The effect of using self-compacting concrete on the behavior of deep hollow beam exposed to torsion torque

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Abstract*: This study includes five samples of deep beams divided into three groups, where the first group is samples with a solid cross section and the second group includes samples of square hollow across the sample length, while the third group is of samples containing a circular hollow through the entire length of the sample. It is worth noting that the three groups Samples were prepared from two types of concrete mixtures, which are a mixture of ordinary concrete (NRC) and a mix of self-compacting concrete (SCC). The behavior of these samples was studied when pure torsion was applied and studied the response of the samples through the results obtained from longitudinal strains readings, angle of twist, and concrete strains readings.*

All results were included in a table and presented through the charts, which were discussed. As the results of laboratory work showed that the increase in the strength of compression makes the deep beam more hardenand thus clearly reduces the angle of twist as well as reduces the longitudinal strains, as was noted an improvement was also observed in the response of prepared samples from the mixture (SCC) to the concrete strain.

I. Introduction

Torsional loading on the deep beam occurs in special cases such as bridges, so the cracks that appears on the Reinforce concrete member after loaded should be considered. The concrete behaves as a flexible material before cracking and the reinforcement can be ignored [1].

In square cross section members, the shear stress in the beam flows about the member and is at a maximum at the midpoint of the outside face when the essential tensile stress arrives to tensile strength of concrete, however cracking happens in RC members under pure torsion. The stiffness of the uncracked member can be predicted by several theoretical approaches while after cracking, the member behaves as a composite member so all concrete's properties, their interactions, and its reinforcement must be considered to accurately predict the response to torsion. Many buildings as bridges elements are Exposed to a significant torsional torques that affect the design and may need to strengthening. the previous torsional strengthening investigations have focused on different strip layouts for ordinary RC beams only [2, 3, 4, and5].

Self-Compacting Concrete (SCC) is distinguished from ordinary concrete with many advantages. This concrete no need vibrations because it becomes levelled and pressed under the influence of its weight [6, 7].

The presence of an opening in deep beams reduces the ultimate load of concrete samples containing reactive powder under repeated load by 2.27 times with a volume fraction of 1 percent [8].

It was noted that an increasing the compressive strength of the section of the reinforced concrete beam increases the rigidity of the beam under the influence of pure torsional torque and reduces the longitudinal strain [9].On the other hand, it was found that an increase in the compressive strength of the beam section would reduce the rotation angle by about 100 percent in the reinforced concretebeam[10]. While, Retrofitting with CFRP epoxy-bonded strips is a feasible technique for strengthening two-span RC beams under torsion, although the torsion angle is significantly increased [11].

II. Study plan

This research aims to study the behavior of deephollow beam samples under the effect of the pure torsion with considering some variables, which are:

● Concrete Mix Type (NRC, SCC).

● The shape of the cross section which were:

a) deep beam of solid section poured by using (NRC) mixtures (one sample tested).

b) deep beam of circular hollow section poured by using (NRC and SCC) mixtures (for each mixture one sample is used).

c) deep beam of square hollow section poured by using (NRC and SCC) mixtures (for each mixture one sample is used).

The samples had dimensions of (1300mm*400mm*115) mm and had the same design as the shear reinforcements of 100mmc / c in both horizontal and vertical directions with a rebar diameter of 4 mm, while the longitudinal rebar had three bars with a diameter of 20 mm as shown in Figure (1).

Compressive strength, splitting tensile strength, and constant elasticity modulus were implemented for all mixtures, and the results are described in Tables (1) and (2).

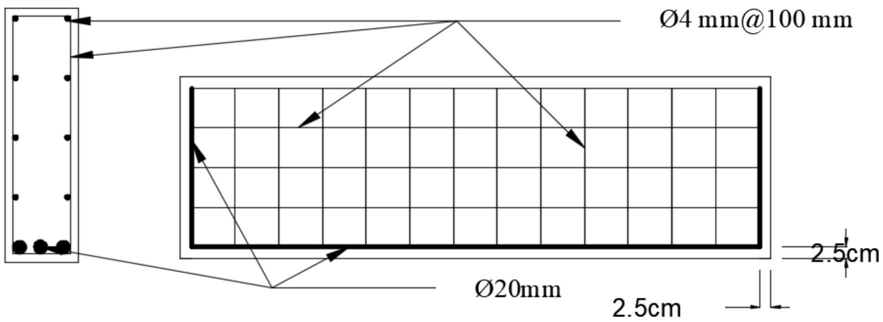


Figure (1).Details of the steel reinforcement

Table (1). Test results of hardened concrete

Mix Type	Compressive Strength (MPa)		f_r (MPa)	f_t (MPa)	E_c (MPa)
	f'_c	f_{cu}			
NRC	32	37.5	2.7	3	27111
SCC	42	49.5	3.5	4.3	29233

