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THE EFFECT OF SIFCON ON TORSIONAL BEHAVIOR OF REINFORCED CONCRETE BEAMS

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Abstract: In recent years, research into the effects of torsion in concrete members and the impact of novel materials on torsional behavior has increased. Slurry Infiltrated Fiber Concrete (SIFCON) is a special kind of Fiber Reinforced Concrete (FRC). The purpose of this research is studying the influence of SIFCON on torsion behavior of reinforced concrete beams. In experimental program, five beam specimens are casted and tested under pure torsion. Two of them from normal concrete as a references, two from SIFCON with steel fiber volume 10% and the last beam was normal concrete strengthening by SIFCON with the steel fiber volume 10%. The results have been indicated enhancement in ultimate torsional moment of SIFCON beams when compared with reference, normal concrete beam. In addition, by reducing the twist angle and increasing torsional stiffness, the resistance moment of torsion was improved.

Keywords: *SIFCON, Torsion, strengthening beams, reinforced concrete beams*

1. Introduction

The torsion moment in construction structures was happen when the resultant force be eccentric with respect to the longitudinal axis of the element. In spite that, it happens often, in most cases the torsion is slight and has less effect (compared with other types of loading) in the event of the ultimate limit state [1].

For conventional concrete, the bearing capacity is quite low in terms of tension, with a tensile strength of 0.01-0.1% and a toughness of 0.2-4% when compared with steel structure, so it is a brittle material. The problem of brittle concrete may be solved by adding fiber to the concrete to increasing the energy absorption capacities and flexural strength [2]. So, in 1983 was developed a new concrete type, called Slurry Infiltrated Fiber Concrete (SIFCON) by Lankerd in New Mexico Engineering Research Institute (NMERI) [3,4].

SIFCON is classified as a form of fiber reinforced concrete but it different in the amount of the volume of fiber fraction, may be range from (5-30%) [5,6] and the method of preparing.

The SIFCON is containing on high volume of fibers so the preparing it with ordinary mixing procedure is impossible and to solve this problem, the fibers are filled to capacity in molds before being penetrated by a cement-based slurry. [7-10]. The matrix contains on sand, cement, water, superplasticizer and

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admixture such as silica fume, blast furnace slag or any type of admixture [11-13]

2. Previous Studies

Wang and Keierleber (1991) [14] studied the shear strength of SIFCON, depending on torsion test. Cylindrical specimens of SIFCON were cored from cast blocks, fibers were placed in specimens parallel or perpendicular to cylinder axis. The diameter of cylinder was (44.4 and 69.8) mm, three specimens were used for each diameter and tested in unconfined compression and in torsion. The results showed that the shear strength in specimens that fibers were parallel to cylinder axis greater than specimens that fibers were perpendicular to cylinder axis.

Elavarasi and Mohan (2016) [15] studied effect of silica fume on mechanical properties of SIFCON and compare results with fiber reinforced concrete (FRC), the amount of fiber in FRC was 1% in all samples. In compressive strength and split tensile strength test, the amount of fiber in SIFCON was 10% and percentage of silica fume was (5, 10, 15, 20 and 25) %. The dimensions of cube that used in compression strength were (100) mm while the cylinder dimensions that used in spilt tension strength were (100 mm diameter and 200 mm length). The results showed that SIFCON with 15% of silica fume was the high value in compressive and tension strength. In flexural strength test, reinforced beam used with dimensions 1200 x 100 x 200 mm, the percentage of silica fume was constant (15% optimum value) and the amount of fiber was (6, 8 and 10) %. From results, the flexural strength was optimum value when SIFCON contain on 6 % fiber while there was an improvement in toughness energy absorption at an increase fiber volume

Patil Premachand and Kanase Jayant (2016) [16] investigated improvement the torsional strength of reinforced concrete by add steel fibers. The experimental work included cast four beams with dimension (150x150x2000) mm, one of them without steel fiber while other beams casted with different amount of steel fibers (0.5, 1.0 and 1.5) %. The results showed enhancements in torsion strength when increasing the steel fibers.

