Experimental study on torsional behavior of fiberious reifoced concrete beams with different concrete strength

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Abstract. This study is intended to deal with twelve reinforced concrete beams cast into three categories of Concrete type with Normal, Self Compacted and High Strength Concrete. Two beams of each category have steel fibers and the other used as reference one. Test results are presented in graphs also listed in Tables. Test results indicated that, category of High Strength Concrete beams is the strongest category depending on the ultimate load capacity and the highest stiffness, followed by the Self Compacted Concrete beams category then the Normal Strength Concrete beams category comes later, with an increase of about (3.6-5.3%). Increasing steel fibers contained in concrete beam section will rise the ultimate load capacity of fiberious concrete beam, an increase of about 36% has been obtained. Increasing steel fiber contained with increasing concrete compressive strength of the fiberious concrete section will help increasing the ultimate load capacity of beam, an increase of about 166% has been noted. Due to continuing in rising the steel fibers contained in fiberious concrete section, the rate of development of ultimate load capacity of the fiberious concrete beam will decrease.

1. Introduction

Practically, there are wide range of different structures where torsional loading could be a significant loading condition. The most noticeable are bridges and spandrel beams. In bridges, the torsion could be due to the geometric complexities of horizontally curved bridges and/or to large eccentric vertical loads. The concrete behaves as an elastic material and the reinforcement can be ignored [1]. In RC members under pure torsion, the stiffness of the uncracked member can be predicted by theoretical approaches. After cracking, the member behaves as a composite member and the properties of the concrete, the reinforcing, and their interaction must be considered to accurately predict the member response to torsion. Many buildings and bridge elements are subjected to significant torsional moments that affect the design. Clearly, further research was needed to address this gap in knowledge [2-8].

Self Compacting Concrete is a type of concrete that does not require external or internal compaction, because it becomes leveled and compacted under its self weight. SCC can spread and fill every corner of the formwork, purely by means of its self weight, thus eliminating the need of vibration or any type of compacting effort [9]. The notion behind developing SCC was the concerns regarding the homogeneity and compaction of conventional cast-in-place concrete within intricate (i.e., heavily-reinforced) structures and to improve the overall strength, durability and quality of concrete [10]. An increasing in torsional capacity of concrete beam sections can be obtained using modified technique of strengthening [11,12].

Fiber Reinforced Concrete (FRC) is a composite material in which steel fibers or other tension materials are incorporated to improve the tensile strength and other properties of concrete. The amount of fibers
added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed \( V_f \). Typically, the amount of steel fibers varies between (0.0) and (2.0) percent, by volume [13]. The advantage of adding fibers. A matrix include enhancement of compressive strength, tensile strength, flexural toughness, shear strength, durability and resistance to impact [14].

2. Research casting plan
This study aims to investigate different parameters on the torsional behavior of reinforced rectangular concrete section beams. Such as:
1-type of concrete (Normal, high strength and self compacted)
2-concrete strength (20, 40, 60 and 75MPa)
3-percentage of fibrous (0, 0.6 and 1.2%)
It have been cast 12 beams with details as shown in Figure 1 and Table 1;
   a. Dimensions of (width=100, depth=200 and length=2000mm)
   b. Longitudinal reinforcement = 0.0094
   c. Stirrups Spacing = 80mm c/c.
   d. specimens of normal strength concrete =4
e. specimens of high strength concrete =4
   f. specimens of self-compacting concrete =4
g. Steel fiber percentage= (0.6 and 1.2)%

3. Properties of hardened concrete
Control specimens of cylinders and prisms are cast and tested at age of (28 days) to determine the properties of hardened concrete, as listed in Table 1. The properties of these beams consist of cylindrical compressive strength \( f'_c \), modulus of elasticity \( E_c \) and modulus of rupture \( f_r \).

![Figure 1. Tested beams details](image)

4. Results and discussion
Beams are tested under torsional moments come from eccentricity of the applied load by 750mm from the center of the beam as shown in Figure 2, the test continues up to failure, this failure mode leads to noticeable cracking and this is clear in Figure 3. Two dial gages are poisoned at the points of maximum torsional actions to measure the angle of twist. Another two dial gages are poisoned at the two ends of the tested beam to measure the longitudinal elongation of the beam due to formation and propagation of torsional cracks. The average of angles of twist and the total longitudinal strain are calculated for each tested beam. Test results are shown in Table 2.
### Table 1. Hardened concrete properties.

