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# EFFECT OF STRENGTHENIG BEAM SIDES ON TORSIONAL BEHAVIOR BY USING SIFCON

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**Abstract:** The needed of strengthening or repair damaged beams which has been increased at the last years. In this research, the main aim is investigated the effect of strengthening beams sides on behavior of torsion. The strengthening was by using Slurry Infiltrated Fiber Concrete (SIFCON). The SIFCON is regarded to be a specific form of Fiber Reinforced Concrete (FRC). Hooked ends steel fibers were utilized with aspect ratio 64 and steel fiber volume percent were 8, 10 and 12%. Nine beams have been casted and tested under pure torsion, four beams taken as a reference (two from conventional concrete and two from SIFCON) and five beams strengthening by SIFCON. The strengthening implemented in two, three and four sides. According to results, torsion capacity has been improved in strengthening beams. Also, the strengthening in four sides was better than strengthening provided by two and three sides which has an increasing the torsion moment. In addition, the increasing steel fiber leads to improve the torsion strength in strengthening beams.

***Keywords:*** strengthening beams, SIFCON, torsion, steel fiber and toughness.

## 1-Introduction:

The torsion moment in reinforced concrete member was studies firstly in the early twentieth century. There have been theoretical models developed; these models can be classified into two categories: The Skew–Bending Theory and the Analogy of the Space Truss. The American code depending on the skew-bending theory between 1971 and 1995 since that time, is depending on space truss analogy. Also, the European code depending on space truss analogy ever since 1978. The most recent theory is the Variable Angle Truss-Model, which was developed to unify the torsion design of small and large sections of reinforced and prestressed concrete (for example, small parts in building structures and large sections in bridges) [1].

Torsional loads are applied to reinforced concrete (RC) structural components such as ring beams, edge beams, shell roofs, peripheral beams on each level of multi-story structures, supporting beams for canopy slabs, and spiral stairs. [2].

Sometimes, the existing structures may be damaged due to the environmental effects such as change in temperature, the corrosion of steel and freeze-thaw cycles so it is needed to repair. On another hand, many structures are needed to strengthening due to the increasing in allowable loads or new codes have made the structures substandard [3]. So, the using of the technical of strengthening beam under pure torsion have been increased.

In 1983, Slurry Infiltrated Fiber Concrete (SIFCON) was introduced to the New Mexico Engineering Research Institute (NMERI) by Mr. David Lankard and then developed [4,5]. SIFCON is contain on fiber between 5-30% is relative to volume [6,7]. To preparing SIFCON, the fiber putting on the bed of molds and then infiltrated by the cement-base slurry [8-10]. The cement in SIFCON replace with mineral admixture, for example silica fume, to reduce the permeability and increasing the strength in concrete [11]. There are various types of steel fiber utilized to preparing the SIFCON, but the most commonly utilized types are hooked end and crimped fibers. Also, the straight and deformed fibers are utilized, but they are less popular [12]

SIFCON is a relatively new concrete that is primarily used in applications that require both ductility and strength. Shells, plates, pressure vessels, marine structures, military installations, prestressed concrete, underground structures, earthquake-resistant structures, airport pavement parking, bridge decks, explosive-resistant structures, and other significant structures are examples of using SIFCON. Because of their excellent energy absorption capabilities, they are also used in bridge structure rehabilitation and pavement repair, defensive structures, and safe basements. However, SIFCON has a disadvantage in that it has a relatively high density because it contains a high amount of fiber and is corrosive. [13].

## 2- Previous Studies

Jamal Shannag et al (2001) [14] studied the influence of using SIFCON as a repair material to enhancement the shear capacity in beams. The experimental work included cast fourteen reinforcement concrete beams, with cross- section (150x200) mm and span 2000 mm, after tested all the beams under third-point loading until reach to failure, four of these beams were rehabilitated by SIFCON jackets. The results showed enhancement in shear strength about 25-50% and prohibited brittle shear failure in repaired beams.

