Journal of Engineering and Sustainable Development
http://jeasd.uomustansiriyah.edu.iq/index.php
https://doi.org/10.31272/jeasd.25.3.3

Vol. 25, No. 03, May 2021
ISSN 2520-0917

BEHAVIOR OF STEEL FIBER SELF-COMPACTING CONCRETE HOLLOW DEEP BEAMS UNDER TORQUE

*Muhanad S. Mahdi[1]   Saad K. Mohaisen[1]

1) Civil Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.

Received 29/9/2021 ***Accepted in revised form 20/12/2020*** ***Published 1/5/2021***

Abstract: The purpose of this paper was concerned of the behavior of six samples of deep beams under the influence of pure torsion. Such samples were self-compacting concrete (SCC) and two ratios of Steel Fibers (SF (were also added (0.75 % and 1.5 %). This study examined the behavior of the samples when pure torsion was applied and reacted to angles of torsion, longitudinal strains and concrete strains. It was obvious from the results of the test that the addition of steel fiber to the SCC mixture increased the strength of the compression and tensile strength, which increased the hardness of the samples, thereby decreasing the response of the samples to the angle of twisting, longitudinal strains of concrete and concrete strains.

Key words: *Angle of twist, deep beam, steel fiber, torque, torsion.*

1. Introduction

In recent years, due to torsion has been a very significant problem for structural members. There are two key explanations for this trend, initially the approach of design methods was based on more realistic ideas of loads and structure behavior compared to older approaches, and secondly the number and variety of structures where the torsion is the axis of structure behavior and not the secondary effect. [1]

Before cracking Concrete acts as a flexible material and the reinforcement can be ignored [2]. In hopes of preventing torsional failure, many techniques may be used, such as the appropriate design for transverse and longitudinal reinforcements, the use of appropriate mixtures to improve response, and concrete structural components may be strengthened to withstand torsional stress by adding transverse reinforcement, increasing the cross-section of structural elements and applying axial load through the use of pre-stress technique. [3, 4]. Previous torsional enhancement investigations focused on different strip configurations for ordinary Reinforced Concrete(RC) beams [5, 6,].

Self-compacting concrete has many advantages over normal concrete, such as its ease of casting in crowded reinforced steel environments, its ability to pour large quantities in a short time, filling any part of the mold, reducing the need for vibration as it compacts under its weight effect. [7, 8].

Steel Fiber Reinforced Concrete (SFRC) is a composite material incorporating steel fibers or

**Corresponding Author*: muhanadshaker1@gmail.com

other materials for the purpose of enhancing tensile strength and other concrete properties. The volume of steel fiber in concrete is measured as a percentage of the volume, usually between 0.0% and 2.0 % of the size of the steel fibers. [9], the advantages of using steel fibers are the improvement of compressive strength, tensile strength, shear strength, flexural strength, durability and impact resistance. [10].

Test findings show that the strength of the deep beams in the shear is significantly affected by steel fibers [11].

Previous studies have found that increased compressive strength of concrete leads to an increase in total torque capacity [12]. Increased steel fiber content in the cross-section reduces the angle of twisting of the reinforced concrete beam and increases the stiffness of the beam [13, 14].

2. Research plan

The aim of this work is to study and improve the response of deep beam samples to torsional resistance, using some variables.

- SCC Mixture with and without SF
- Deep beam samples with a hollow section shape, such as a square hollow section or a circular hollow section.
- Adding the proportion of the ratio of steel fiber (1.5 % and 0.75 %) in the SCC mixture.

Six deep beam samples were made of dimensions (130cm, 11.5cm and 40cm) with one steel reinforcement configuration in which the longitudinal reinforcement steel consisted of three bars with a diameter of 20 mm, while the shear reinforcements had a diameter of 8 mm with a spacing of 100 mm c / c in both vertical and horizontal directions as shown in Figure1.

The six samples were divided into two groups, one with a square hollow section (4.5cm * 4.5cm) and the other with a circular hollow section(r = 2.5 cm), three models in each group, three of which were SCC mixtures, 0.75 % steel fiber SCC and 1.5 % steel fiber SCC ,All samples were tested prior to failure under the influence of pure torsion.

The compressive strength of the SCC mixture was 42 MPa, and the SCC mixture with0.75% SF was 45 MPa, while the SCC mixture with 1.5% SF was 47.5 MPa.

Tests were carried out in the fresh and hardened state of the SCC mixture as shown in Tables (1 and 2), Where all the values were obtained from the laboratory test.

