Behavior of Hollow and Solid Section of Reinforced Concrete Beams under Pure Torsion Strengthened by Steel Fiber

Mazen D. Abdullah

Civil Engineering Department, Basrah University, Basrah, Iraq

mazend081@gmail.com

Submission date:- 11/6/2018	Acceptance date:- 12/9/2018	Publication date:- 12/11/2018

Abstract

Twelve of reinforced concrete beams, with (hollow and Solid) square section tested under pure torsion, with dimensions of 160 mm height and 1000 mm length. The effects of steel fiber percentage and concrete core on ultimate torsional were studied, as well as the crack torsional capacity and angle of twist. For solid section an increase of 98.2% and 178%, and for hollow section an increase of 91.3% and 163%in the ultimate and crack torsional capacity respectively obtained when steel fibers percentage was increasing from zero to 2.5%.Transverse and longitudinal reinforcement ratios were kept constant. Experimental study showed that, the ultimate torsional strength and beam elongation were not affected by concrete core.

Key Words: VF: Fibers, Volume, Tcr: Cracking torque, Tu: Ultimate torque.

1. Introduction

Torsion may occurs when the external loads turn far from the bending vertical plane causing the beam twisted from its longitudinal axis together with bending moment and shear force.

There are two types of torsions. The first one is called statistically determinate, and the second one is called statistically indeterminate. Fig 1 show example of beam that is subjected to torsion. One way of getting torsion is by reinforcing a slab or a beam on one side only. The other way is by projecting loads that can turn far away from the diagonal to the longitudinal axis of the beam. Sometimes, diagonal tensions, which leads to diagonal cracking, are created because of the shear stresses. A sudden failure happens when the member is not supported sufficiently for the torsion[1].

Allawi [2] presented an experimental study of RC beams strength by CFRP in torsion. The study showed that an increase of ultimate torque between 90% and 84% depending on the pattern of strengthen. For hollow and solid sections in RC beams the cracking torque increase of 130% and 81% respectively, especially when the beam reinforced in the form of nonstop packaging.

Al-Mahaidi [3] presented a numerical and experimental study of torsion strength of box and solid section RC beams. In this study, the CFRP laminates have been used. The study recorded an increase of ultimate and cracking strength up to 78% and 40% respectively.

2. Test Program

Twelve RC beams have been tested in this experimental part. They were used under pure torsion with hollow and solid sections. These beams are supported with 1000 mm length, 300 mm width and 300 height as shown in Fig 2.

Solid and hollow cross section has been used for the test beam in order to evaluate the effect of cross section on the torsional strength of RC beams.

This study mainly focuses on the effect of beam types and volume fraction of fibers (VF) on the torsional capacity of the beam. Six values of (VF) (0%, 0.5%, 0.75%, 1.75%, 2% and 2.5%) were used in this study to check the impact of (Vf) on the torsional strength of RC beams.

The researcher depends on using identical sizes of steel supporting bars in the beams under test. As longitudinal reinforcement, deformed bars of size φ12mm were used. On the other hand, for closed loops a (φ 8) mm size deformed steel bars were used, as shown in Fig 3-a and Fig 3-b.

Steel fibers used were of length 11 mm and of a diameter of 0.155 mm where the aspect ratio was 75 Fig 3-C. In a concrete mixes super plasticizer known as PC-260 was used [4].

The researcher used a special clamping loading frame on both sides of beam. As shown in Fig 4, the frame, which is made of 16 mm steel plate having two shafts made of steel and attached by screws, involves two arms represented by two large steel clamps. These arms are used to apply torque with separated faces connecting them with four large bolts for each arm over the sample.

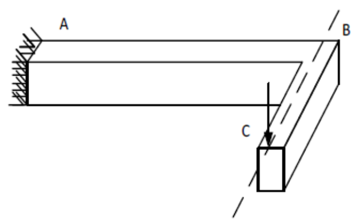


Fig. (1): Reinforced concrete members subjected to torsion:

The aim of the study is to investigate the influence of beam types hollow or soiled section) and different volume fraction of fibers on torsional capacity of beam. In casting the beams six values of (VF) (0%, 0.5%, 0.75%, 1.75% ,2% and 2.5%) were used to study the effect of (Vf) on torsional strength of RC beams.