Adel M. Gilani (2007) [15] studied some characterizes of SIFCON and influence matrix type, fiber content and steel fiber geometry on durability of SIFCON. The matrices used for SIFCON were slurry and mortar, in addition to a plain concrete mix. Each SIFCON mix was made with two different types of steel fibers, hooked and crimped, and three different fiber volume fractions, 7 %, 9.5 %, and 12 %. The cylindrical specimens' dimensions were 68mm in diameter and 135 mm in high. Despite its apparent high water absorption, the results indicated that SIFCON prepared with mortar had good durability characteristics. Also, the highest steel fiber in SIFCON showed better results.

Mehran et al (2007) [16] studied the using of (FRP) as a strengthening material for reinforced concrete beams under pure torsion. In experimental part, twelve beams with cross section (150x350) mm and length 1900 mm were casted and tested under pure torsion. Theses beams divided into two sets, each set included reference beam, the first set had strengthened by carbon fiber while the second set had strengthened by glass fiber. There was difference in application the strengthening such as warped (fully or U-warped), number of layer (1 or 2) and the composite was applied in discrete strips or continuous along the length of the test region. The results indicated that occurs increasing in the strength of torsion of fully wrapped beams considerably. Also, there was enhancement in ductility. The numerical section contains results from analyses performed with the ANSYS finite element program. Predictions are compared to experimental results and are found to be in reasonable agreement.

Abdul-Hussein (2010) [17] investigated the torsional behavior of reinforced reactive powder concrete (RPC) beams. The contain of fractional steel fiber volume was (0, 0.5, 0.75 and 1) %. The experimental work included tested fifteen beams, solid and hollow section, with cross section (150x150) mm and length 1020 mm. Transverse and longitudinal steel ratios in varying amounts were employed. The results indicated that the cracking torque increased by 43.3 % and 65.6 %, respectively, for solid and hollow RPC beams and ultimate torque was 57.7% and 53.2% for solid and hollow RPC beams respectively when adding 1 % fibers to concrete mix. The increasing in transverse and longitudinal have been improved in cracking and ultimate torque. Furthermore, it was discovered that, at various stages after cracking, the length of solid and hollow RPC beams increases almost linearly with the increase in applied torque.

Mohammed et al (2016) [18] investigated the torsional behavior of reinforced concrete beams strengthening with ultra-high performance fiber reinforced concrete (UHPFC) jackets. The experimental work included casted eleven beams without any transvers reinforcement, with cross section of beams (100x200) mm and length 1600 mm, one beam was taken without strengthening as a control beams while other beams had strengthened. The strengthening was on two, three and four sides and also there was different in the thickness of strengthening which was (10, 15, 20, and 25 mm) except two sides (15 and 25 mm). In addition, finite element analysis was carried out in conjunction with experimental work in order to compare and justify the effectiveness of the repair technique used. The results indicated enhancement in torsion behavior of all strengthening beams compared with control beams. In addition, the optimum value of torsion was in the beam strengthening by four sides with thin layer. Finally, there was a good agreement between finite element analysis and experimental results.

Al-Rousan and Shannag (2018) [19] studied the SIFCON as shear strengthening and repairing materials for normal strength reinforced concrete beams. The experimental works included cast thirteen reinforced concrete beams (150x170x2000) mm with a shear span to effective depth (a/d) ratio of 1.2, 2.2, and 3.0, respectively; additionally, the longitudinal reinforcement content was1.29%, 1.76% and 2.28%. The thirteen beams had tested under four-point loading, nine of them were as reference while the four remain were strengthening by using SIFCON jackets after testing as reference beams. The volume of steel fiber was 8%. The results showed that SIFCON jacketed beams had perfect shear capacity, improved crack stiffness, brittle shear failure, and increased the ultimate shear strength of strengthened beams from 37% to 53%. As a result, SIFCON is an excellent repair and strengthening material.