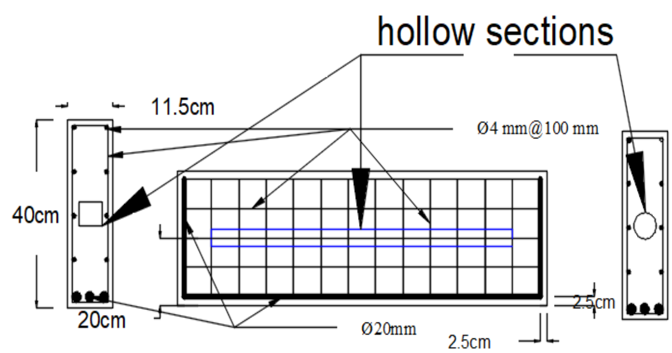


Figure1. Details of the Steel Reinforcement

Table 1. Test Results of Hardened Concrete

Mix Type	Compressive Strength (MPa) f'_c	f_{cu}	f_r (MPa)	f_t (MPa)	E_c (MPa)
SCC	42	49.5	3.5	4.3	29233
SCC with 0.75% SF	45	53	4.5	5.4	31225
SCC with 1.5% SF	47.5	56	5.9	6	32450

Table 2. Test Results of Fresh SCC

Test	Property	Unit	Result	Range [15]
Slump Flow	Filling ability	mm	680	650-800
T_{50}		Sec	3.3	2-5
V-funnel	Segregation resistance	Sec	8	6-12
L-Box	Passing ability	H2/H1 %	0.90	0.8-1.0

3. Material Characteristics

The choice of materials included in the ingredient of the concrete according to the approved engineering specifications and determination of mixing ratios According to the methods of approved designs depending on the standard specifications is the way to obtain concrete with high efficiency while taking into account the quality control during the casting of samples.

3.1. Cement

In the present work, the ordinary Portland cement (OPC) "type (1)" has been utilized, which was made in Iraq and is a successful and suitable cement for laboratory tests

3.2. Admixture

The production of concrete mixtures (SCC, SCC-0.75% and SCC-1.5%), is carried out with the use of super plasticizer (HRWRA) based on polycarboxylate based. The product with the brand name Glenium 51 was used to produce self-compact concrete, where the use ratios in the concrete mixture range between (0.5-0.8) liters per 100 kg of cement and these ratios succeed in producing high strength and performance concrete.

3.3. Silica fume

Silica fume is defined as very fine and amorphous silica, which has been created in arc furnaces for the silicon or the silicon-containing alloys. Silica fumes are a fine spherical powder with an average diameter of about 0.1 µm, and are characterized by about 100 times smaller than cement granules. Silica fumes with the SICA brand are used in this study, which is gray in color similar to color of Portland cement or some types of fly ash ,

Silica fumes are added as one of the mineral additives to the mix.

4. Results and Discussion

The six samples of the deep beam were tested in the Al-Mustansiriya structure Laboratory, where pure torsion was applied to the samples by loading two steel arms on either side, and the loading distance applied was 45 cm from the deep beam center.

To measure the angle of twist, two dial gauges were placed on the lower ends of the samples and also two dial gauges were placed at both ends of the deep beam to measure the longitudinal elongation, see Plate1 and figure 2.

The load applied resulted in the behavior of the samples as a flexible behavior before the first crack occurs, after having passed the first crack stage with the emergence of cracks at the angle of inclination before the failure, see Plate 2.

Test of fresh and hardened SCC shown in plates 3, 4, 5, 6, 7, 8 and 9

Three strain gauge strips were also used in the concrete to measure deformation. See table (3)