Daniel et al. (2017) [17] investigated the effect of silica fume (SF) based geopolymer on the pure torsion. There were some trail mixes with a different percentage in SF (20, 40 and 60) %, the optimum value in compressive strength and spilt tensile strength was when the percentage of SF 40% which was depended in experimental part. Four beams tested with dimension (150x200x1200) mm, two beams from conventional concrete and two beams from geopolymer concrete, the area of longitudinal reinforcement was (383 and 275) mm^2. Torsion moment, stiffness, and toughness increased with increasing area of reinforcement in traditional concrete, but not in geopolymer concrete, because the partial replacement of cement with silica fumes likely reduced interfacial bonding between aggregates, as evidenced by the lower performance of geopolymer concrete. While the ductility was decrease with increasing in area of reinforcement and the geopolymer concrete better than conventional.

Salih et al. (2018) [18] studied the influence of steel fiber and silica fume on some properties of SIFCON. The percentage of silica fume was 10% and the amount of the fiber used were (6, 8.5 and 11) %. Two mixes were used, without silica fume and with silica fume, and each mix had been prepared with three percentages (6, 8.5 and 11) % of steel fiber. The fresh properties for two mixes were convergent such as slump flow test and V-funnel test. In compression test, the specimens were a cubes (100) mm. In spilt tensile test, the specimens were a cylinders

(100x200) mm. The specimens were tested in 7 and 28 days. The results showed increasing in compressive strength and splitting tensile strength with increased the fraction volume of steel fibers. Also, when mix contained on silica fume, the results showed increasing in compressive strength up to 83.7 MPa and splitting tensile strength up to 17.3 MPa at age 28 days.

3. Research Significance

From the previous studies, it can be seen the effect of material on the torsional behavior of reinforced concrete beam, in addition, study the properties of SIFCON. So, the research significance is how it can the employment SIFCON to improve the torsional behavior of reinforced concrete beam.

4. Experimental work

4.1. Experimental Program

The experimental program included casted and tested five reinforced concrete beams under pure torsion up to failure. Two of them was normal concrete beams as references, two beams from SIFCON and another beam made from normal concrete and then strengthening by SIFCON in four sides (fully jackets). The amount of steel fiber in this study was (10%) by volume. In this experimental program, some tested were to find the hardened properties of normal concrete and SIFCON which included compressive strength, tensile strength, modules of rupture and modules of elasticity. Also, to check of fresh properties of SIFCON including, Slump flow and (T50 cm), L-box and V-funnel have been done.

4.2. The Details of Beams

The details of beams have been shown in Table 1. The length was constant (1200mm). In strengthening beam, the cross section before strengthening was (100x200) mm and then strengthening by SIFCON in all sides with thickness (25mm). The reinforcement was constant for all beam specimens. The beams were reinforced by longitudinal reinforcement (4ϕ8), 2 at the top and 2 in the bottom. There wasn't used transvers reinforcement except before the support to work as fixed support as shown in "Fig .1".

Table 1. Specimens' details

Specimen Designation*	NC20	NC25	SC20	SC25	ST25
Length (mm)			1200		
Width (mm)	100	150	100	150	150
Depth (mm)	200	250	200	250	250
Steel Fiber (%)	0	0	10	10	10

*****NC refer to normal concrete, SC refer to SIFCON, ST refer to strengthening beam and the number refer to the depth of beam

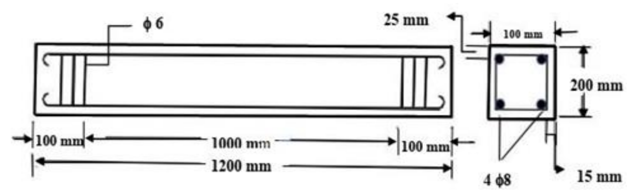


Figure 1. Reinforcement Details of Beams (NC20 & SC20).