3. Materials

Ordinary Portland in Iraq of united cement component (UCC) as trade mark was used in casting all the specimens Table (1,2).Coarse and fine aggregate meet the requirements of ASTM C33-03[5]and Iraqi specification No. 45/1984 [6]were used. Grading of fine and coarse aggregates are presents in Table(3).

Two sizes of steel reinforcing bars were used in the tested beams, deformed bars of size φ12mm were used as longitudinal reinforcement, and deformed steel bars of size (φ 8)mmwere used as closed stirrups, as shown in Fig 3-a and 3-b.

Straight brass coated steel fibers 11 mm long with a diameter of 0.155 mm and an aspect ratio of 74 were used throughout the experimental program, Fig 3-c.

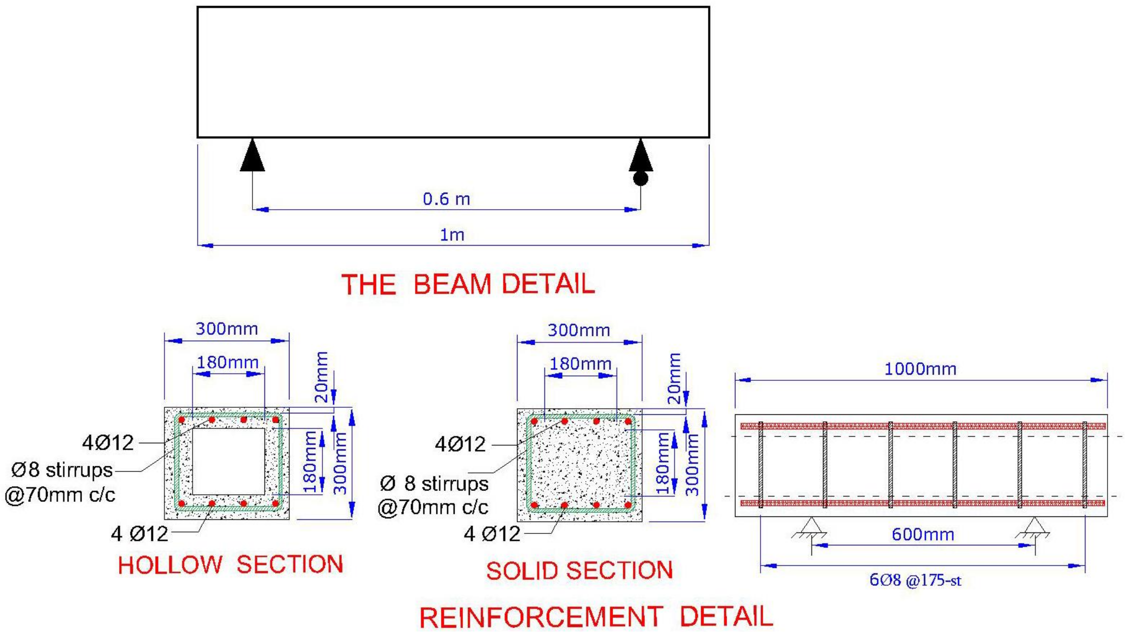


Fig. (2): Top and Side Views of Beam Specimen

Table1: Chemical properties of cement.

Composition ofcement	(%)	Specificationlimit (IQS,5/1984)[23]
(CaO)	62.83	
AL_2O_3	5.4	
SiO_2	22.54	
Fe_2O_3	2.64	
SO_3	2.45	2.8%
MgO	3.23	5%
(K_2O)	0.62	
(Na_2O)	0.24	
(L.O.I)	0.71	4.00 (Max.)
(I.R)	0.57	1.50 (Max.)
(L.S.F)	0.91	0.66-1.02
compoundofcement		
C_3S	38.51	31.03-41.05
C_2S	33.65	28.61–37.9
C_3A	10.21	11.96-12.3
C_4AF	7.93	7.72-8.02

Table2: physical properties of cement.