Table (2). Teats Results of Fresh SCC

Test	Property	Unit	Result	Range[12]
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

III. Results and Discussion

Loading of 45 cm from the center of the deep beam as shown in Figure (2) to achieve a pure torsion torque and continued until the failure was reached as the cracks appeared and the angle of torsion increased as shown in Figure (3). Two dial gauges were positioned at the maximum torsion points to measure the angle of torsion, also the longitudinal elongation of the deep beam was measured and the results illustrated in Table (3).

In order to measure the strain on the concrete, three slides of the concrete strain gauge were mounted on the deep beam sides at the top, middle and bottom positions

Figure (2). Details of the tested deep beam

Table (3). Overall results from tests

No.Group	Type of 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	D.B.N.S	32	95	21.375	0.02461	1.92
Group 2	D.B.N.□	32	87.5	19.6875	0.026148	2
	D.B.Se.□	42	108.5	24.4125	0.025225	1.8
Group 3	D.B.N.○	32	90.5	20.3625	0.025225	1.95
	D.B.Se.○	42	112.5	25.4125	0.02461	1.75

Where:-
D.B.N.S : Deep beam normal solid

D.B.N.□ : Deep beam normal concrete with square hollow section

D.B.Se.□ :Deep beam self compacting concrete with square hollow section

D.B.N.○ : Deep beam normal concrete with circular hollow section

D.B.Se.○ : Deep beam self compacting concrete with circular hollow section

Figure (3). Deformation of the Tested deep Beams

IV. Angle of Twist (Ø)

The angle of twisting is a three-dimensional deformation occurring towards the torque, the angle of twist was determined by applying two dial gages on both sides of the deep beam and the rate was taken for them, Curves showing a linear behavior relationship until the first crack , after which deep beam samples show inelastic behavior before failure due to a gradual increase in the angle of twisting.

All torque angle values have been included in the charts to encourage comparison as clearly as shown in Figure (4).

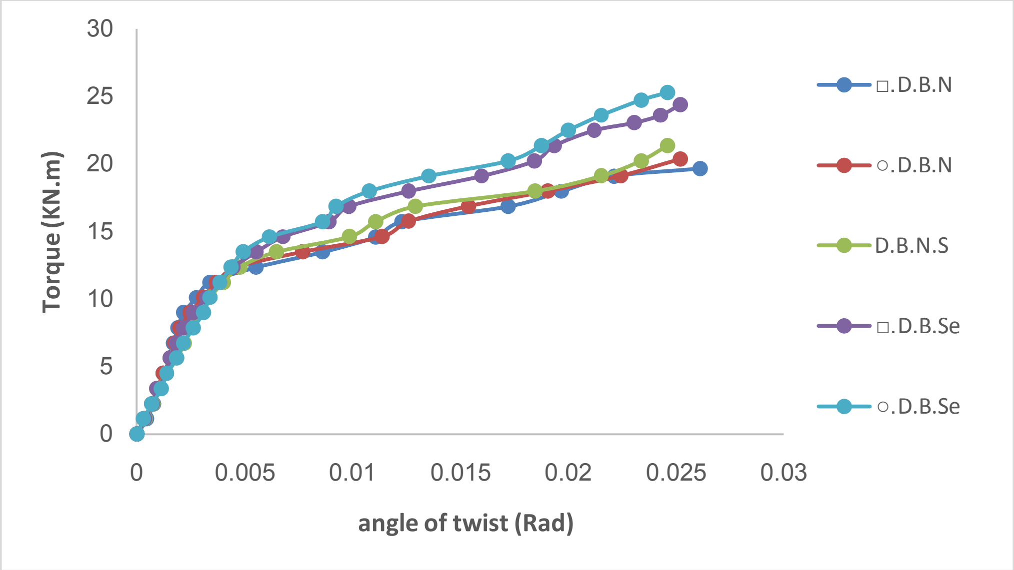


Figure (4). Torsional moment vs. angle of twist for all tested deep beams

4.1-The effect of the hollow section shape on angle of twist: -

When comparing the sample of group one (D.B.N.S) with the reference of group two (D.B.N.□) and the reference of group three (D.B.N.○) to see the effect of the hollow section on the value of the angle of twisting, it was found that the solid sample (D.B.N.S) gave the best response to the angle of twisting between the samples included the hollow where the value (0.02461 rad) was record at ultimate torque (21.375 kN.m).