Plate 1. Details of the Tested Deep Beam

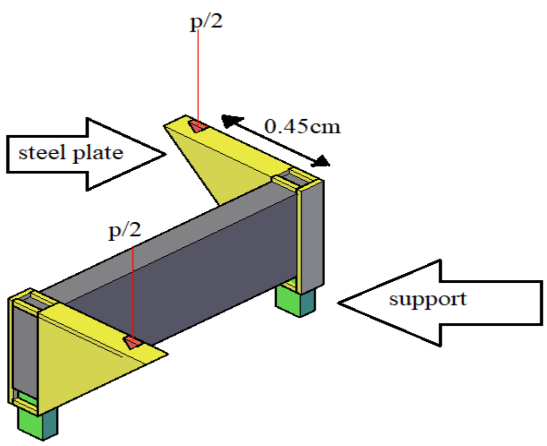
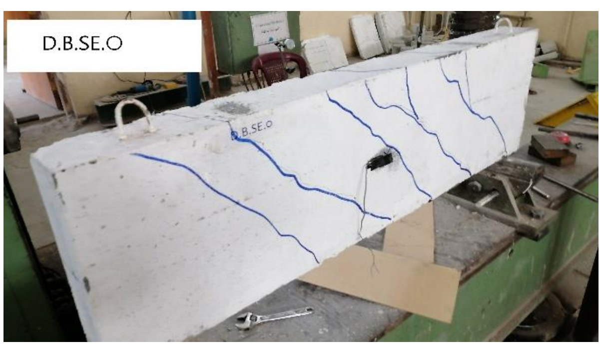
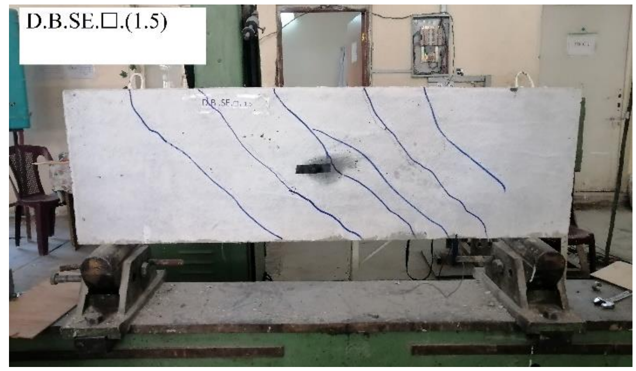
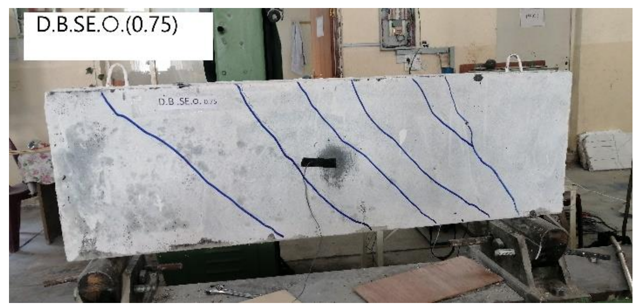


Figure 2. Details of the examination







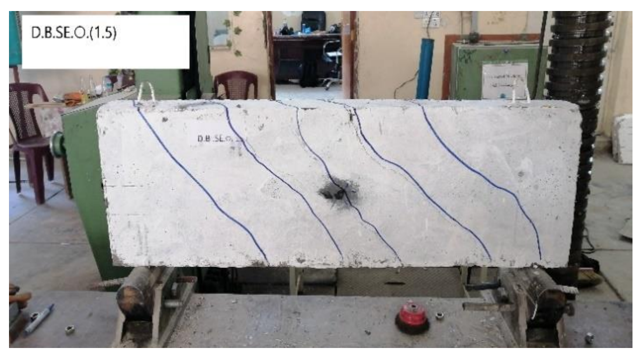


Plate 2. deformation of the tested deep beams

Plate 3. Splitting Tensile Strength Testing

Plate 4. V-funnel test

Plate 6. V-Funnel Test for SCC

Plate 8. Concrete Compression Strength Testing

Plate 5. Slump Flow Test for self-compacting concrete

Plate 7. Elasticity Modulus Testing

Plate 9. Rupture Modulus Testing

Table 1. Results of tested Deep Beam Samples

N.O Group	Type of deep Beam	Compressive Strength (MPa)	Ultimate load (P_u) (kN)	Ultimate torque (T) (kN.m)	Ultimate Angle of Twist (Ø)(rad.)	Ultimate Longitudinal Elongation (mm)
Group 1	DP.B.SCC.□	42	108.5	24.4125	0.025225	1.8
	DP.B.SCC.□.(0.75)	45	125	28.125	0.022765	1.67
	DP.B.SCC.□.(1.5)	47.5	145	32.625	0.021535	1.55
Group 2	DP.B.SCC.○	42	112.5	25.4125	0.02461	1.75
	DP.B.SCC.○.(0.75)	45	132.5	29.8125	0.023073	1.6
	DP.B.SCC.○.(1.5)	47.5	147.5	33.1875	0.01969	1.5

Where the form symbol definitions are:

Dp: deep

B: beam

SCC: self compacting concrete

□: square hollow section

○: circular hollow section

(0.75): the ratio of steel fiber %

(1.5): the ratio of steel fiber %

5. Longitudinal Elongation

Longitudinal elongation is a deformed elongation that occurs in the longitudinal direction of the deep beam axis determined by placing two dial gauges at the center of the deep beam section on both ends and taking the readout rate, the maximum elongation is calculated at the maximum torque and the results are expressed through the charts to allow comparison and conclusions. While comparing the results of the group one samples, it was shown that the best reading was for the sample (DP.B.SCC. □. (1.5)) where longitudinal elongation (1.55 mm) was given at the ultimate torque of 32.625 kN.m, while the sample (DP.B.SCC.□.(0.75)) was gave a longitudinal elongation (1.67 mm) at the ultimate torque of 28.125 kN.m Whereas the more response (the highest) was the longitudinal elongation at ultimate torque (1.8 mm) of 24.4125 kN.m for sample (DP.B.SCC. □.). As shown in Figure 3.