Hameed, et al (2020) [20] studied the behavior of layers SIFCON used as a retrofing material. The purpose of this study is to indicate the impact of different volumes of steel fibers [6.0, 7.5, and 9.0] % utilized in the casting of different thicknesses layers of SIFCON [15, 25, and 35] mm on the response of ductility, toughness, prisms to the load-deflection curve and flexural strength of SIFCON layers. In addition, the position of the SIFCON layer [top, top and bottom, and jacking] was investigated following the above-mentioned characteristics. It was discovered that increasing the volume percentage of steel fibers as well as the thickness of the SIFCON layer improves the ductility, toughness and load-carrying capacity of the strengthened prisms. The maximum load was reached approximately ten times that of the control. The toughness was approximately 105 times greater than the control. The ductility was also increased when using epoxy-bonded the SIFCON layer.

## 3. Experimental Part

### 3.1 Experimental Work

The aim of this research is to investigate and improve the torsional behavior of rectangular beams under pure torsion. Also, the efficiency of strengthening technique and then compared the results with normal concrete beams and SIFCON beams. In addition, cubes, cylinders, and prisms were used to determine the hardened qualities of concrete. Various tests were used to calculate the fresh characteristics of SIFCON.

### 3.2 Description of Beams

Nine beams were casted and tested under pure torsion, two beams had made from normal concrete, two beams had made from SIFCON (the four beams taken as a reference) and five beams had made from normal concrete and then strengthened by SIFCON. The length of beam was constant 1200 mm while the cross section was varied, also there were some variables such as the steel fibers volume fractional and the number of warped sides as shown in the table 1. For all beams, the reinforcing was the same. Longitudinal reinforcement (4ϕ8), two at the top and two at the bottom, was used to reinforce the beams. Transvers reinforcement (ϕ6) was not employed except before the support to act as a fixed support, as indicated in figure1.

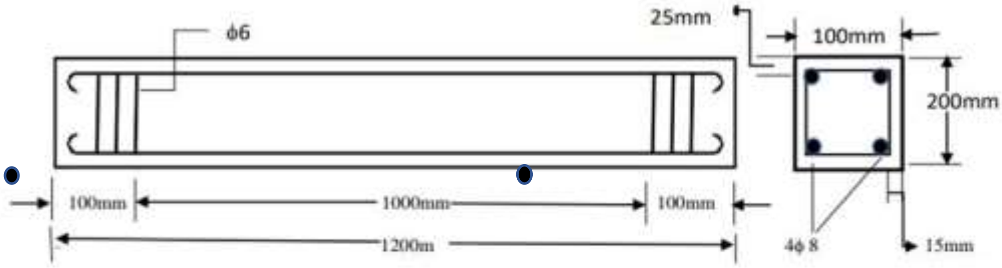


Figure 1. Reinforcement in Beams

Table 1. Description of Beams

| Symbols | Description | Section Dimension (h x b) (mm) | Steel fiber volume % |
|---|---|---|---|
| NC20 | Normal concrete | 200x100 | ____ |
| NC25 | Normal concrete | 250x150 | ____ |
| SC20 | SIFCON | 200x100 | 10% |
| SC25 | SIFCON | 250x150 | 10% |
| ST20 | Strengthening beam (two sides) | 200x150 | 10% |
| ST22 | Strengthening beam (two sides and bottom) | 225x150 | 10% |
| ST25 | Strengthening beam (Fully jackets) | 250x150 | 10% |
| STE25 | Strengthening beam (Fully jackets) | 250x150 | 8% |
| STT25 | Strengthening beam (Fully jackets) | 250x150 | 12% |

### 3.3 Construction Material

#### 3.3.1 Cement

Ordinary Portland Cement (OPC) (Type-1) have been used according to Iraqi Specifications Limits (IQS) NO.5/1984 [21].

#### 3.3.2 Fine Aggregate

The fine aggregate used in this study was from Iraqi Origen (zone 3) according to IQS No. 45/1984 [22].

#### 3.3.3 Coarse Aggregate

The maximum size of coarse aggregate was 19 mm according to IQS No.45/1984 [22].