The sample containing the circular hollow section also provided a better result than the sample containing the square hollow section where the angle of twist values were (0.02522 rad) at ultimate torque (20.3625 kN.m) and (0.026148 rad) at (19.6875 kN.m) respectively.

It is clear that the presence of hollows had an effect on the twisting angle response, where the solid section provided the best response and the circular hollow section was better than the square section, as illustrated in Figure (5).

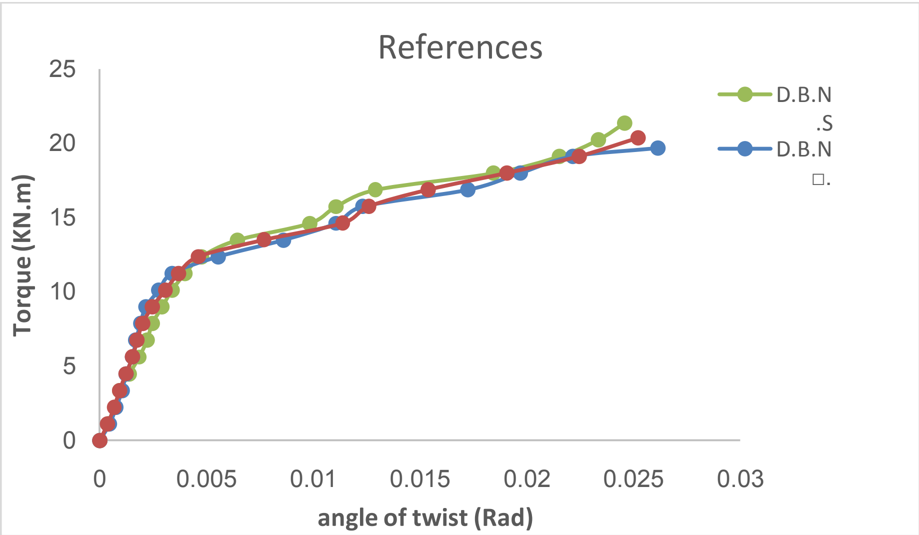


Figure (5). Torsional moment vs. angle of twist for NRC deep beam

4.2- Effect of self-compactingmixture on Angle of Twist: -

When comparing samples from group two and samples from group three, in order to see the effect that occurs when using a self-compacting concrete mixture, there was a clear improvement in the response to the angle of twisting where the sample (D.B.Se.□) gave the angle of twisting (0.025225 rad) at the ultimate torque (24.4125 kN.m) Whereas the sample (D.B.N.□) gave the angle of twisting (0.026148 rad) at the ultimate torque (19.6875 kN.m).

As for group three, the angle of twist "sample (D.B.Se.○)" (0.02461 rad) was given at ultimate torque (25.4125 kN.m), while the angle of twist (0.025225 rad) was given at ultimate torque (20.3625 kN.m) by the sample (D.B.N.○).As shown in Figure (6).

Obviously, the effect of using the SCC mixture on improving the response of the deep Beam to the distortion resulting from the angle of twist is due to the fact that the SCC mixture had a higher compressive strength than the NRC mixture, which increased the durability of the mixture and reduced and delayed the appearance of cracks..

