Ø8mm distribution at 100mm, 150mm, and 60mm for B1, B13, and B25, respectively. The longitudinal reinforcement effect is represented by beams B1, B19, and B26. The stirrups on the beams (B1, B19, and B26) are the same (Ø8mm @ 100mm), and the longitudinal reinforcements are changed, as presented in Figure 1 and Table 1. Figure 11 depicts the influence of stirrups on ultimate torque and twist angle, whereas Figure 12 depicts the effect of longitudinal reinforcement on the torque and twist. Generally, as the percentage of steel fibers increases, the cracks appear late. Also, the first group is the best in this regard. Cracks emerged wider in the second group than in the first, which could be attributed to the reduced transverse steel reinforcement ratio in the second group. The failure was faster, and fractures formed quickly in the third group due to the lowered longitudinal reinforcement ratio. Also, as seen in Figure 11, the ultimate torque increased as the proportion of stirrup area increased. Beam B25 outperformed beams B1 and B13, with ultimate torque increases of 56.5 % and 130.4 %, respectively, and torsional ductility index improvements of 10.47 % and 24.35 %, respectively. Figure 12 depicts the influence of longitudinal reinforcement on torsional behavior, demonstrating that as the fraction of longitudinal reinforcement increases, so does the ultimate torque. So, beam B26 showed apparent decrease in the ultimate torque compared to beams B1 and 19. The ultimate torque of beam B26 was reduced by 23.2 % and 28.2 %, compared to beams B1 and 19. Similarly, the torsional ductility index of beam B26 was reduced by 19.09 % and 21.93 %, compared to beams B1 and 19.

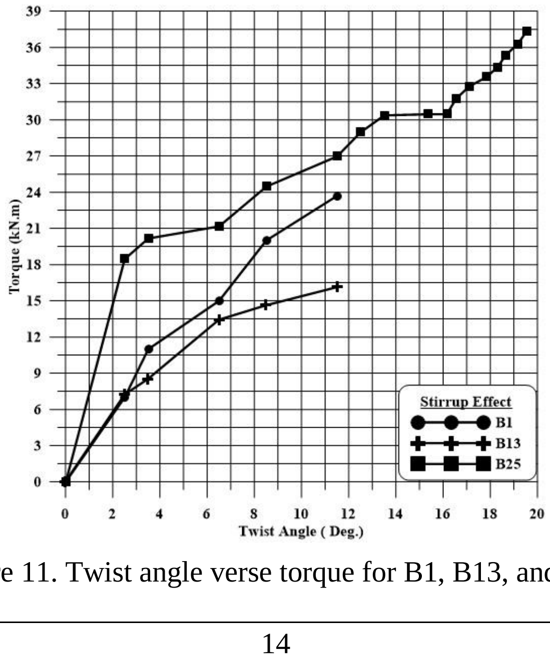


Figure 11. Twist angle verse torque for B1, B13, and B25

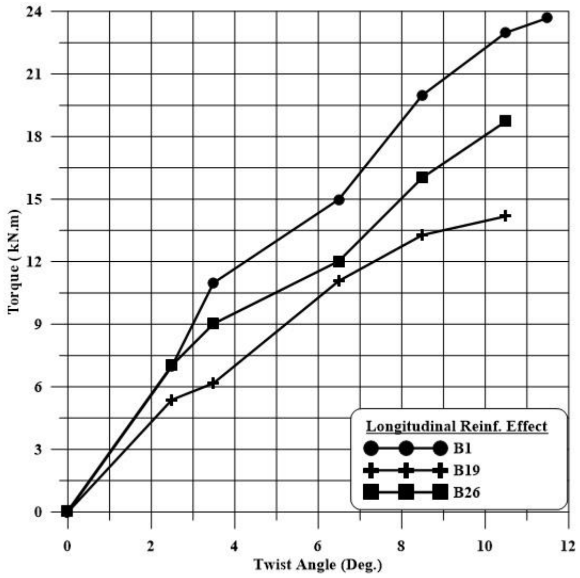


Figure 12. Twist angle verse torque for B1, B19, and B26

3.3. Torsional ductility index

The torsion ductility index as cited by [28] is used in this study and defined as follows:

$$\textbf{Torsional Ductility Index} = \frac{\textbf{Ultimate Twist Angle}}{\textbf{Yielding Twist Angle}}$$

The ductility index improves when the steel fibers ratio increases, as demonstrated in Figure 13. According to Figure 13 and Table 7, the most significant improvement in the torsional ductility index (26.8 %) was obtained in group 2 beam B18 with a steel fibers ratio of 6% and an ultimate torque of 33 kN.m. At the same time, the maximum torsional ductility index (3.98) was recorded in beam B12 with ultimate torque of (34.15 kN.m). This behavior validates the conclusion obtained; that is, as the fraction of steel fibers increases, the RC behavior changes from brittle to ductile.

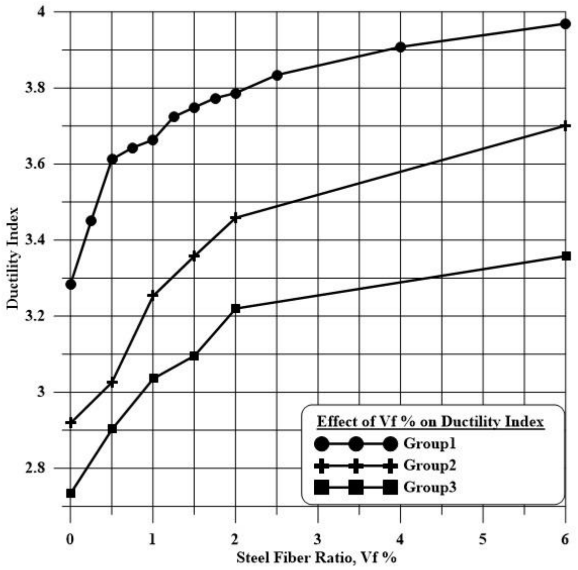


Figure 13. Steel fiber ratio verse ductility index

4. Conclusions

Based on the finding, the following can be concluded:

- As the steel fiber ratio rises, reinforced concrete's brittle characteristic becomes ductile.
- Increasing the steel fibers ratio while keeping the longitudinal or transverse reinforcement ratio constant resulted in an increase in the ultimate torque ratio. The increase in ultimate torque ratio was 44.1%, 105% and 103.5% compared to the reference beams B1, B13 and B19 for the three groups, respectively.

- The ultimate torque has increased due to an increase in the ratio of transversal reinforcement while the ratio of longitudinal reinforcement and steel fibers remains constant. This increase reached 10.47% and 24.35% compared to B1 and B13, respectively.
- The ultimate torque rose as the longitudinal reinforcement ratio increased while the stirrups and steel fibers remained constant. In comparison to reference beam B1, the ultimate torque ratio decreased by 23.2% when the stirrup proportion in beam B26 was reduced.
- As the proportion of steel fiber increased, the torsional ductility index also increased. In comparison to the reference beam B1, the torsional ductility index and the ultimate torque for beam B18 (steel fiber ratio 6%) increased by 26.8% and 105%, respectively.
- The ideal value, which is 2 percent steel fiber ratio, may be applied. A rise exceeding this threshold had no influence on the beam's ability to withstand torsional forces.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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