#### 3.3.4 Water

The water had used in casting and curing the specimens was ordinary tap water according to Iraqi specifications No. 1703/1992 [23]

#### 3.3.5 Silica Fume

Silica fume was from sika company. The silica fume chemical composition conforms to ASTM C-1240-05 [24].

#### 3.3.6 Steel Fiber

Hooked ends steel fiber with aspect ratio 64 was used as shown in figure 2. 8, 10 and 12 % volume fraction of steel fiber have been utilized in SIFCON.

Figure 2. Hooked Ends Steel Fiber

### 3.3.7 High Range Water Reducing Admixture

The high range water reducing admixture (superplasticizer) was used in the present study based on polycarboxylate. The commercially name was (GLENIUM51), it is in accordance to ASTM C494M-99a (Types F and A) [25].

### 3.3.8 Acrylic Bonding

The acrylic bonding was used to bond the SIFCON with normal concrete in strengthening beams. The Commercial name was Cempatch AB.

### 3.4 Mixing and Casting

As shown in table 2, two mixes were used in this investigation, normal concrete and SIFCON mixture. Rotary mixing was employed to mix the material. Wooden molds with a thickness of 18 mm and dimensions of (1200x250x150) mm and (1200x150x100) mm were used. Figure.3 shows the molds after they have been cleaned and oiled and the steel reinforcement has been added. After casting, the beams cure in the water tank for 28 days, with the exception of strengthening beams, which are initially cast as a normal concrete beam and cured in the water for 7 days before being left to dry for three days. The strengthened sides have been scraped with a hammer and then painted with acrylic bonding and strengthening as shown in figure 4, followed by the beam curing in water tank for 28 days

Table 2. Mixing Design

| 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 |
| Water (Kg/m$^3$) | 180 | 308.72 |
| Superplasticizer (Kg/m$^3$) | ____ | 15.436 |

Figure 3. Wooden Molds

Figure 4. Preparing the Strengthening Beams

## 5. The Fresh and Hardened Properties

### 5.1 Fresh Properties of SIFCON

The SIFCON is classified as a Self-Compacting Concrete (SCC). Three tests were carried out to finding the fresh properties of SIFCON included slump-flow and $T_{50}$, L-box and V-funnel. The results listed in table 3.

Table 3. Testes Results of Fresh SIFCON

| Test | Property | Unite | Result | EFNARK limitation [26] |
|---|---|---|---|---|
| Slump flow | Filling ability | mm | 705 | 650-800 |
| $T_{50}$ | | sec | 3.2 | 2-5 |
| V-funnel | Filling ability | sec | 10 | 6-12 |
| L-box | Passing ability | - | 0.95 | 0.8-1 |

### 5.2 2 Hardened properties of concrete

There are some tests carried out in this study included compressive strength ($f_c'$ and $f_{cu}$), splitting tensile strength ($f_t$), modules of rupture ($f_r$) and modules of elasticity ($E_c$) to determining the hardened properties of normal concrete and SIFCON with different in volume fraction of steel fiber (8, 10 and 12%) as shown in figure 5. The results of tests have been listed in table 4.


Figure 5. Hardened Properties of Concrete Tests

Table 4. The Hardened Concrete Characterizes

| Mix type | Compressive strength (MPa) | | $f_r$ (MPa) | $f_t$ (MPa) | $E_c$ (MPa) |
|---|---|---|---|---|---|
| | (fc') | ($f_{cu}$) | | | |
| NC* | 31 | 37 | 3.375 | 2.4 | 26521 |
| SIFCON-8% | 65 | 70 | 14.6 | 4.1 | 36825 |
| SIFCON-10% | 72 | 77 | 16.65 | 4.3 | 38503 |
| SIFCON -12% | 78 | 84 | 19.125 | 4.6 | 41325 |

*Normal concrete

**6.Test Procedure**

After curing the beams, painted by white color to make cracks as visible. All beam specimens have been tested under pure torsion to failure in a hydraulic machine which an available in Laboratory of Structural Engineering-College of Engineering-Mustansiriyah University, (3000 KN) is maximum capacity of this machine as shown in figure 6. The arm of loading was 460 mm accepted in (NC20&SC20) which is equal to 435 mm. To finding angle of twisting, two dial gauges (0.01mm/div) have been utilized at the ends of arm loading. The dial gauge is recorded the vertical deviation at each loading stage.