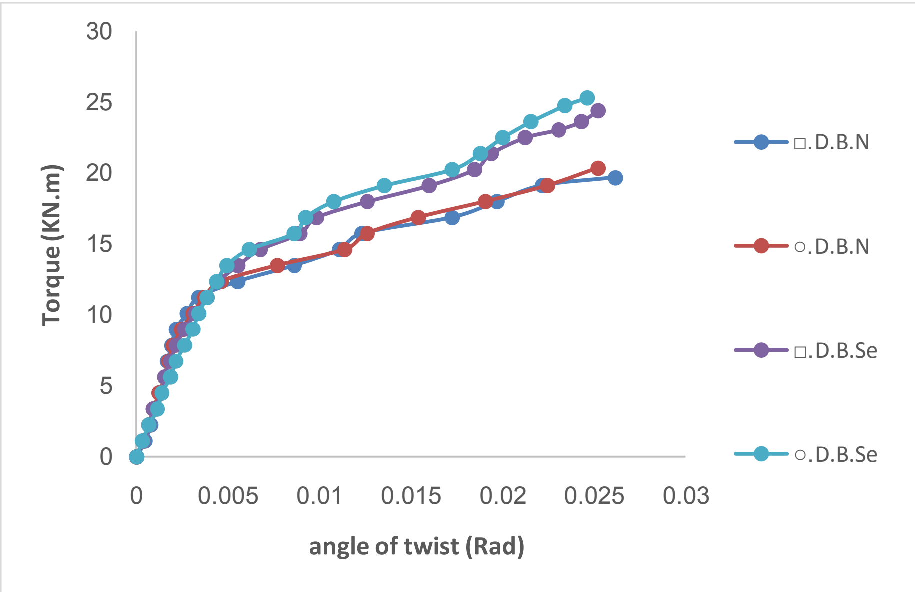


Figure (6). Torsional moment vs. angle of twist for NRC and SCC samples

4.3- Improvements in Angle of Twist

In the angle of twist, the change reflects a decrease in the value with load rises, indicating a decrease in the member's deformation.

Decreases in the angle of rotation of each group were compared. using of SCC mixture was decrease the angle of twist of samples with a square hollow section by 3.6 percent and to decrease by 2.4 percent for samples with a circular hollow section.

Conclude from this that the angle of twisting can be reduced by the compressive strength, and the use of the circular hollow section has also been shown to increase the response compared to the square hollow section.

V. Longitudinal Elongation

The longitudinal elongation is a less deformed unit in the direction of the longitudinal axis of the deep beam, which appears to be a diffuse torsional crack across the width. A total of two longitudinal elongations are drawn at the torsional torque in each deep beam.

5.1-The effect of the hollow section shape on Longitudinal Elongation

In order to determine the effect of the presence of a hollow in deep beams on longitudinal elongation, the first group sample (D.B.N.S) was compared with the reference of group two (D.B.N.□) and the reference of group three (D.B.N.○) , noticed that the sample (D.B.N.S) had the best response to longitudinal elongation of 1,92 mm, while the sample (D.B.N.□) and sample (D.B.N.○) had a longitudinal elongation of 2mm and 1.95 mm respectively.

The use of the square hollow section increased the longitudinal elongation by 4.2 percent compared to the longitudinal elongation record for the solid sample, but increased by 1.6 percent when using the circular hollow as shown in Figure (7).

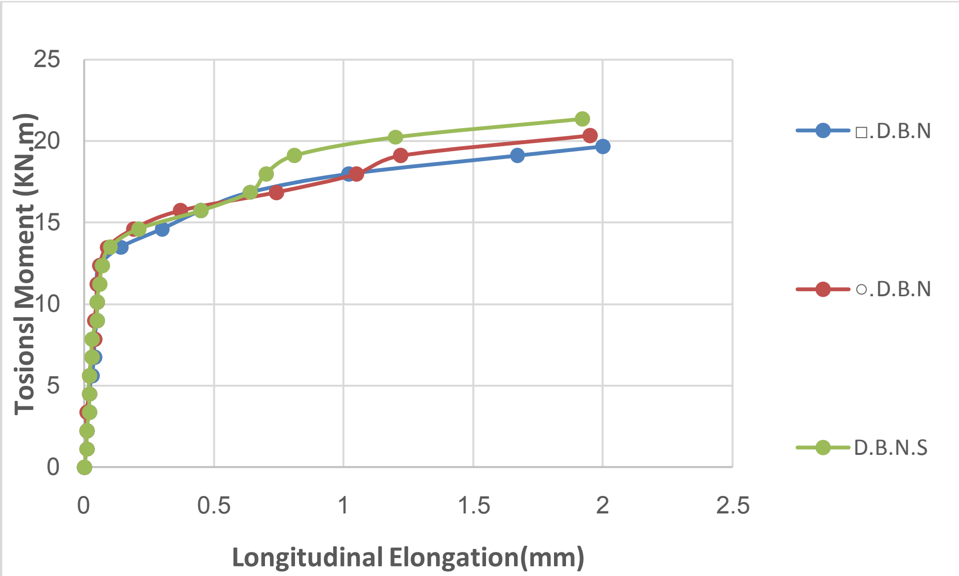


Figure (7): Torsional moment vs. Longitudinal Elongation for NRS deep beams

5.2- effect of Self-compactingmixture onLongitudinal Elongation: -

In order to determine the effect of the use the SCC mixture in deep beam on its response to Longitudinal Elongation, samples from group two were compared and samples from group three which poured from the SCC mixture and the NRC mixture, it was found that the sample (D.B.Se.○) was best measured of 1.75 mm at the ultimate torque of 25.3125 kN.m followed by the sample (D.B.Se.□) of 1.8 mm at the ultimate torque of 24.4125 kN.m.,whereas the sample (D.B.N.○) gave a 1,95 mm reading with a maximum torque of 20,3625 kN.m.The weakest sample was a sample of 2 mm with a maximum torque of 19,6875 kN.m. (sample (D.B.N.□).