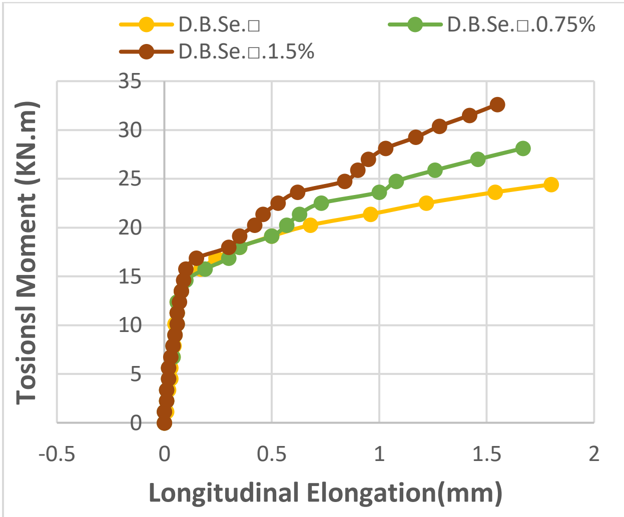


Figure 3. Torsional moment vs. Longitudinal Elongation for group one

It concludes that the effect of adding steel fiber to the SCC mixture was evident in decreasing the response to longitudinal elongation where, by adding 1.5 % of steel fiber, the response to elongation decreased by 13.9 % and by adding 0.75 %, the response will decrease by 7.2 %.The explanation for this is that the addition of steel fiber to the mixture improves compression strength and tensile strength, thereby decreasing the longitudinal elongation response.

By comparing the two samples, it was shown that the best reading was for the sample (DP.B.SCC. ○.(1.5)) where the elongation value (1.5 mm) was given at the ultimate torque of 33.1875 kN.m, while the sample (DP.B.SCC. ○.(0.75) was given Elongation with (1.6 mm) at the ultimate torque of 29.8125 kN.m. Although the sample (DP.B.SCC.○) at the ultimate torque of 25.3125 KN.m gave the more response to elongation (1.75 mm). As illustrated in Figure 4.

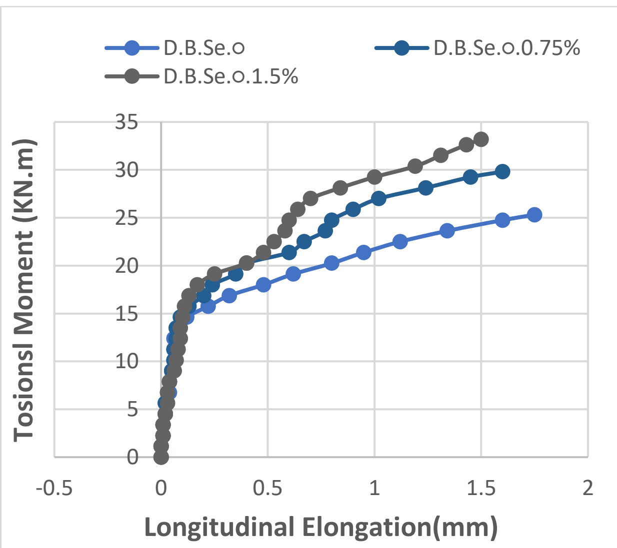


Figure 4. Torsional moment vs. Longitudinal Elongation for group two

The addition of steel fiber to the SCC mixture significantly decreased the response to longitudinal elongation, as the addition of 1.5% of steel fiber decreased the response by 14.3 percent and the addition of 0.75 % of steel fiber decreased the response by 8.6 percent.

The explanation for this is that the addition of steel fiber to the mixture increases compression resistance and tensile strength, thus decreasing longitudinal elongation response.

6. Angle of Twist (Ø)

Twist angle is a three-dimensional deformation that occurs along the axis of the deep beam towards the torsion projection, the angle of the torsion was determined by putting two dial strain gauges at the lower ends of the deep beam and taking the rate of measurement, all results are included in the charts to allow comparison.