| Mix Notation | Beam Symbol | Compressive Strength Nominal (MPa) | Steel Fibers (Vf) | Compressive Strength Tested (MPa) | Modulus of Elasticity (GPa) | Modulus of Rupture (MPa) |
|-------------|-------------|-----------------------------------|------------------|-----------------------------------|---------------------------|--------------------------|
| NSC         | NCA         | 20                                | -                | 21.00                             | 23.20                     | 3.53                     |
|             | NCB         | 40                                | -                | 39.34                             | 24.33                     | 4.73                     |
|             | NCA_{0.6}   | 20                                | 0.6%             | 22.04                             | 23.64                     | 5.76                     |
|             | NCA_{1.2}   | 40                                | 1.2%             | 40.22                             | 24.86                     | 7.65                     |
| HSC         | HSCC        | 60                                | -                | 61.23                             | 33.62                     | 6.84                     |
|             | HSCD        | 75                                | -                | 73.31                             | 42.53                     | 8.41                     |
|             | HSCC_{0.6}  | 60                                | 0.6%             | 65.36                             | 37.87                     | 8.44                     |
|             | HSCC_{1.2}  | 60                                | 1.2%             | 68.81                             | 38.82                     | 9.83                     |
| SCC         | SCCB        | 40                                | -                | 40.7                              | 24.05                     | 4.59                     |
|             | SCCC        | 60                                | -                | 68.32                             | 39.85                     | 7.76                     |
|             | SCCB_{0.6}  | 40                                | 0.6%             | 42.96                             | 24.44                     | 7.69                     |
|             | SCCB_{1.2}  | 40                                | 1.2%             | 44.15                             | 24.45                     | 8.08                     |

**Figure 2.** Eccentricity Detailing at Testing  
**Figure 3.** Deformation of a tested beam

### Table 2. Results of tested beams.

| Mix Notation | Beam Symbol | Nominal Compressive Strength, (MPa) | Steel Fibers (Vf) | Ultimate Load (P_u) (kN) | Torsional Moment (T) (kN.m) | Angle of Twist (Ø) (rad.) | Total Strain (ε), (%) |
|-------------|-------------|-------------------------------------|------------------|-------------------------|-----------------------------|----------------------------|-----------------------|
| NSC         | NCA         | 20                                  | -                | 25                      | 18.75                       | 0.01165                    | 0.0555                |
|             | NCB         | 40                                  | -                | 38                      | 28.50                       | 0.01300                    | 0.0440                |
|             | NCA_{0.6}   | 20                                  | 0.6%             | 31                      | 23.25                       | 0.01165                    | 0.0471                |
|             | NCA_{1.2}   | 20                                  | 1.2%             | 34                      | 25.50                       | 0.01200                    | 0.0471                |
|             | HSCC        | 60                                  | -                | 57                      | 42.75                       | 0.01570                    | 0.0630                |
|             | HSCD        | 75                                  | -                | 66.5                    | 49.88                       | 0.02120                    | 0.0770                |
|             | HSCC_{0.6}  | 60                                  | 0.6%             | 62                      | 46.50                       | 0.03896                    | 0.0590                |
|             | HSCC_{1.2}  | 60                                  | 1.2%             | 66                      | 49.50                       | 0.03320                    | 0.0550                |
| SCC         | SCCB        | 40                                  | -                | 40                      | 30.00                       | 0.01085                    | 0.0395                |
|             | SCCC        | 60                                  | -                | 55                      | 41.25                       | 0.01700                    | 0.0630                |
|             | SCCB_{0.6}  | 40                                  | 0.6%             | 47                      | 35.25                       | 0.02220                    | 0.0415                |
|             | SCCB_{1.2}  | 40                                  | 1.2%             | 51                      | 38.25                       | 0.01220                    | 0.0405                |
5. Load carrying capacity (Pu)

The ultimate load carrying capacity reflects the maximum torsional moment and represents the ultimate applied load on the tested beam, Figure (4) graphs these values for the tested beams.

![Load carrying capacity of the tested beams](image)

5.1 Concrete type Effect on Ultimate Load

Three samples of concrete NSC, HSC and SCC were cast in recent study, when analysis the three types, it can be seen that, the HSC group is the strongest group depending on the ultimate load capacity and the second group is the SCC group and the NSC group comes later. Also, by contrast between the two beams, the normal strength concrete R-NCB and the self compacted reinforced concrete beam SCCB it can be noted that, the two discussed beams had convergent compression strength equals to about 40MPa, it is found that the carrying capacity of SCCB beams is greater than that of R-NCB by about 5.3%. In same manner, the HSCC and SCCC and the two beams which haves 60MPa nominal compressive strength, the result is the carrying capacity of HSCC is greater than that of SCC by about 3.6%.

5.2 Compressive Strength Effect on Ultimate Load

The results indicated that by augment the concrete compressive strength of the beam, will increases ultimate carrying capacity clearly. However, the rate of increasing in ultimate load capacity of the samples decreases due to continuous increasing compressive strength of the beam.