Figure 6. Test Beams Machine

**7. Results and Discussion**

**7.1 Cracking and Ultimate Torque**

The load was applied to the tested beam specimens until they failed. The cracking torque ($T_{cr}$) and ultimate torque ($T_u$) have been measured and listed in table 5 and figure 7.

When the three reference beams are compared to reference beam one (NC20), the cracking torque increases by roughly (26.908%) for beam (NC25), and between (29.98% and 90.362%) for SIFCON beams (SC20 and SC25), respectively. The SIFCON with small section (SC20) showed an increase of approximately (2.434%) over (NC25), while (SC25) showed an increase of around (50%) and 46.434%) over (NC25 and SC20), respectively. When compared (ST20) with reference beam (NC20), there is increasing in cracking torque about (22. 677%) while there is decreasing when compared with NC25, SC20 and SC25. Also, (ST22 and ST25) are appeared improvement in cracking torque excepted when compared it with SC25. Full jacket strengthening has been more effect on cracking torque. So, the type of strengthening has been effect on cracking torque. The volume of steel fiber fraction has effective influence on cracking torque. The beam which strengthening by SIFCON with steel fiber (12%) increasing the cracking torque about (79.786%, 41.666% and 38.299%) when compared with NC20, NC25 and SC20 respectively and decreasing about (6.556%) when compared with SC25. The beam (STE25) has impact on cracking torque less than ST25 and STT25, see figure 8.

Also, the ultimate torque has been improved. For reference beams (NC25, SC20 and SC25), when compared with (NC20), there is an increasing in ultimate torque reach to (31.231, 62.652 and 145.819%) respectively. The SIFCON beams (SC20 and SC25) have strength more than normal concrete beams, SC20 and SC25 better than NC20 and NC25. Also, the change the cross section of beams has affected on ultimate torque, SC25 given increasing in ultimate torque about (56.665%) more than (SC20). For strengthening beams with steel fiber volume fraction (10%) SIFCOIN, (ST20) indicated the increasing in ultimate torsional moment when compared with (NC20 and NC25) but there is decrease when compared with SIFCON beams (SC20 and SC25). The beams strengthening in three sides (ST22) was better than conventional concrete beams (NC20 and NC25) and almost equivalent to (SC20) in ultimate torque, so that means it can be used the technique of strengthening the beams by SIFCON to given ultimate torque almost equivalent to (SC20) and at a lower cost which is very important in civil engineering. (ST25) is the best in ultimate torque compared with (ST20 and ST22). the effect of steel fiber volume fraction on ultimate torque. (12%) of steel fiber have been more effective on ultimate torque. (STT25) have an increasing in ultimate torque reach to (135.707, 79.611, 44.951, 27.586 and 8.823%) when compared with (NC20, NC25, SC20, STE25 and ST25) respectively. So, it can observe the increasing in steel fiber gave increasing in ultimate torque, see figure 9.

