Behaviour of steel fiber reinforced high strength self-compacting concrete beams under combined bending and torsion

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ABSTRACT

This paper investigates experimentally and analytically the behavior of steel fiber reinforced high strength self-compacting concrete beams under combined bending and torsion. In the recent decades, steel fiber reinforced high strength self-compacting concrete (SFHSSCC) is considered a very important material in the structural engineering field. High strength concrete attracts designers and architects as it offers good durability and the esthetics of a construction as well. One of the advantages using the SFHSSCC is to provide high ductile behavior. SFHSSCC has also a high toughness, with improvement in workability, and high residual strengths after the initiation of the first crack. The main challenge in many past studies is to select the effective fiber contents that should be added to the concrete mixture. In the present study, a Hooked shape steel fibers are used; the hooked steel fibers were evaluated using the volume fractions, which varied between 0.0%, 0.75% and 1.5%. A total of six beams were tested, and classified into three groups. The beam shapes are chosen to create the torsional and bending moments simultaneously. All beams, have 200 cm length, a cross section of (10 × 20) cm, longitudinal bottom steel reinforcement of 3Φ10, longitudinal top steel reinforcement of 2Φ10, additional longitudinal steel 1Φ8 placed in the mid height of the cross sections, and closed stirrups of 10Φ8/m. The first group is considered as a reference group consisting of a beam casted from conventional normal weight concrete. The second group is consisted of two beams casted from self-compacting concrete, the first beam in the second group was casted without steel fibers and the second beam was casted with steel fibers volume fraction equal to 0.75%. The third group is consisted of three beams that were casted from high strength self-compacting concrete (HSCC) with steel fiber volume fractions equal to 0.0%, 0.75% and 1.5% respectively. The experimental results were validated using finite element analysis. It is concluded that the effect of steel fiber reinforced high strength self-compacting concrete (SFHSSCC) enhances the behavior of beams under combined bending and torsion.

Keywords: Self-compacting concrete; torsion; bending and torsion; steel fiber; steel finite element analysis.

1. Introduction

The addition of steel fibers in concrete mixtures has long been recognized as a non-conventional mass reinforcement that enhances the mechanical properties of concrete and provides crack propagation control. This property is attributed to the tensile stress transfer capability of the steel fibers across crack surfaces, which known as crack-bridging, and also to the fact that such fibers...
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provide significant resistance to shear across developed cracks. Cracking of steel fiber concrete is associated with debonding and pull-out of the randomly distributed steel fibers in concrete. Therefore, steel fiber concrete demonstrates a pseudo-ductile tensile response and enhanced energy dissipation capacities, relative to the brittle behavior of plain concrete. Early experimental efforts pointed out that the behavior of an element under pure torsional moment is fully characterized by the behavior of the material under direct tension. Thus, in order to enhance the torsional response of concrete members, improvement of the poor performance of concrete in tension by incorporating steel fibers has been proposed and extensively studied in the last decades. Most of the conducted research on the torsional behavior of fibrous concrete elements present experimental results of rectangular beams containing steel fibers without conventional reinforcement and rectangular beams with steel fibers, bars and stirrups. Experimental investigation of fibrous concrete beams with circular cross-section under torsion was conducted by. All these experimental studies have shown that the use of steel fibers improves the cracking characteristics and the overall torsional behavior of concrete beams with rectangular and circular cross-sections.

The engineering characteristics and economic advantages of high-strength concrete (HSC) are distinct from conventional concrete, thereby popularizing the HSC concrete in a large variety of applications in the construction industry. The comparable higher compressive strength of HSC is an attractive advantage; whereas, the strength behaves against the ductility of concrete by welcoming brittleness pronouncedly. To foster the compressive strength without sacrificing the ductility, a strategy is adopted to add discrete steel fibers as reinforcement in HSC. As the high-strength steel fiber-reinforced concrete (HSFRC) hardens, shrinks, or bears service loads, the fibers evenly distributed throughout the composite intersect, block, and even arrest the propagating cracks. This way, the addition of fibers contributes strength to the concrete. First, Khaloo and Kim investigated the strength improvement in HSC containing 0.5%, 1.0%, and 1.5% volume fractions of steel fibers, declaring that compressive and splitting tensile strengths improved to 1.0% fraction, whereas the modulus of rupture did up to 1.5%. Eren and Celik studied the strength-producing effect of steel fibers and silica fume in HSC, indicating that the fiber volume and fiber aspect ratio governed the compressive strength of the concrete. The foregoing discussions indicate the steel fiber additions primarily exerting the pick-up effect on the compressive strength. However, the additions play also devotedly in developing splitting tensile and flexural strengths.