Physical property	Test results	Limit of I.Q.S No. 5/1984
Setting time (Vicat apparatus), hr:min Initial Final	00:57 8:35	00:45 (Min.) 10:00 (Max.)
Compressive strength (70.7mm cube), MPa 3-day 7-day	19.7 26	15 (Min.) 23 (Min.)

Table (3): Grading of the coarse and fine aggregate used

Coarse aggregate			Fine aggregate		
Sieve Size mm	Passing (%)	ASTM C33 limits	Sieve Size mm	Passing (%)	ASTM C33 limits
25	100	100	9.5	100	100
19	97	90-100	4.75	95.6	95-100
9.5	37	20-55	2.36	80.4	80-100
4.75	2	0-10	1.18	68.9	50-85
2.36	1	0-5	0.60	33.4	25-60
			0.30	9.7	5-30
			0.15	1.4	0-10

a- Longitudinal Reinforcement

b- Closed loops

c- Steel Fiber

Fig. (3) Sample of Steel Mesh, and steel fiber Used in Present Investigation

In this research on each end of beam, the clamping loading frame was used, shown in Fig. (4). This frame consists of two arms (made of steel clamps) which used for applying torque, four bolts are used to connect them over a sample. (16 mm)steel plate was used to make this frame, with two steel shafts.

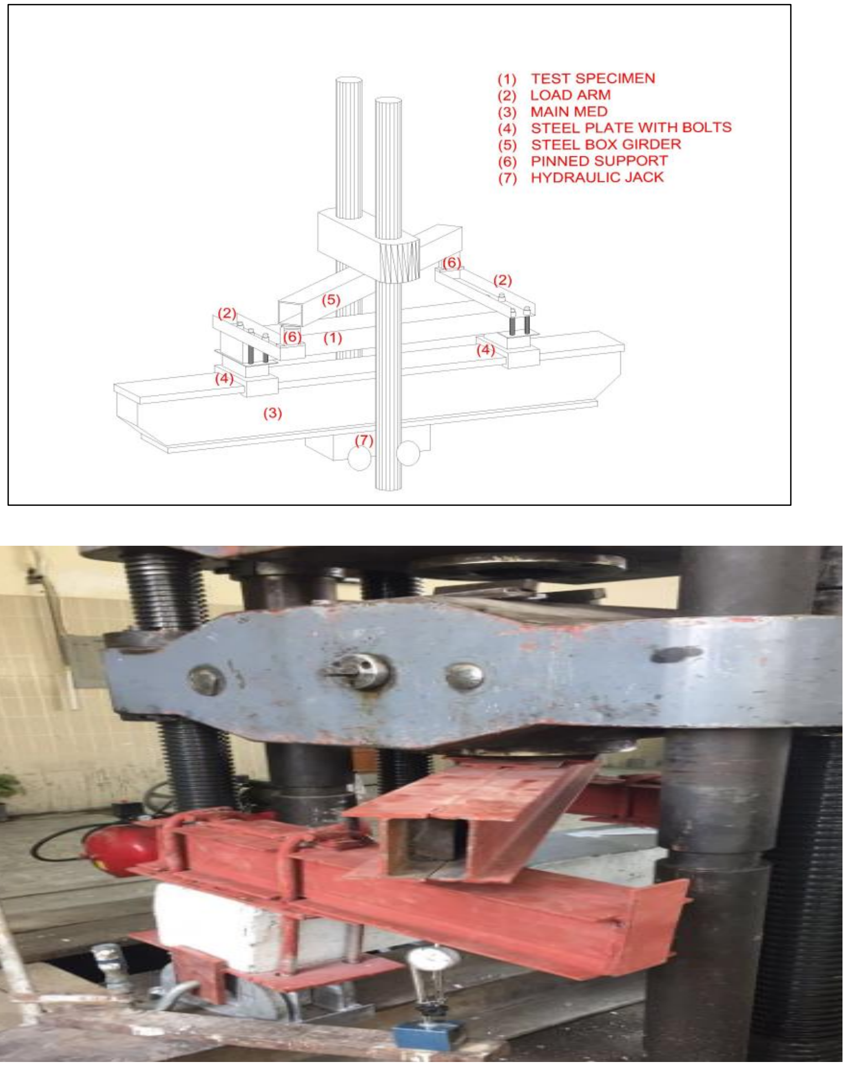


Fig. (4) Suggestions of load Arrangement Showing the Test Rig.