Table 5. Cracking and Ultimate Torque

| Sample | NC20 | NC25 | SC20 | SC25 | ST20 | ST22 | ST25 | STE25 | STT25 |
|---|---|---|---|---|---|---|---|---|---|
| $P_{cr}$ (KN) | 25 | 30 | 32.5 | 45 | 29 | 32.5 | 40 | 37.5 | 42.5 |
| $P_u$ (KN) | 41.5 | 51.5 | 67.5 | 100 | 57.5 | 65 | 85 | 72.5 | 92.5 |
| $T_{cr}$ (KN.m) | 5.437 | 6.9 | 7.086 | 10.35 | 6.67 | 7.475 | 9.2 | 8.625 | 9.775 |
| $T_u$ (KN.m) | 9.026 | 11.845 | 14.681 | 23 | 13.225 | 14.95 | 19.55 | 16.675 | 21.275 |
| Increasing[1] in $T_{cr}$ % | _ | 26.908 | 29.988 | 90.362 | 22.677 | 37.483 | 69.21 | 58.63 | 79.786 |
| Increasing[1] in $T_u$ % | _ | 31.231 | 62.652 | 145.819 | 46.521 | 65.632 | 116.596 | 84.744 | 135.707 |
| Increasing[2] in $T_{cr}$ % | _ | _ | 2.434 | 50 | -3.333 | 8.333 | 33.333 | 25 | 41.666 |
| Increasing[2] in $T_u$ % | _ | _ | 23.492 | 94.174 | 11.650 | 26.213 | 65.048 | 40.776 | 79.611 |
| Increasing[3] in $T_{cr}$ % | _ | _ | _ | 46.434 | -5.631 | 5.785 | 30.164 | 22.028 | 38.299 |
| Increasing[3] in Tu % | _ | _ | _ | 56.665 | -9.917 | 1.832 | 33.165 | 13.582 | 44.915 |
| Increasing[4] in $T_{cr}$ % | _ | _ | _ | _ | -35.555 | -27.777 | -11.111 | -16.666 | -5.555 |
| Increasing[4] in $T_u$ % | _ | _ | _ | _ | -42.5 | -35 | -15 | -17.5 | -7.5 |

1 refer to increasing relative to NC20, 2 refer to increasing relative to NC25, 3 refer to increasing relative to SC20 and refer to increasing relative to SC25

The increase in cracking torque (Tcr) is smaller than the increase in ultimate torque (Tu). This might be due to the fact that at the start of loading, the concrete just resists the applied stress, and the first crack appears at the mid-span. Following that, reinforcing steel begins to play a part in resisting the imposed load. The imposed load will be mostly resisted by steel fiber in SIFCON at the latter phases of loading. In other words, the (Tcr) value is primarily determined by the contribution of concrete to the resistance of applied load, whereas the (Tu) value is determined by the contributions of concrete, reinforcing steel, and steel fiber. As a consequence, it is possible to conclude that the ussing SIFCON in strengthening provides a significant increase in torsional capacity.