4.3. Preparing and Casting Beams

4.3.1 Material

The material used in preparing the beam is listed in "Table 2". All material is according to the Iraqi Specifications.

4.3.2 Mixing and Casting

In this study, two mixtures were employed, as stated in Table 3. The first mixing for normal concrete and the second for SIFCON. Rotary mixing was used to mixing the material as seen in Fig .2. Two wooden molds that thickness is 18 mm have been utilized with dimensions (1200x250x150) mm and (1200x150x100) mm. "Fig .3" shows the molds after clean and oil it and putting the steel reinforcement. After casting, the beams cure in the water tank for 28 days, except (ST25), where at the beginning casted a normal concrete beam and curing in the water for 7days and then leaved it to dry for three days. The sides that will be strengthening have been scratched by hammer and then painted by the acrylic bonding and strengthening as shown in "Fig.4", then the beam curing in the water for 28 days.

Table 2. Characters of Material

Descriptions	Material
Cement	Ordinary Portland Cement (Type I)
Fine aggregate (Sand)	Maximum size was (4.75 mm)
Coarse aggregate (Gravel)	Crushed coarse aggregate with maximum size (19 mm)
Silica fume	Silica fume from SIKA company and marked Mega-Add-MS (D)
Steel Fiber	Steel fiber is hooked-ends with with aspect ratio (64)
Superplasticizer	Superplasticizer is GLENIUM51
Acrylic bonding	Acrylic bonding is compatch AB
Water	Conforming to tap water specification.

Table 3. Mix Design of Concrete

Material	Normal Concrete	SIFCON
Cement (kg/m^3)	400	771.8
Sand (kg/m^3)	600	908
Gravel (kg/m^3)	1200	-
Silica fume (kg/m^3)	-	136.2
Superplasticizer (kg/m^3)	-	15.44
Water (kg/m^3)	180	308.72

Figure 2. Rotary Mixing

Figure 3. Wood Molds

Figure 4. Strengthening Beam

5. Properties of Concrete

5.1. Fresh Property of SIFCON

The SIFCON considered as Self-Compacting Concrete (SCC), according to the EFNARC-2002 (The European Guidelines for SCC) [19] and ACI 237R-07 [20], three tests were conducted in order to determine the fresh properties of SIFCON, which included the filling ability, passing ability and resistance to segregation. The three tests include; slump flow and T50, L-box and V-funnel as shown in "Fig .5&6." The result of tests indicated the SIFCON utilized conforms to the requirements of EFNARC [13] as listed in "Table 4".

Figure 5. L-box Test

Figure 6. V-funnel Test

Table 4. Fresh property of SIFCON

Test	Unit	Result	EFNARC limitation
Slump Flow	mm	705	608-800
T_{50}	sec	3.2	2-5
V-Funnel	sec	10	6-12
L-box	-	0.95	0.8-1

5.2. Hardened Property of Concrete

To find hardened property of concrete, there was a set of testing such as compressive strength (fc' and fcu), tensile strength (ft), modulus of rupture (fr) and modulus of elasticity (Ec). Compressive strength is measured using three cubes and cylinders, tensile strength is measured using three prisms, and modulus of rupture is measured using three prisms and the average results of them were recorded. In modulus of elasticity test, cylinder was used and attached by dial gauge. The dimensions of cubes are (150 mm), cylinders are (150x300) mm and prisms are (500x100x100) mm. The results of tests normal concrete and SIFCON, have been listed in the "Table 5".

Table 5. The Hardened Concrete Properties

Mix type *	NC	SC
fc' (MPa)	31	72
f_{cu} (MPa)	37	77
f_t (MPa)	2.4	4.3
f_r (MPa)	3.375	16.65
E_C (MPa)	26521	38503

*NC refer to normal concrete, SC refer to SIFCON

6. Measurements, Instrumentation and Test Procedure

6.1. Measurements and Instrumentation

All beam specimens have been tested in a hydraulic machine which an available in Laboratory of Structural Engineering-College of Engineering-Mustansiriyah University, (3000 kN) is the maximum capacity of this machine. To find the twist angle, two dial gauges have been used and the result token as the average of them. The accuracy of dial gauge is (0.001 mm), located at the end of arm loading, as shown in "Fig .7".