When comparing the results of the group one tests, it was found that the best response to the angle of twist was a sample (DP.B.SCC. □.(1.5)) with an ultimate torque value (0.021535 rad) of 32.625 kN.m, while a sample (DP.B.SCC. □.(0.75)) gave an angle of twist (0.022765 rad) of 28.125 kN.m at the ultimate torque, Whereas the sample (DP.B.SCC.□) at the ultimate torque of 24.4125 kN.m gave the worst response to the angle of twisting (0.025225 rad). see Figure 5.

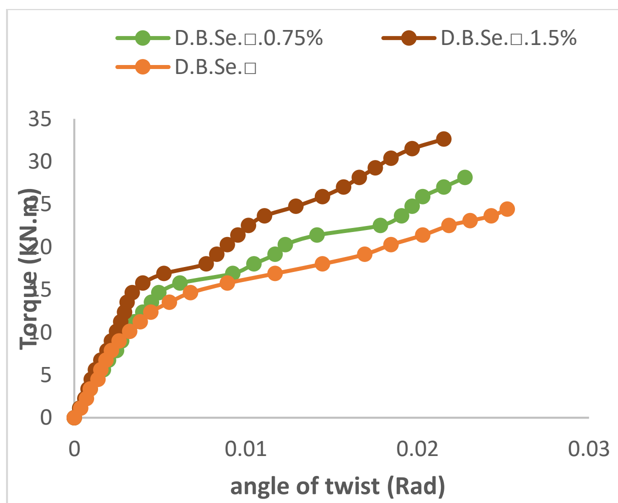


Figure 5. Torque-Angle of Twist for Group- one

While comparing the results of the samples that of group two, it was noticed that the best response to the twisting angle was a sample

(DP.B.SCC. ○.(1.5)) with a value (0.01969 rad) at the ultimate torque of 33,1875 kNm, on the other hand a sample (DP.B.SCC. ○.(0.75)) had a twisting angle value (0.023073 rad) at the ultimate torque of 29,8125 kN.m, while sample (DP.B.SCC.○), at the ultimate torque of 25.4125 kN.m, gave the more response to the angle of twist (0.02461 rad). see Figure 6.

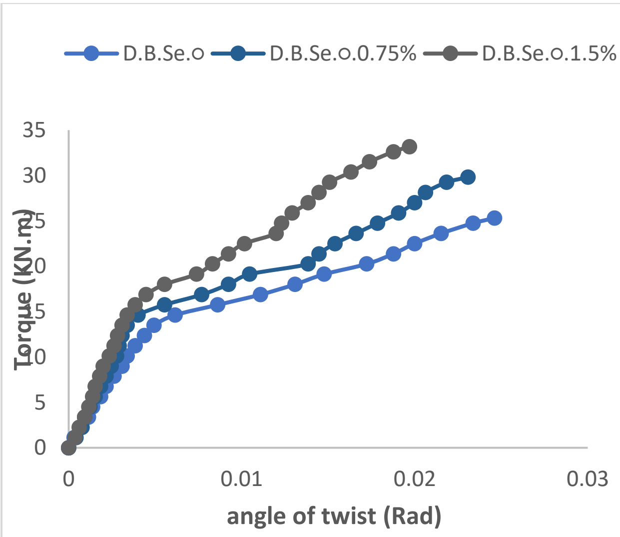


Figure 6. Torque-Angle of Twist for Group- two

The use of steel fibers in the SCC mixture decreased the response of the samples to the angle of twist as they decreased the response of the sample (DP.B.SCC. □.(1.5)) and the sample (DP.B.SCC. □.(0.75)) as compared to the sample (DP.B.SCC. □.) (14.6 percent and 9.8 percent) respectively. decreased the response of the sample (DP.B.SCC. ○. (1.5)) and the response of the sample (DP.B.SCC. ○. (0.75)) against the response of the sample (DP.B.SCC. ○.) with (20% and 6.24%) respectively.

The reason behind this is that use of steel fiber in the SCC mixture has improved the compressive strength and tensile strength of the mixture and other properties, thus increasing the strength and hardness of the samples and thus decreasing their response to the angle of twisting.

6. Concrete Strains:

Three strain gauge strips were used to measure the deformation value of the concrete, as three positions were selected at the top, middle and bottom, as shown in Figure 7.

The maximum value of the compressive strain moment in normal concrete when crushed is (0.003-0004) according to ACI code (318-14)[16], but in many types of concrete mixtures it may be corporal (0.008), the strain values are recorded in this laboratory at each increment load of 5 kN.

All samples failed to crack diagonally, which means that the torque stress exceeds the capacity of the concrete torque.

In order to analyze the effect of the addition of steel fibers on the response of the deep beam of the concrete strain, the two groups were compared to each other.