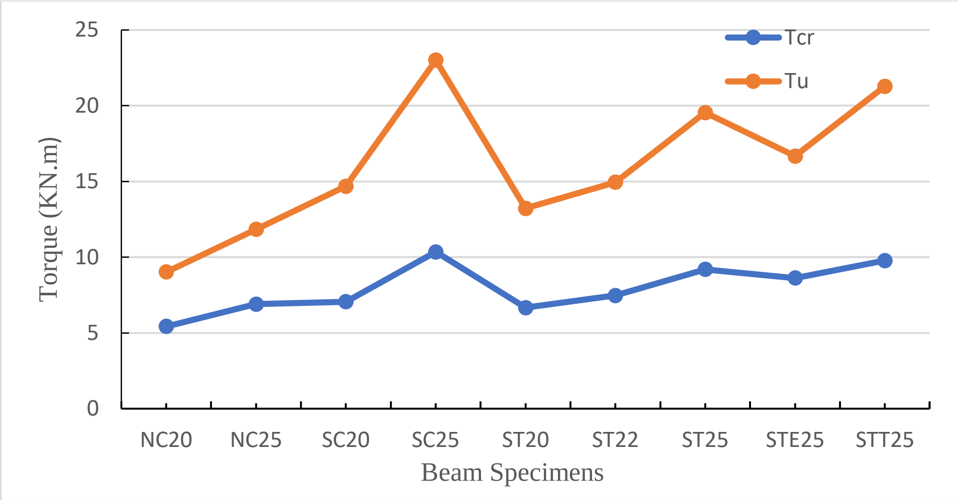


Figure 7. Cracking and Ultimate Torque

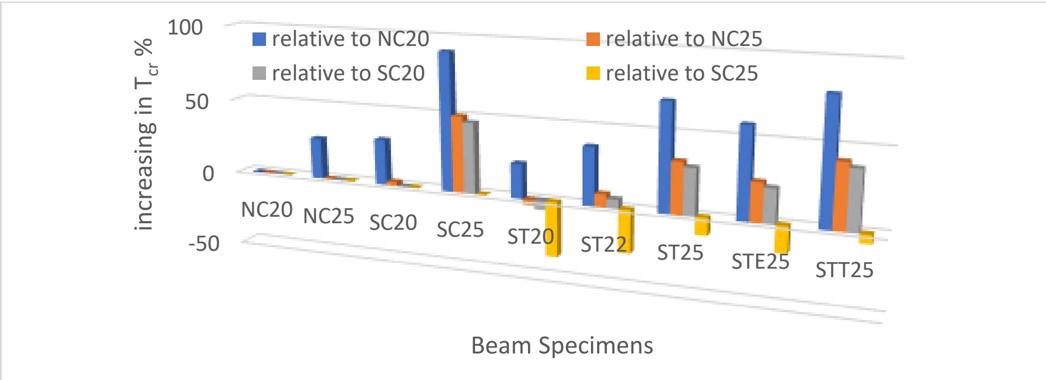


Figure 8. Increasing in Cracking Torque

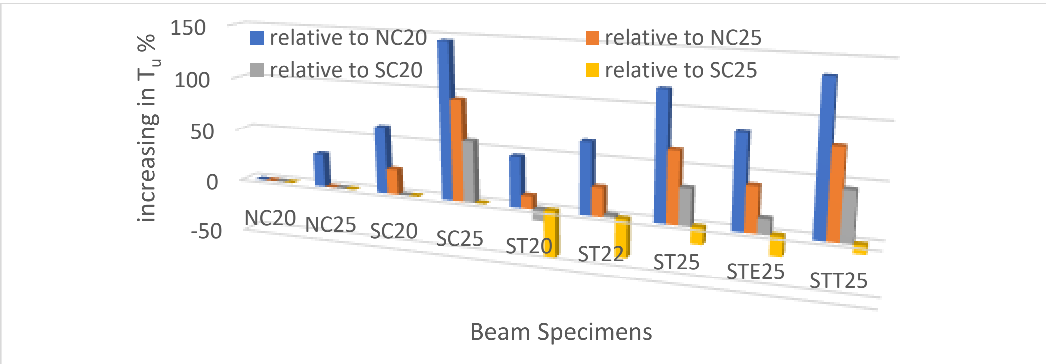


Figure 9. Increasing in Ultimate Torque

**7.2 The Mechanism of the Failure**

The progression of crack revealed valuable information on the failure mechanism of the tested beam specimens. All of the tested beams failed in torsion. In any specimen, the initial crack occurred in the weaker zone and eventually expanded in size. When the torque moment was increased, cracks formed on both sides, eventually forming a helix shape. Figure 10 depicts the failure mechanisms for the tested beams. All beam specimens collapsed due to significant diagonal concrete cracking (torsional spiral cracks).

For the conventional concrete beams (NC20 and NC25), the beams were twisted prior to loading without developing any cracks. When the loading reaches the cracking load, the first crack appears in the mid-span of beams (tensile limit). With increased loading, cracks propagate around both sides of beams, forming a continuous spiral structure. The beams failed due to developing cracks in the mid-span.

SIFCON beams (SC20 and SC25) have had the steel fibers treated to reduce cracking width compared to normal concrete beams. The cracks appeared in the middle of the span.

For strengthening beams, the reinforcement was designed to withstand twisting caused by applied stresses These beams, when the cracking occurring, the cracking was formed at the strengthening area and the core of beams this mean that strengthening was well worked. Indicating that the strengthening was properly performed. Additionally, these cracks were larger and more numerous in beams with a lower in sides of strengthening as shown in beam (ST20). Also, in fully jackets beams, the cracks were a large when the volume of steel fiber be less as shown in (STE25). Also, The SIFCON layer that was used in the strengthening did not separate from the beam during the loading stage, and this indicates the effectiveness of the SIFCON strengthening technique.