Figure 7. Dial Gauge Located

6.2. Procedure of Testing

Install tested beam samples as shown in "Fig .8". The sample of the beam attached to be tested to the supports of the machine that can be adjusted to be rotatable, so the sample can rotate freely at the ends around the axis of its longitudinal axis the load is applied to the center of a wide-flanged steel beam, which distributes it evenly to the loading arms as two loads centered out of the longitudinal axis of the beam samples under test with a distance of (460 mm), except the beam (NC20 and SC20) with distance (435 mm). This eccentric distance is required for the twisting to occur at the sample ends by transferring the loading on the arms as a concentrated torque at the sample ends and a concentrated vertical force transmitted directly to the support. The applied loads of the first visible crack (Pcr) and final failure (Pu) were recorded. Obviously, this setting is symmetric around the middle of the sample period except for (T) which has the opposite meaning at the ends.

Figure 8. Installation Tested Beam

7. Test results and Discussion

7.1. Mechanism Failure

The progress of cracks provided useful facts regarding the failure mechanism of tested beam specimens. It was found that all of the beams that were tested failed in torsion. In all specimens, the first crack was appeared at weaker zone and after that it increased gradually. When the torque moment was increased, cracks appeared on each side and finally took the helical shape. For the beams made from normal concrete (NC20 and NC25) The first cracks have been occurring at the mid-span of beams when the loading reach to cracking load (tensile limit). Any increasing in loading, the cracks increasing until appeared around all sides of beams to formed continuous spiral shape. For SIFCON beams (SC20 and SC25), the steel fibers have been worked to made the beams less twisting from normal concrete beams. The cracks were occurred at the mid of span. The strengthening beam (ST25), the strengthening was working to resists the twisting results the applied of loads. These beams, when occurring the cracking it, the cracking was formed at the strengthening area and the heart of beams, "Fig .9".

7.2. Cracking and Ultimate Load

The load was applied on tested beam specimens up to point of failure, Scientifically, the cracking torque capacity is defined as the load when the tensile stresses have attained the tensile strength of concrete. Practically, the load of cracking is the first crack which apparent on the specimen, while the ultimate torque is the moment that beams have been failed and cannot resists any increasing in applied load. The cracking and ultimate load (Pcr and Pu) have been recorded, then, the cracking and ultimate torque (Tcr and Tu) calculated, see “Table 6” and "Fig .10”.

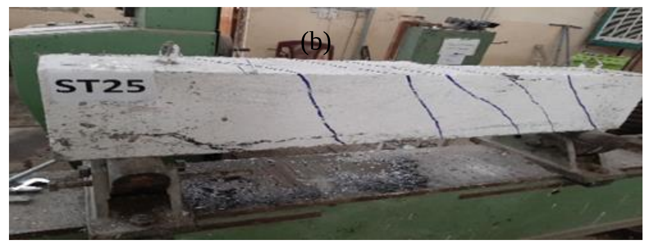
When compared the beams with reference beam (NC20), the cracking torque (Tcr) is increasing about (29.99%), (90.36%) and (69.21%) and ultimate torque (Tu) is increasing about (62.65%), (145.82%) and (116.59%) for SC20, SC25 and ST25 respectively. Also, when compared the beams with NC25, there are increasing in cracking torque reach to (2.43%), (50%) and (33.33%) and ultimate torque reach to (23.49%), (94.17) and (65.05%) for SC20, SC25 and ST25 respectively.