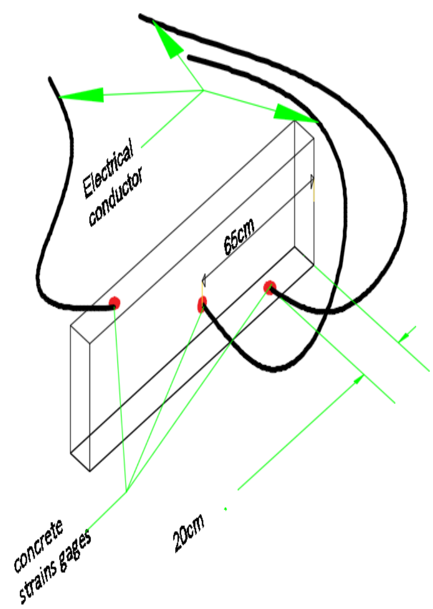


Figure 7. Locations Of Concrete Strain Gauges On Deep Beams

When comparing group, one samples using measurements at three positions (top, middle and bottom positions), it turns out that the best response was given by the sample (DP.B.SCC.

□. (1.5)) with the concrete strain (1205 micro strain, 1186 micro strain and 1120 micro strain) at a maximum torque of 32,625 kN.m. Whereas the concrete strain (1118 micro strain, 1088 micro strain and-1113 micro strain) was yielded by the sample (DP.B.SCC.□. (0.75)) at a maximum torque of 28,125 kN.m, respectively.The weakest sample in group one (DP.B.SCC.□), with a maximum torque of 24,4125 kN.m, yielded values for concrete strain with (1055 micro strain, -890 micro strain and-943 micro strain). As seen in Figures (8,9 and 10).