5.3 Steel fibers Effect on ultimate Load Capacity

The result indicated that augment the steel fibers contained in the sample will increase ultimate load carrying capacity clearly. However, the rate of augment in the ultimate load capacity of the sample will decrease, due to contained in increasing steel fibers contained in the beam sample.

5.4 Improvement of Ultimate Load Carrying Capacity

This work contains three types of concrete with different concrete compressive strength and steel fibers content, the increasing in carrying load capacity will be compared to the reference of each group of concrete type and then will be compared with the weakest beam in this work which it R-NCA as shown in Table 3.

From Table 3, it can be noted that by increasing concrete compressive strength, ultimate load capacity can be improved. the biggest improvement (52%) is in the normal strength concrete samples. It may be noted also that, augment the concrete compressive strength is more effective than utilization of steel
fibers in improving ultimate load carrying capacity, for example (52 and 24)% of R-NCB and NCA0.6 in Table 3. Counting rising steel fibers contained, the load carrying capacity may be increased, as shown in Figure 5.

**Table 3.** Improvement of load carrying capacity.

| Mix Notation | Beam Symbol | Nominal Compressive Strength (MPa) | Steel Fibers ($V_f$) | Ultimate Load ($P_u$) (kN) | Increasing According to the Reference Beam (%) | Increasing According to NCA Beam (%) |
|--------------|-------------|-----------------------------------|----------------------|-----------------------------|-----------------------------------------------|-------------------------------------|
| NSC          | *R-NCA      | 20                                | -                    | 25                          | -                                             | -                                   |
|              | R-NCB       | 40                                | -                    | 38                          | 52                                            | 52                                  |
|              | NCA0.6      | 20                                | 0.6%                 | 31                          | 24                                            | 24                                  |
|              | NCA1.2      | 20                                | 1.2%                 | 34                          | 36                                            | 36                                  |
|              | *HSCC       | 60                                | -                    | 57                          | -                                             | 128                                 |
| HSC          | HSCD        | 75                                | -                    | 66.5                        | 16.7                                          | 166                                 |
|              | HSCC0.6     | 60                                | 0.6%                 | 62                          | 8.8                                           | 148                                 |
|              | HSCC1.2     | 60                                | 1.2%                 | 66                          | 15.8                                          | 164                                 |
|              | *SCCB       | 40                                | -                    | 40                          | -                                             | 60                                  |
| SCC          | SCCC        | 60                                | -                    | 55                          | 37.5                                          | 120                                 |
|              | SCCB0.6     | 40                                | 0.6%                 | 47                          | 17.5                                          | 88                                  |
|              | SCCB1.2     | 40                                | 1.2%                 | 51                          | 27.5                                          | 104                                 |

* this symbols refers to the reference beam in each group

Also, "from Table 3, it can be emphasized that, when comparison adopted according to specific compressive strength. By continuing rising the compressive strength of the section, the load carrying capacity will improve, so that, the HSC beams achieved the highest values (166%). In addition the compressive strength is better than the steel fibers in improvement the load carrying capacity, as shown in Figure 6. "

**Figure 5.** Improving of load carrying capacity in each type of beams.
6. Twist Angle (Ø)
Average of two twist angles in every tested sample is graphed vs. torsional moment as shown in Figure 7, twist angle is two dimensional deformation with direction of torsional moment path. The comparative of twist angle for all tested samples are at 25kN which was the load of failure of beam sample R-NCA.

6.1. Effect of Concrete Type on Twist Angle
From tests results of three concrete type groups which are normal strength and high strength and self compacted concrete, it may be seen that, the HSC samples of beams is the high stiffness samples according to the twist angle and then the SCC samples and after that the NSC samples. Also, if it has been compared between two samples of beams R-NCB which was concrete beam of normal strength and SCCB which was beams cast of self-compacted concrete where the selected samples have an approximate concrete compressive strength near 40MPa, it is found at the applied load of 25kN the twist angle of sample SCCB was 0.0051rad, which is smaller than that of beam sample R-NCB which was 0.0066 rad. Using the same manner, by comparison between beam sample HSCC which was beam with high strength concrete and beam sample SCCC which was beam sample cast with self-compacted concrete where both beams samples have about 60MPa concrete compressive strength, test result was twist angle of HSC at applied load 25kN is 0.00235 rad. which less than that of SCC which was 0.00295 rad.

6.2. Effect of Concrete Compressive Strength on Twist Angle
In normal strength concrete samples, by comparative analysis between beam sample R-NCA which was about 21.00MPa concrete compressive strength and R-NCB which was about 39.34MPa concrete compressive strength, the test result indicated that the twist angle of beam sample R-NCB is less than that of beam sample R-NCA which they were 0.0066rad. and 0.0116 rad. respectively.
In the HSC beam samples, due comparison between HSCC which was 61.23MPa concrete compressive strength and HSCD which was 73.31MPa concrete compressive strength, test results indicates that, the twist angle of beam sample HSCD is less than that of the beam sample HSCC which they were 0.00216rad. and 0.00235rad. respectively.
For the SCC group, by comparison between SCCB which is 40MPa nominal compressive strength and SCCC which a 60MPa nominal compressive strength, the result is the angle of twist of SCCC is smaller than that of the SCCB which they were 0.00235 rad. and 0.0051 rad. respectively.
Test result indicated that by augment the compressive strength of the beam sample will decrease the twist angle clearly.