4. Measuring Instruments

4.1 Measurements of Twist Angle

The method of this study was simple. It uses two dial gages to estimate the angle of twist. They are both attached to the end of beam at bottom fiber point 90 mm of the center of the beam's longitudinal axis Fig (5-a). Gages on both sides recorded the values. After that, average is used to measure twisted angle (in radians).

4.2 Elongation Measurements

The axial displacement of RC beam was measured by using two gages attached horizontally to the center of the beam's end Fig (5-b).

(A)

(B)

Fig. (5) Angle of Twist and Elongation Measurement

5. Test Results

The results of this research have shown the following:

5.1 Effect of Volume Fraction of Fibers

Torque-twist behavior of of solid RC (B1, B2, B3, B4, B5 and B6) and hollow RC beams (H1, H2, H3, H4, H5 and H6) with (Vf) of (0%, 0.5%, 0.75%, 1.75%, 2% and2.5%) respectively are shown in Fig. (6). the steel ratios of transverse and longitudinal reinforcements were kept constant.

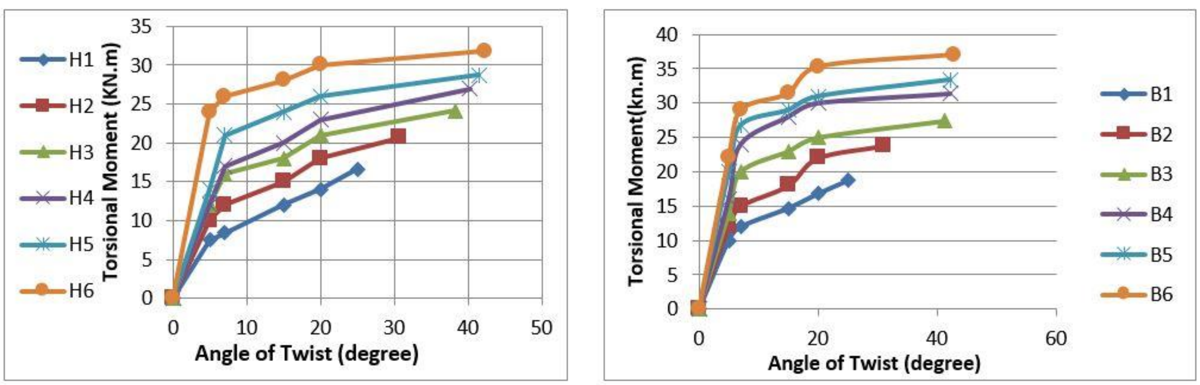
Table (4) Effect of Variation in Steel Fiber Ratio on Cracking and Ultimate Torque

Beam No.	Vf %	(Tcr) (kN.m)	Increasing in(Tcr) (%)	(Twt) (kN.m)	Increasing in(Tu) (%)
H1	0	8.3	---	16.6	0
H2	0.5	15.77	82	20.65	24.4
H3	0.75	17.59	112	24.16	45.6
H4	1.75	19.25	132	27.00	62.7
H5	2	20.23	158	28.70	72.9
H6	2.5	22.71	163	31.75	91.3
B1	0	9.6	---	18.7	---
B2	0.5	18.52	93	23.8	27.5
B3	0.75	20.73	116	27.43	46.7
B4	1.75	23.32	143	31.37	67.8
B5	2	25.53	166	33.41	78.7
B6	2.5	26.68	178	37.06	98.2