The effect of the SCC mixture was evident in improving the response of deep beam samples to longitudinal elongation by reducing longitudinal elongation by 10.25 percent in the circular hollow section sample and by 10 percent in the square hollow section sample.

This is due to the fact that the SCC mixture increased compressive strength and also increased tensile strength by examining the Splitting Tensile Strength and thus improving the response of the samples to Longitudinal Elongation as shown in Figure (8).

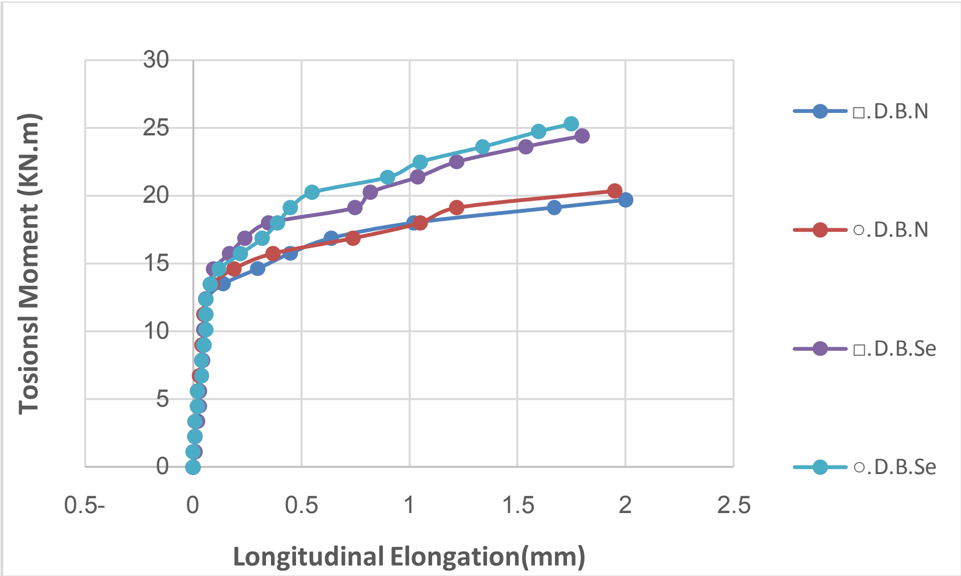


Figure (8): Torsional moment vs. Longitudinal Elongationfor NRC and SCC samples.

VI. Concrete Strains:

The torsional torque relationship with the deep beam concrete strain is determined at three positions on the surface of the deep beam by applying three strain gauges as shown in Figure (9).

The maximum value of the compressive strain moment in normal concrete when crushed is (0.003-0004) according to ACI code (318-14), but may be reached by several other types of concrete mixture (0.008).

The strain values for each strain (load = 5 kN) are reported in this laboratory research. With a diagonal concrete crack, all deep beam tests have failed, which means that the torque stress exceeds the torque capacity of the concrete and that the sample is approached at the peak response.

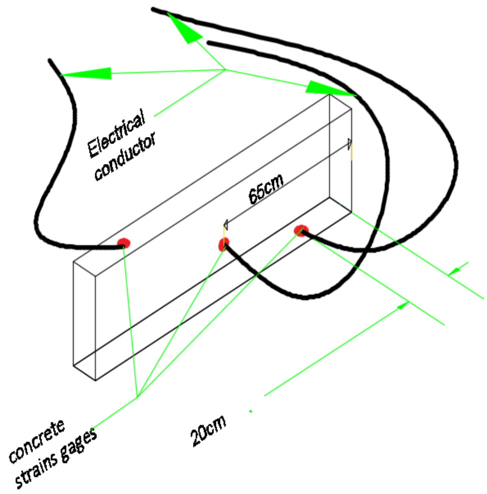


Figure (9) locations of concrete strains gauges on deep beams

6.1 - effect of the hollow section shape on concrete strain: -

In order to investigate the effect of inserting hollows in the deep beam on the concrete strain, there were three measurements of the strain gauges at the top, middle and bottom three positions for the NRC mixture samples. The final strain (960 micro strain, 910 micro strain,-852 micro strain) of ultimate torque (21,375 kN.m) was better read by the sample (D.B.N.S), While the sample (D.B.N.○) measured the ultimate strain (-850 micro strain, 950 micro strain,-833) at the ultimate torque (20.3625 kN.m) and the sample (D.B.N.□) measured the ultimate strain (886 micro strain, 920 micro strain,-846 micro strain) at the ultimate torque (19.6875 kN.m).