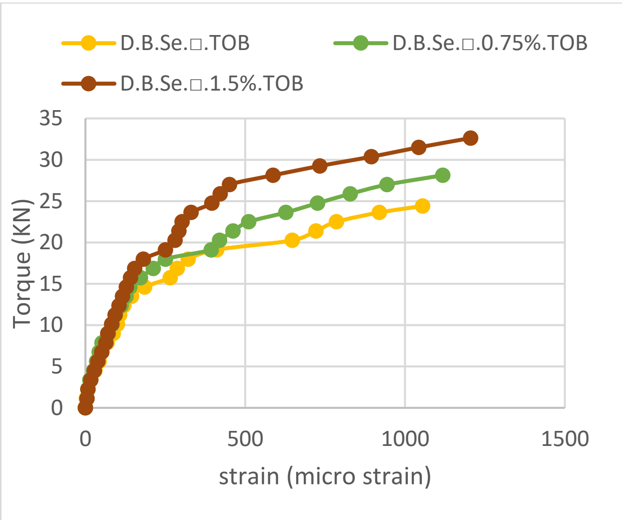


Figure 8. Top Reading of Concrete Strain Gauge For Group One Samples

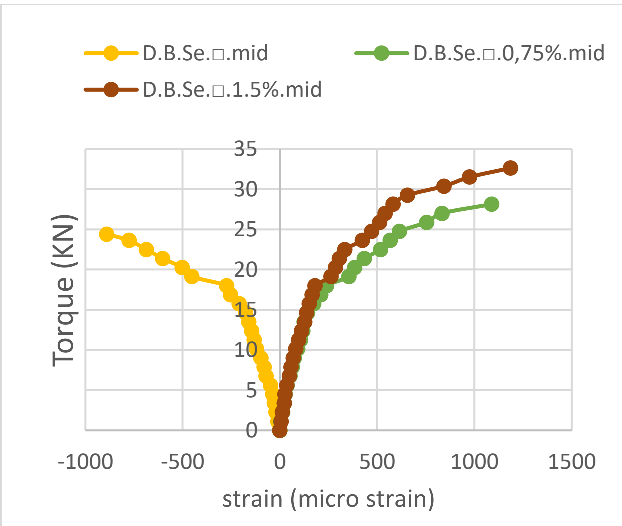


Figure 9. Middle Reading Of Concrete Strain Gauge For Group One Samples

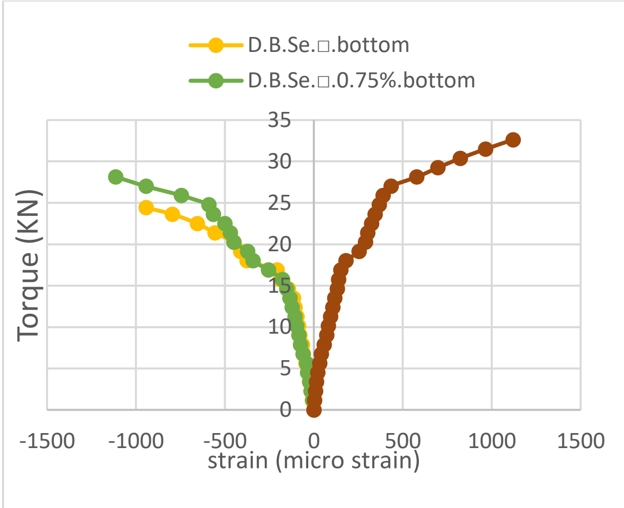


Figure 10. Bottom Reading of Concrete Strain Gauge For Group One Samples

Note that the best response was provided by a sample (DP.B.SCC. ○. (1.5)) with a concrete strain (1306 micro strain, 1255 micro strain and -1155 micro strain) at a maximum torque of 33.187 kN.m for samples of the group two and by readings at three positions (top, middle and bottom). The concrete strain values (770 micro strain, 1155 micro strain and-1102 micro strain) were measured in the sample (DP.B.SCC.○. (0.75)) at a maximum torque of 29.8125 kN.m, respectively.

As shown in Figures (11,12 and 13), the weakest group sample (DP.B.SCC.○) provided values for concrete strain (1010 micro strain, -924 micro strain and -1064 micro strain) with a maximum torque of 25,3125 kN.m. respectively.

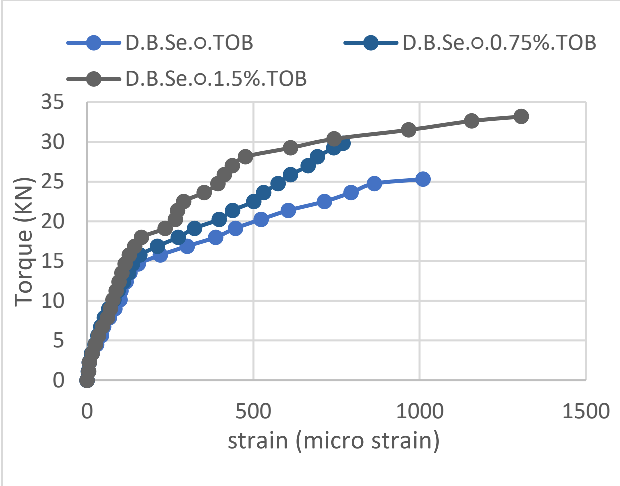


Figure 11. Top Reading of Concrete Strain Gauge For Group Two Samples

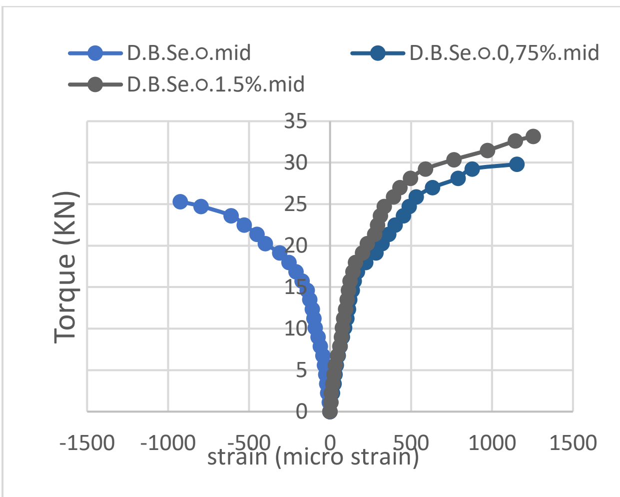


Figure 12. Middle Reading of Concrete Strain Gauge for Group Two Samples

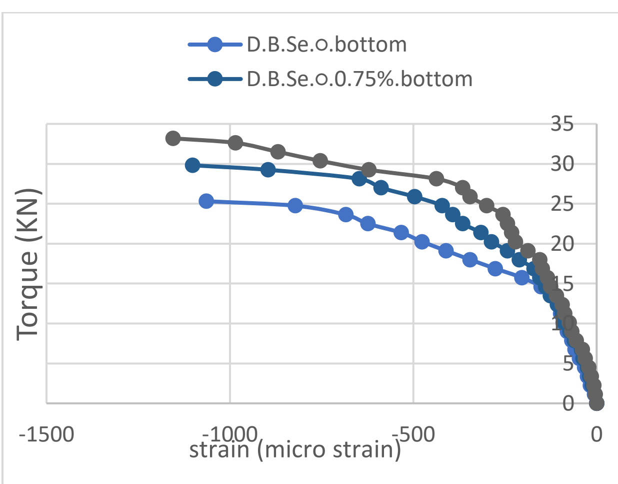


Figure 13. Bottom Reading of Concrete Strain Gauge for Group Two Samples

It is clear that the addition of steel fibers to the SCC mixture has contributed to an improvement in the response of the concrete strain, as it has resulted in a increase in the value of the ultimate strain due to the fact that the addition of steel fibers increases the compressive strength of the mixture, increases the tensile strength of the mixture and also enhances other properties. Some of the values were negative and the other positive. The explanation for this is because of the position where the crack moves in relation to the slice of the strain guage, if it moves over the slice, the tension on the slice gives a positive value, but if it passes next to the slice, the slice gives a negative value due to the compression action that occurs on the slice.