Table (4) shows that there is an increase in both the ultimate torque and cracking whenever the (Vf) is increased. It also indicates an increase in the ultimate torque (Tu) of hollow beam in about 24.4%, 45.6%, 62.7%, 72.9% and 91.3%. Moreover, there is an increase in crack torque (Tcr) 82%, 112%,132%, 158% and 163% whenever there is an increase in the (VF) from zero to 0.5%, 0.75%, 1.75%, 2% and 2.5% respectively. Concerning the solid beams, there is an increase in the ultimate torque (Tu) about 27.5%, 46.7%, 67.8%, 78.7% and 98.2%. Crack torque (Tcr) increased by 93%, 116%, 143%, 166% and 178% as the (VF) of fibers was increased from zero to 0.5%, 0.75%, 1.75%, 2% and 2.5% respectively.

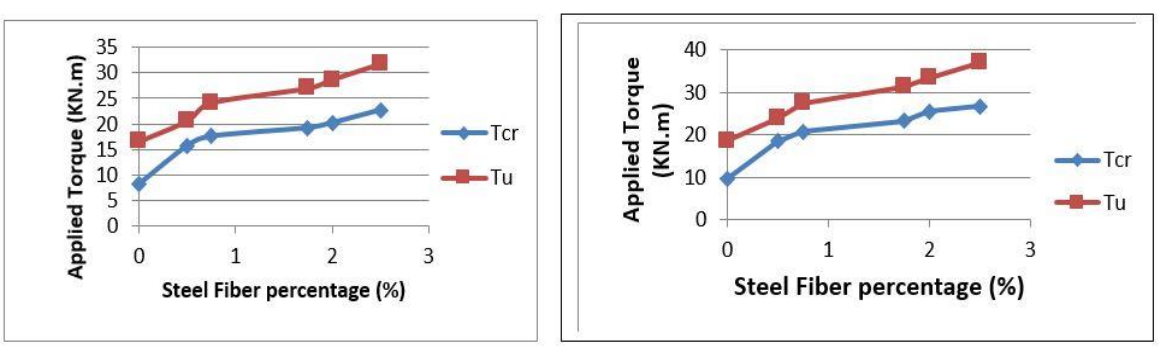
Fig.(7) shows that both the cracking and ultimate torques increase as the steel fiber content is increased for both hollow and solid sections. Fig.(8) shows the behavior of beam longitudinal elongation decrease as the steel fiber content is increased for both hollow and solid sections.

The ductile behavior of beams was improved by using the steel fiber because the tensile strength of concrete increased. Beams with relatively high percentage of fibers were observed diagonal cracks at faces of all fibrous, after beam cracking the fibers continue to resist tensile stresses and the tensile stresses increasing, this resistance continue until the complete pullout of all fibers at a critical crack. Experimental results show that in beam of hollow section the number of cracks was larger than in the beam of solid section. The angle of inclination of the cracks was no effected by type of beam (solid or hollow). The failed in all beams occurred due to high torsional shear stress by forming extensive diagonal torsional crack.



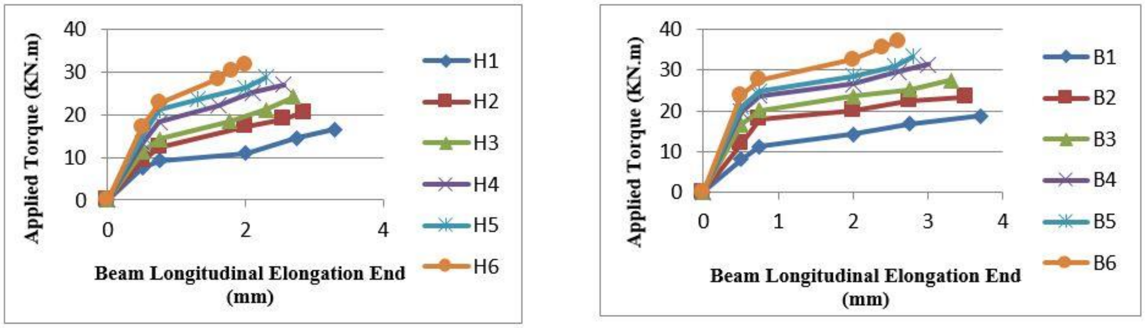
(a): Hollow section **(b): Solid Section**