(a)

(b)

(c)

(d)



(e)

Figure 9. Cracking of Tested Beams: (a) NC20, (b) NC25, (c) SC20, (d) SC25, (e) ST25

It can be seen that used the SIFCON improvement the torsional behavior, see "Fig .11". Also, the use large cross section gives more increasing in torque compared with small cross section. The increasing in cracking torque (Tcr) less than the increasing in ultimate torque (Tu). This may be resulted from the fact that at beginning of loading, the concrete only resists the applied loading and first crack appeared at mid-span. After that reinforcing steel begin to have its role in resisting the applied load. During the final phases of loading, the steel fiber in SIFCON will primarily withstand the imposed load. On other point of view, it can be said that, the (Tcr) value depends mostly on concrete's contribution to the applied load, but the (Tu) value depends on concrete, reinforcing steel, and steel fiber contributions. SIFCON's torsional ultimate capacity has been significantly improved as a result of its adoption.

Table 6. Cracking and Ultimate Torque

Beam Specimens	NC20	NC25	SC20	SC25	ST25
P_{cr} (kN)	25	30	32.5	45	40
P_u (kN)	41.5	51.5	67.5	100	85
T_{cr}(kN.m)*	5.44	6.90	7.07	10.35	9.20
T_u (kN.m) *	9.03	11.85	14.68	23	19.55
Increasing** in Tcr (%)	0	-	29.99	90.36	69.21
Increasing** in Tu (%)	0	-	62.65	145.82	116.59
Increasing*** in Tcr (%)	-	0	2.43	50	33.33
Increasing *** in Tu (%)	-	0	23.49	94.17	65.05

*T=P*L/2
**refer to increasing relative to NC20 and ***refer to increasing relative to NC25

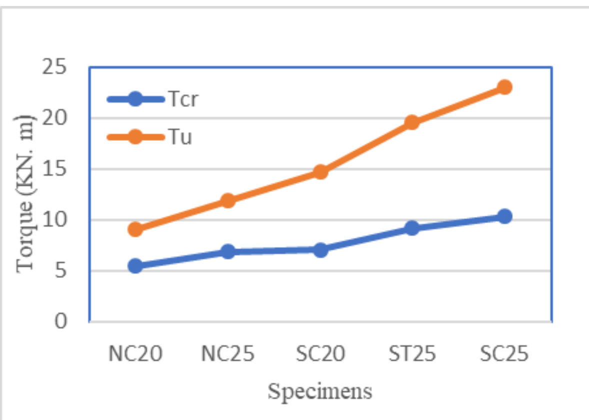


Figure 10. Cracking and Ultimate Torque

7. 3. Behavior of Twisting Angle

Torque-angle of twist (θ) relationship is shown in "Fig.12". The formula was applied to determine the twist angle as follow:

$$\text{Angle of twist } (\theta) = \tan^{-1} \Delta/L$$

It can be seen; the stronger beam has small angle of twist when compared with other beams. In this research the stronger beam is SC25, the decrease in angle of twist for beam (SC25) was due to the increasing in torsional stiffness. see "Table 7".

Table 7. Angle of Twist

Beam Specimens	θu* (rad)	$\theta u/\theta_1$ *(%)	$\theta u/\theta_2$ *(%)
NC20	0.03519	100	-
NC25	0.03345	-	100
SC20	0.03254	92.469	97.279
SC25	0.02022	57.459	60.448
ST25	0.02431	69.082	72.675

*θu refer to ultimate twist angle in beam specimens, θ_1 refer to ultimate twist angle in reference beam (NC20) and θ_2 refer to ultimate twist angle to reference beam (NC25)

7.4. Torsional Stiffness (KT)

Rotational stiffness can be specified as an ability of a body to resisting the deformations as a response to all applied loading [21]. It's considered a function of material property (a function of rigidity). Structural members may have a rotational stiffness (KT); which is given by: - KT=M/θ

Where: -
M= Applied torque (kN.m).
Ѳ= Twist angle (rotational in radian), see "Table 8".