From Figure (10,11and12) a better response to the sample (D.B.N.S), which was hollow free, due to the strength and stiffness of the solid section more than the hollow section, whereas the circular hollow section response was better than the square hollow section.

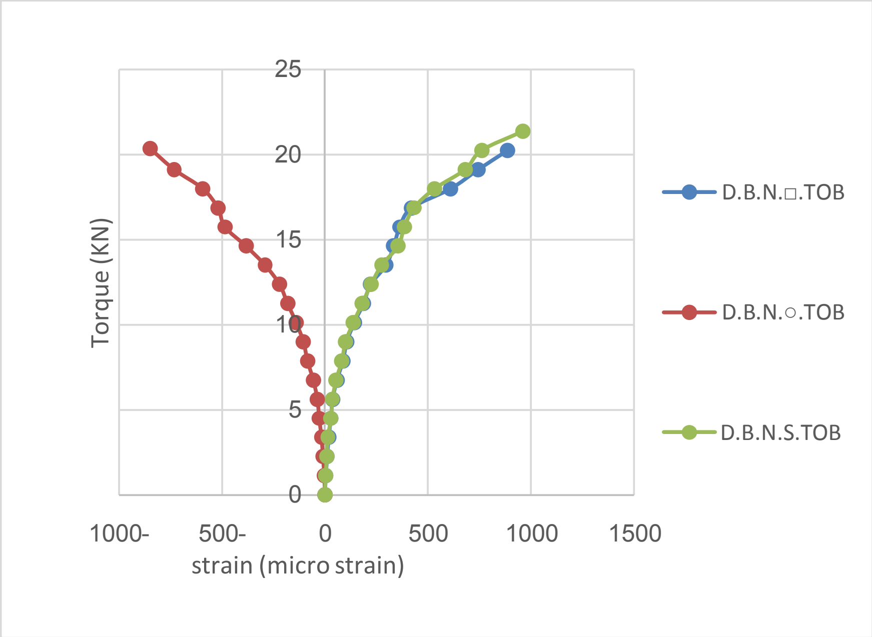


Figure (10) values of Top location of strain gauges

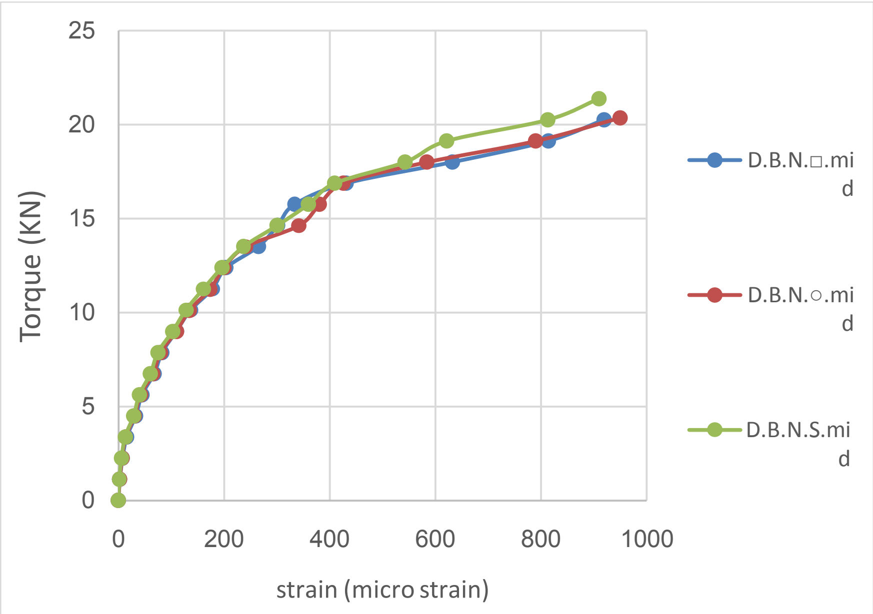


Figure (11) values of middle location of strain gauges

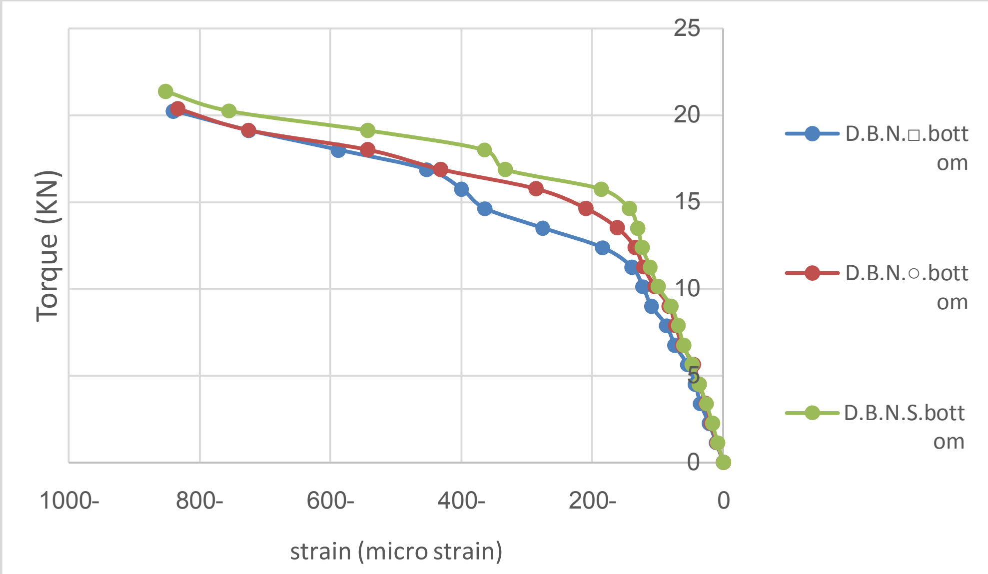


Figure (12) values of bottom location of strain gauges

6.2 - Effect of Self-compacting mixtureon concrete strain: -

In order to see the effect of the use of the SCC mixture on the deep beam samples on their response to the concrete strain, a comparison of the group two samples with the group three samples was made based on the values of the concrete strain gauge which slides into the deep beam at three positions (top, middle and bottom).The sample (D.B.Se.