Fig. (6) Torque-Twist Behavior of with Different Steel Fiber Ratio in Hollow & Solid Section



(a): Hollow Section **(b): Solid Section**

Fig. (7): Experimental Crack and Ultimate Torques



(a): Hollow Section **(b): Solid Section**

Fig. (8) Effect of Steel Fiber Content on Beam Longitudinal Elongation.

To study the effect of beam section types (solid and hollow), two plain RC (non- fibrous) beam with (Vf=0) was taken. Fig. 9 and Fig. 10 shows the torque-twist and longitudinal elongation of the plain RC beams for H1(hollow) and B1(solid) section respectively. For beam B1, the first diagonal crack was observed at an applied torque of 9.6kN.m and the beam reached an ultimate torque of 18.7kN.m and exhibited a ductile behavior. Ductility of beam B1 was mainly due to the amount of steel provided. For the beam H1, cracking was recorded at a torque value of 8.3kN.m, while the ultimate torque was 16.6kN.m. It can be seen that the post cracking torsional behavior of B1 was similar to that H1 and the failure surface was inclined at approximately 45 degree with respect to the longitudinal axis of beam at the front side and then turned gradually to 45 degrees as it approached the opposite face and the beam failed by torsion. Table (5) and Figs (9 &10) indicate that the concrete core has a slight effect on the ultimate torsional strength and beam elongation.

Table (5) Effect of Cross Section Shape on Cracking and Ultimate Torque

Beam No.	Section	**(Tcr) (kN.m)**	**Increasing in(Tcr) (%)**	**(Tult) (%)**	**Increasing in(Tult) (%)**
H1	Hollow	8.3	---	16.6	----
B1	Solid	9.6	13.5	18.7	11.2

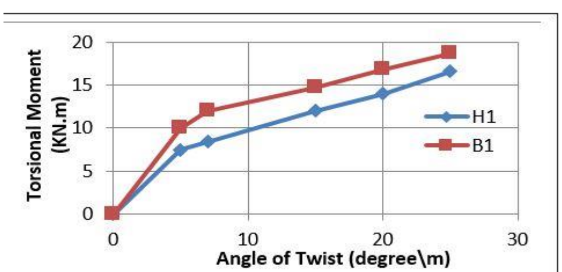


Fig. (9): Torque-Twist Behavior of Plain concrete

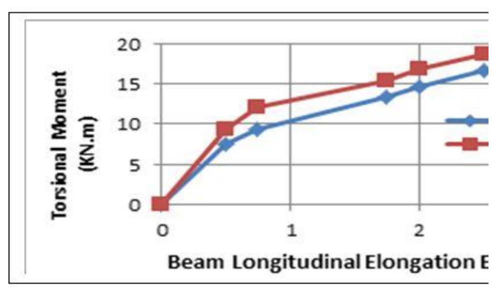


Fig. (10): Beam Longitudinal Elongation of Plain concrete

7. Crack Patterns of Tested RC Beams

The study reveals that the number of cracks occurred at the beginning of the beam failure and proportional to the percentage of (Vf) in beam. One of the cracks occurs at one side of the beam while the other one occurs at the other side of the beam. This occurs while increasing the applied torque. They both developed and formed a helical pattern around the beam.

The solid section B1 and hollow section H1 without steel fibers failed to form extensive diagonal torsional cracks. This happens with successive circulation around the beam. It also goes along with by small crushing of concrete cover. Fig. 11 and 12 show the failure patterns of solid and hollow specimens.