Table 8. Torsional Stiffness (K_T)

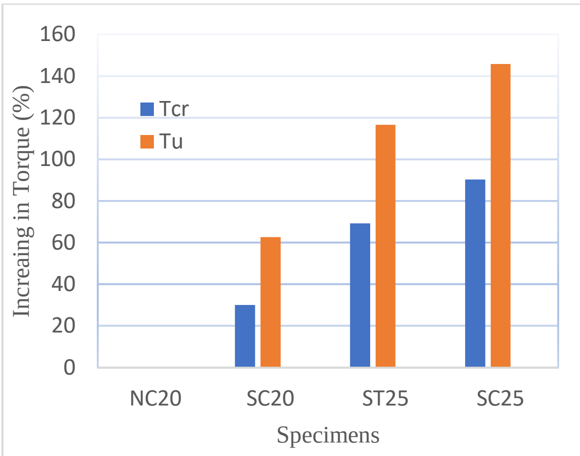
Beam Specimens	K_T(kN.m/rad)
NC20	256.493
NC25	354.110
SC20	451.167
SC25	1137.784
ST25	804.195

8. Conclusion

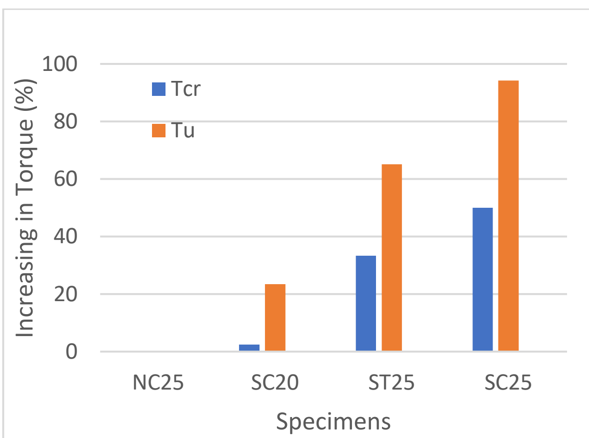
The following conclusion is depending on the results and discussion which be present in this research.

1. Ultimate torque capacity has been increased by 62.65%, 145.82%, 116.59% for SC20, SC25 and ST25 respectively when compared with reference beam NC20. Also, when compared the (SC20,

SC25 and ST25) with other reference beam (NC25), the increasing in ultimate torque reach to 23.49%, 94.17% and 65.05% respectively.



(a)



(b)

Figure 11. Increasing in Cracking and Ultimate Torque, (a) Relative to NC20, (b) Relative to NC25

2. Using SIFCON has been improving the torsional capacity, in both SIFCON and strengthening beams when compared with normal concrete, the SIFCON with a large cross-section beam (SC25) has the maximum value in comparison with other sections.

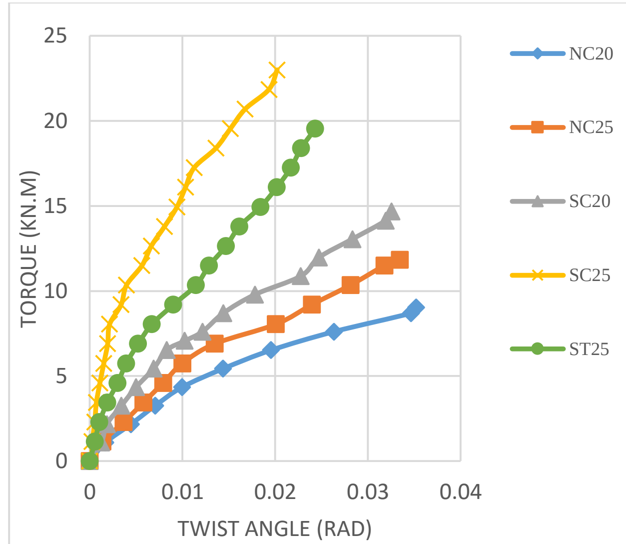


Figure 12. Torque-Angle of Twist in Beam Specimens

3. Using SIFCON in strengthening gave improving in torsional behavior and it's the smallest cast section when compared with strengthening by normal concrete.
4. The resistance moment of torsion was improved when using SIFCON by reducing the twist angle and increasing torsional stiffness.

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Conflict of Interest

There is no conflict of interest associated with the publishing of this paper.

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