○) was found to have the strongest response to the concrete strain (1010 micro strain, -924 micro strain and -1064 micro strain) at the top, middle and bottom positions respectively. Whereas the sample (D.B.N.□) was weaker in response to the concrete strain (886 micro strain, 920 micro strain and-846 micro strain).Figure (13,14, and15) shows more details.It is clear that the use of the SCC mixture has improved the deep beam response to the concrete strain by significantly improving the behavior of the strain samples and reducing the amount of final strain due to the fact that the SCC mixture has a higher compressive and tensile strength than the NRC mixture and also has a lower internal vacuum and therefore is resistant to the concrete strain.It is noted that some of the values had a negative sign, while others had a positive sign. The reason for this is the location where the crack passes. If the crack passes through the segment of the strain gauge, it gives a positive value, and if it passes aside, it gives a negative value.

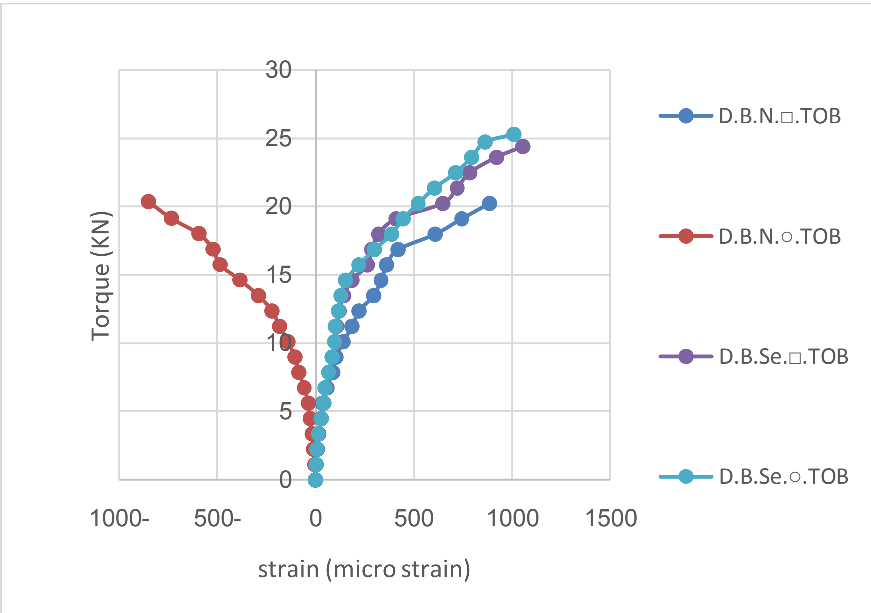
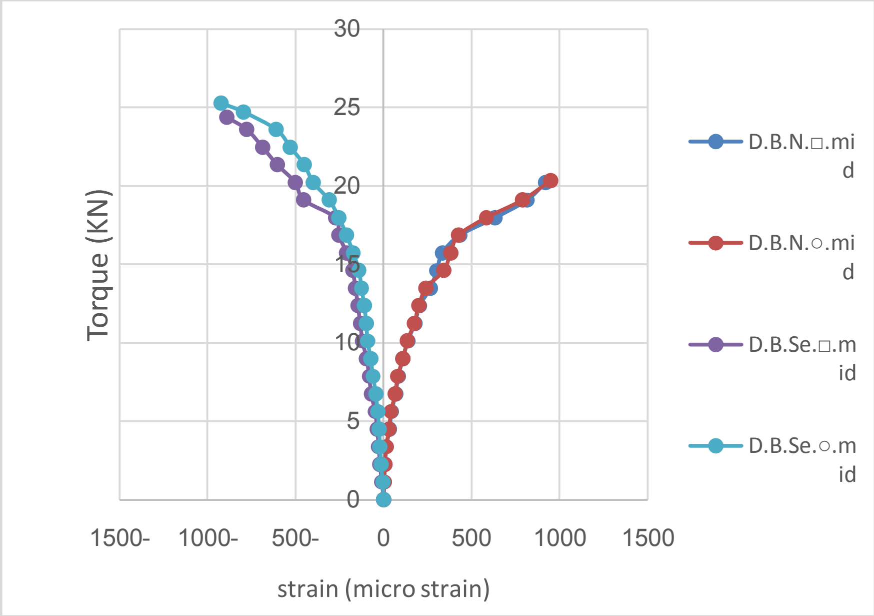