**Figure 6.** Improving of load carrying capacity according to NCA beam.
6.3. Effect of Steel fibers on Twist Angle

Tests result indicated that augment of steel fibers contained in concrete beam section will decrease the value of twist angle of concrete beam samples clearly.

6.4. Improvement of Angle of Twist

In the case of the angle of twist, the improvement is decreasing in value which reflects the deformation in the member. Decreasing in angle of twist will be compared according to the angle of twist of the reference beam of each group of concrete type. After then, the decreasing in angle of twist of any beam will be compared with the angle of twist of the weakest beam in this work which it is R-NCA at applied load of 25kN as in Table 4.

### Table 4. Improvement of angle of twist.

| Mix Notation | Beam Symbol | Nominal Compressive Strength (MPa) | Steel Fibers (Vf) | Angle of Twist (Ø) (rad.) | Decreasing According to the Reference Beam (%) | Decreasing According to NCA Beam (%) |
|--------------|-------------|-----------------------------------|------------------|--------------------------|-----------------------------------------------|-------------------------------------|
| NSC          | * NCA       | 20                                | -                | 0.01165                  | -                                             | -                                   |
|              | NCB         | 40                                | -                | 0.00660                  | 43.3                                          | 43.3                                |
|              | NCA0.6      | 20                                | 0.6%             | 0.00968                  | 16.9                                          | 16.9                                |
|              | NCA1.2      | 20                                | 1.2%             | 0.00900                  | 22.7                                          | 22.7                                |
|              | * HSCC      | 60                                | -                | 0.00235                  | -                                             | 79.8                                |
| HSC          | HSCD        | 75                                | -                | 0                        | 100                                           | 100                                 |
|              | HSCC0.6     | 60                                | 0.6%             | 0                        | 100                                           | 100                                 |
|              | HSCC1.2     | 60                                | 1.2%             | 0                        | 100                                           | 100                                 |
|              | * SCCB      | 40                                | -                | 0.00510                  | -                                             | 56.2                                |
| SCC          | SCCC        | 60                                | -                | 0.00295                  | 42.2                                          | 74.7                                |
|              | SCCB0.6     | 40                                | 0.6%             | 0.00400                  | 21.6                                          | 65.7                                |
|              | SCCB1.2     | 40                                | 1.2%             | 0.00240                  | 52.9                                          | 79.4                                |

From Table 4, that is clear, the angle of twist can be improved by increasing the compressive strength of the section, therefore; the highest improvement (100%) is in the HSC group. On the other hand, the increase of the compressive strength is better than the use of steel fibers in improving the angle of twist,
for example (43.3 and 16.9)% of NCB and NCA_{0.6} in the Table 4 above. By counting in increasing the steel fibers content, the angle of twist can be decreased but not as increasing the compressive strength of the beam, for example the two beams NCB and NCA_{1.2} when reflected the results (43.3 and 22.7)%, Figure 8 shows these results.

Also, from Table 4 can be emphasized that, when comparison adopted according to specific compressive strength, by continuing in rising the compressive strength of the section the angle of twist will improve, so that, the HSC beams achieved the highest values (100%) and also, the compressive strength is better than the steel fibers fraction in improving the angle of twist, Figure 9 shows these notices.

![Figure 8. Twist angle improvement in each types of beams.](image1)

![Figure 9. Twist angle Improvement according to R-NCA beam](image2)

7. Conclusions

Based on the evidence from the experimental results reported in study, the following conclusions can be drawn. It is emphasized that these conclusions are limited to the variables studied:

- The HSC group of beams is the strongest group according to the ultimate carrying load and the most stiffness and followed by the SCC group and the NSC group comes later, with an increase of about (3.6-5.3)%
- Increasing compressive strength of the concrete section will help increasing the ultimate carrying capacity of beam clearly, an increase of about 166% has been noted.
- By continuing in increasing the compressive strength of the section, the rate of increasing the load carrying capacity of the beam will decrease.
- Increasing the steel fibers content in the section will increase the ultimate carrying capacity of beam, an increase of about 36% has been obtained.
- By continuing in increasing the steel fibers content in the section, the rate of increasing the load carrying capacity of the beam will decrease.
- Increasing the compressive strength of the section will decrease the twist angle of about 100%.
- Increasing steel fibers content in the section will decrease the value of angle of twist of the beam.

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