Figure 10. Cracks Pattern in Tested Beams

### 7.3 Torque-Twist of Angle Behavior

As mentioned before, two dial gauges have been used. Twist angle are measured by finding the average of two dial gauge as shown in figure 11. It can be seen, the using SIFCON reduce the twist of angle of both SIFCIN and strengthening beam and that means enhancement torsional behavior

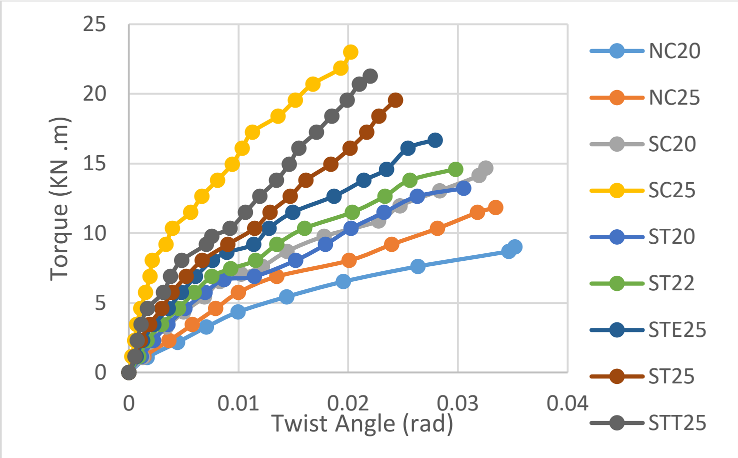


Figure 11. Torque-Twist of Angle Behavior

### 7.4 Toughness

Table 6 listed the toughness measurement for all tested beams. The toughness can be considered as an indicator of ductility. For all beams, the area under the torque-angle twist curve was used to determine toughness [27]. In this study, the program Microsoft Excel used to find the area under the torque-angle twist. Table 6, shows the increasing in the toughness for SIFCON and strengthening beams in compared with normal concrete beams. This increasing occurs due to increasing in ultimate torque and therefore increasing in the area under torque-angle twist curve. For the design of earthquake-resistant structures, Increased beam toughness can be converted into equivalent damping; Which means increased damping force and increased resistance the ability to cause an earthquake.

**Table 6. Toughness of Tested Beam Specimens**

| Samples | Toughness (KN.m. rad) |
|---|---|
| NC20 | 1967.314 $X10^{-4}$ |
| NC25 | 2351.911 $X10^{-4}$ |
| SC20 | 2831.333 $X10^{-4}$ |
| SC25 | 3019.440 $X10^{-4}$ |
| ST20 | 2500.255 $X10^{-4}$ |
| ST22 | 2735.930 $X10^{-4}$ |
| ST25 | 2663.687 $X10^{-4}$ |
| STE25 | 2870.563 $X10^{-4}$ |
| STT25 | 2673.548 $X10^{-4}$ |

### 8. Conclusion

From the results, the conclusion can be followed as:

1. The ultimate torsion capacity increasing when using SIFCON rather than normal concrete.

2. Using the SIFCON as strengthening material is good to improved the torsional behavior of reinforced concrete beams.

3. The fully jackets strengthening have been indicated more increasing in ultimate torsion when compared with two and three sides strengthening.

4. Also, the volume fraction of steel fiber has influence on torsion strength. Higher volume of steel fiber giver more ultimate torsion capacity.

5. The twist of angle have been decreased in strengthening beams and this means improve torsional behavior.

6. The toughness is increased in strengthening beams and this is good in design of earthquake-resistant structures.

7- Finally, The SIFCON layer that was used in the strengthening did not separate from the beam during the loading stage, and this indicates the effectiveness of the SIFCON strengthening technique.

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