Fig. (11): Failure of Solid Specimens

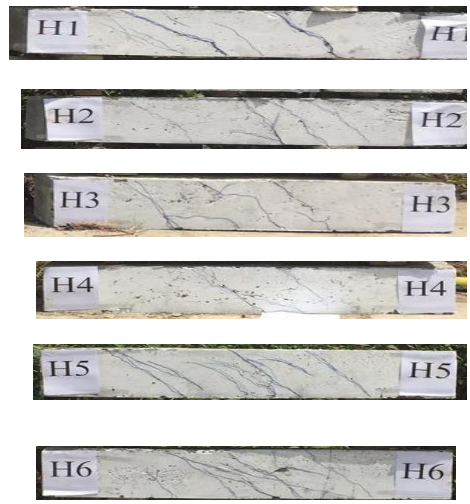


Fig. (12) : Failure of Hollow Specimens

8-Achieved Improvements

The main variety of present work is used the steel fiber with a different percentage to investigate the effect of steel fiber on improving of soiled and hollow RC beams resistance against torsional moments and resultant stresses. The study reveals that some structural properties are improved, these properties are: (Tcr), (Tu) and (Ø). The structural properties were improved with a different rate to the corresponding amount of steel fiber, as shown in Table 6 and Fig. 13, 14 and 15. Improvement in (Tcr) represent the highest, followed by (Tu) and then by(Ø). In general, increasing the steel fiber improves the behavior of the beams.

Table (6) Improvement of cracking, altimate and angle of twist due to steel fiber content.

Beam No.	VF %	Increasing in (Tcr) (%)	Increasing in (Tu) (%)	Increasing in (Ø) (%)
H1	0	---	0	
H2	0.5	82	24.4	23.3
H3	0.75	112	45.6	53.2
H4	1.75	132	62.7	61.1
H5	2	158	72.9	66.3
H6	2.5	163	91.3	69.4
B1	0	---	---	
B2	0.5	93	27.5	24.1
B3	0.75	116	46.7	54.4
B4	1.75	143	67.8	65.1
B5	2	166	78.7	69.3
B6	2.5	178	98.2	71.4

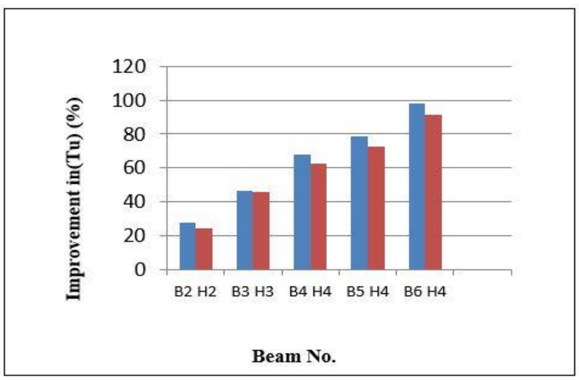


Fig. (13): Improving of (Tcr) for all tested beams.

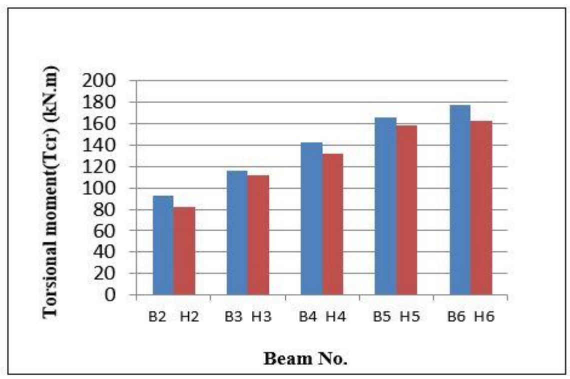


Fig. (14): Improving of (Tu) for all tested beams.