7. Conclusions

The following conclusions indicate on the basis of the results of the experimental work:

1. Added of 1,5 % of the steel fiber to the mixture of SCC enhanced the behavior of the samples better than the other ratios of steel fiber.
2. the samples with circular hollow sections behave in better than to the samples with square hollow sections.
3. Increasing of compressive strength and tensile strength of concrete increases stiffness and reduces longitudinal elongation of the samples.
4. Increased compressive and tensile strength of concrete increases the stiffness and therefore reduces the angle of twisting of the sample.
5. Increased compressive strength and tensile strength would increase the strength and stiffness of the samples, thus increasing the concrete strain recorded at testing.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

8. References

1. Hosseini, M., Ashrafi, H. R., Beiranvand, P., & Ghanbari, B. (2016). Nonlinear analysis of torsion in reinforced concrete members after developing initial crack. Indian Journal of Science and Technology, 9(7).
2. Vecchio, F. (1981). Stress-strain characteristics of reinforced concrete in pure shear, final report. In IABSE colloquium on advanced mechanics of reinforced concrete ,International Association for Bridge and Structural Engineering, (pp. 211-225).
3. Abeer, A. M., Allawi, A. A., & Chai, H. K. (2013). Theoretical study on torsional strengthening of multi-cell RC box girders. World Acad. Sci. Eng. Tech. Int. J. Civil Envir. Struct. Constr. Arch. Eng, 7(2), 115-122.
4. El-HakimKhalil, A., Etman, E., Atta, A., & Fayed, S. (2015). Torsional Strengthening of RC Box Beams Using External Prestressing Technique. IOSR Journal of Mechanical and Civil Engineering, 12(2), 30-41.
5. Ghobarah, A., Ghorbel, M. N., & Chidiac, S. E. (2002). Upgrading torsional resistance of reinforced concrete beams using fiber-reinforced polymer. Journal of composites for construction, 6(4), 257-263.
6. Hii, A. K. Y., & Al-Mahaidi, R. (2005). Torsional strengthening of solid and box-section RC beams using CFRP composites. Composites in construction, 59-68.
7. Okamura, H. (1997). Self-compacting high-performance concrete. Concrete international, 19(7), 50-54.
8. Jost, P., & Campion, M. (2000). Self-compacting concrete: Expanding the possibilities of concrete design and placement. Concrete International, 22(4), 31-34.
9. Shah, R. H., & Mishra, S. V. (2004). Crack and deformation characteristics of SFRC deep beams. Journal of the Institution of Engineers. India. Civil Engineering Division, 85(mai), 44-48.
10. Vondran, G. L. (1991). Applications of steel fiber reinforced concrete. Concrete international, 13(11), 44-49.
11. Muhaison, S. K., Abd, W. K., & Alwan, M. K. (2018). Behaviour of Reactive Powder Rectaingular Deep Beam with Shear Zone Opening Subjected to Repeated Load. Journal of Engineering and Sustainable Development, 22(1), 77-94.
12. Mohaisen, S. K. (2020). Experimental Study of Continuous RC Beams Strengthened with CFRP Fabrics Under Torsion. International Journal of Civil Engineering and Technology (IJCIET), 10(01), 2019.
13. Waryosh, W. A., Mohaisen, S. K., & Dkhel, R. H. (2018, November). Deformation responses of reinforced concrete beams under pure torsion. In IOP Conf. Series: Materials Science and Engineering (Vol. 433).
14. Waryosh, W. A., Mohaisen, S. K., & Dkhel, R. H. (2019, August). Experimental study on torsional behavior of fiberious reifoced concrete beams with different concrete strength. In IOP Conference Series: Materials Science and Engineering (Vol. 584, No. 1, p. 012052). IOP Publishing.
15. EFNARC, F. (2002). Specification and guidelines for self-compacting concrete. European federation of specialist construction chemicals and concrete system.

16. ACI Committee 318 "Building Code Requirements for Structural Concrete (ACI 318-M14)", American Concrete Institute, Detroit, USA, 2014.