Figure (13) Topreading of concrete strain gage for NRC and SCC samples.



Figure(14) middlereading of concrete strain gage for NRC and SCC samples.

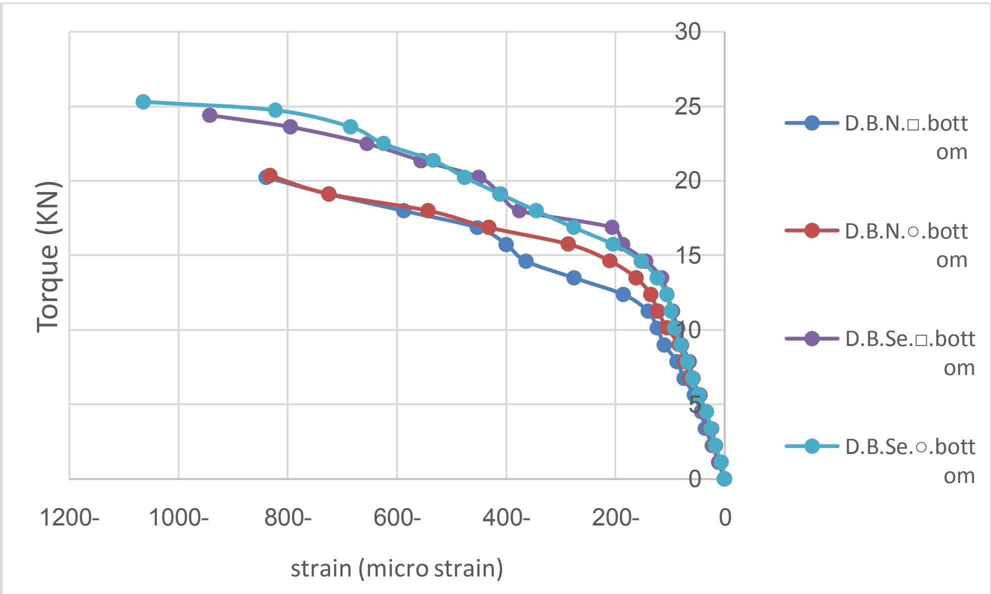


Figure (15) bottom reading of concrete strain gage for NRC and SCC samples

Conclusions

According to the laboratory test results referred to above, the following findings can be reached.

1. The SCC mixture is the strongest in terms of its ultimate load.
2. All samples with a hollow circular section had a better response than those with a hollow square section.
3. 3. Increased compressive strength in the section increases the strength of the deep beam and reduces the angle of twisting.
4. Increasing the compressive strength of the section increases the stiffness of the deep beam, which reduces longitudinal elongation.
5. Increasing the compressive strength and tensile strength of the section increases the strength of the deep beam and reduces the concrete strain.

VII. Acknowledgment

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