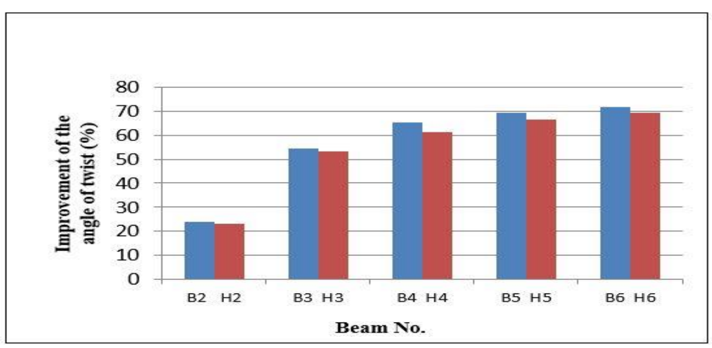


Fig. (15): Improving of angle of twisting for all tested beams.

8. Conclusions

The present study reveals that:

1. The number of cracks in fibrous RC beam is greater than those in non- fibrous ones.
2. The effectiveness of steel fibers stats just after the formation of cracks. Resistance to tensile tension continues until the complete retreat of fibers at a critical crack.
3. As fibers added to the concrete mix in 2.5 %, an increase of 94.2% and 91.3% obtained in the ultimate torque for both solid and hollow RC beams an increase in the cracking torque about 178% and 163% for both solid and hollow beams.
4. Both types of RC beams have no noticeable effect on the cracks angle inclination, ultimate torque, and beam elongation. Generally ????cracks numbers in hollow sections are greater than those in solid sections. Beams in both types failed by forming extensive diagonal torsional crack because of high torsional shear stress.
5. As fibers added to the concrete mix caused an improvement of beam torsional strength ($Tcr$and Tu) better than the improvement of stiffness (resistance of Ø).
6. The behavior of beam longitudinal elongation increase as the (Vf) is increased for both hollow and solid sections.
7. The concrete core has a slight effect on the ultimate torsional strength and beam elongation.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

9. References

[1] Al-Saraj W. K. “Structural Behavior of RPC T-beams Under Pure Torsion” Ph.D. Thesis, Al-Mustansiriyha University, p.189, 2013.

[2] Allawi A., "Nonlinear Analysis of Reinforced Concrete Beams Strengthened by CFRP in Torsion", Ph.D. Thesis, University of Baghdad, p.213, 2006.

[3] Hii K. Y. and Al-Mahaidi R., "An Experimental and Numerical Investigations on Torsional Strengthening of Solid and Box-Section RC Beams Using CFRP Laminates." Journal of Composite Structures, (Article in Press) , 2006.

[4] ASTM C 494/C 494M – 1999a, "Standard Specification for Chemical Admixtures for Concrete", Vol. 04.02, pp.1-9, 1999.

[5] ASTM C33-03," Standard Specification for Concrete Aggregates", American Society for Testing and Material, approved June 10, 2003.

[6] Iraqi Specification No. 45, "Natural Sources for Gravel that is Used in Concrete and Construction", Baghdad, 1984.

سلوك العتبات الخرسانه المسلحه ذات المقاطع المجوف والصلدة المقوات بالاياف الحديد والمعرضة الى عزم لي

مازن ديوان عبد الله

قسم الهندسة المدني، جامعة البصرة، البصرة، العراق

mazend081@gmail.com

الخلاصه

تم في هذا البحث دراسة تصرف العتبات الخرسانيه المجوفه والصلده والمقواة بالياف الحديد والمعرضه الى عزم لي فقط حيث تم اضافة الياف معدنيه الى هذه الخلطات الخرسانيه بنسب تتراوح من (0–2.5) % وقد تم دراسة تأثير هذه الالياف وتأثير شكل المقطع على كل من مقاومة التشقق ومقاومة اللي حيث وجد بأن مقاومة التشقق تزداد بمقدار (178%) و(163%) للمقاطع المجوفه والصلده على التوالي اما بالنسبه الى العزم الاقصى فأنه يزداد بمقدار (91.2%) و(91.3%) عند اضافة الياف معدنية بنسبة 5.2% للمقاطع المجوفه والصلده على التوالي، كما بينت النتائج بأنه لا يوجد اي تأثير للباب الكونكريتي على مقاومة التشقق ومقاومة اللي .

الكلمات الداله: – الخرسانة المسلحة، الصلدة المقوات، عزم لي.