Self-compacting concrete (SCC) has been widely employed to produce beams of complex shapes and/or with high density of reinforcement structures. From a mechanical viewpoint, both the conventional and self-compacting concretes perform less satisfactorily when they are subjected to tensile effects. One way to improve the physical and mechanical properties of a concrete is the production of a composite material either via addition of steel bars commonly used as reinforcement in current civil engineering practices or by random introduction of steel fibers into the concrete mixture. A combination of both approaches is also possible, although the latter has found more restricted and less widespread use. As outlined by Kim and Mai, both the cement matrix and the fibers keep their original chemical and physical identities in the composite material. However, due to the presence of an interface between these two constituents, a combination of mechanical properties that cannot be obtained with the constituents alone is achieved in the hybrid concrete. Bearing in mind the technical and economic benefits of SCC, the addition of steel fibers to this type of concrete should significantly enhance its properties in the hardened state, mainly when it is submitted to tensile stress, as in the case of concrete beams under combined bending and torsion. Therefore, if the
use of SCC is advantageous, the addition of steel fibers should provide it with new positive features and further possibilities of application, since a more efficient material would be obtained both at the fresh and hardened states.

2. Experimental work

2.1 Experimental program

Six reinforced concrete beams were casted having rectangular cross sections. All beams, have 200 cm span, cross section of (10×20) cm, longitudinal bottom steel reinforcement of 3Φ10, longitudinal top steel reinforcement of 2Φ10, additional longitudinal steel 1Φ8 in the mid height of each side and closed stirrups of 10Φ8/m. Figure 1 shows the details of tested beams. The specimen cross sections, dimensions and reinforcement were carefully selected to generate the required torsional and bending moments during the experimental testing.

![Figure 1: Details of tested beams](image)

2.2 Materials

Ordinary Portland cement CEM1 of grade 52.5 obtained from Suez – Factory in Egypt, and complies with ESS 4756-1-2006 [26]. Silica fume is a very fine waste-by–product powder obtained as a fume from the foundry process in the Egyptian company for Iron Foundries. Fly ash used in concrete mixtures, and is imported from India through Goise Company in Egypt, and complies with ASTM C618 class C [27]. The Blaine fineness of the ash is 3200 cm²/gm and its specific gravity is 2.2. The Steel fibers obtained from Master Chemical Technology Company in Egypt. All steel fibers are double hooked edge with a 0.6 mm diameter, 30 mm length, with aspect ratio of 50, and a tensile strength of 850 MPa. Crushed dolomite with nominal maximum size of 10 mm was used as coarse aggregate and is
obtained from Attaka quarry. The fine aggregate was natural sand obtained from pyramids quarry in Egypt and complies with ESS 1109, 2008. Polycorboxylate ether polymerglenium ASE 30 is used in the current study and is obtained from Basf Company in Egypt. The superplasticizer is used to produce self-compacting concrete mixes and calculated as fraction of the cement weight as shown in table 1. Deformed high-grade steel bars of yield strength 400 MPa was used to reinforce all beams.

2.3 Test measurements and instrumentation

The beams were extensively instrumented to record the structural response. Digital gauges and linear variable displacement transducers (LVDTs) were used to measure the concrete compressive, tensile strains at mid span and vertical deflection. The data from digital gauges and (LVDTs) were connected to data acquisition system (DAS).

2.4 Concrete mix proportions

Concrete mixes were designed, prepared and summarized in six groups as shown in table 1. The cement content was 350 Kg/m³ for normal strength beams, while increased to 500 Kg/m³ for high strength ones. Silica fume was added by 15% of cement content in all mixes, fly ash was 10% of cement content in all self-compacting mixes, the water–binder ratio was taken as 0.35 for all self-compacting mixes, super-plasticizer ratio was 2.5% from the cement content to produce self-compacting concrete in the presence of the steel fibers. Steel fibers of double hooked edge were added to mixes no. 4, 5 with a ratio of 0.75% by volume and to mix no. 6 with a ratio of 1.5%. Filling ability and viscosity of self-compacting concrete were evaluated using slump flow test with and without J-ring according to ESS 1109, 2008. Table 1 shows the results.

<table>
<thead>
<tr>
<th>Beam No.</th>
<th>Type of Mix</th>
<th>Mix Proportions (Kg)</th>
<th>Fresh Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>HSCC</td>
<td>Cement: 500, Sand: 850</td>
<td>Slump (cm): 75, Slump Flow (cm): 64, Slump Flow with J-Ring: 51</td>
</tr>
<tr>
<td>B4</td>
<td>SCC, V_f: 0.75%</td>
<td>Cement: 350, Sand: 950</td>
<td>Slump (cm): N/A, Slump Flow (cm): 64, Slump Flow with J-Ring: 51</td>
</tr>
<tr>
<td>B5</td>
<td>HSCC, V_f: 0.75%</td>
<td>Cement: 500, Sand: 850</td>
<td>Slump (cm): N/A, Slump Flow (cm): 64, Slump Flow with J-Ring: 51</td>
</tr>
<tr>
<td>B6</td>
<td>HSCC, V_f: 1.5%</td>
<td>Cement: 500, Sand: 850</td>
<td>Slump (cm): N/A, Slump Flow (cm): 64, Slump Flow with J-Ring: 51</td>
</tr>
</tbody>
</table>

2.5 Test Set-up and loading arrangement

The main purpose for designing and constructing the test set-up was to apply a torsional moment on the specimens. The test set-up dimensions are shown in Figure 2. In order to facilitate applying the complex loading on the testing specimen, the cross sections and dimensions were chosen carefully. The total length for all specimens was taken as 200 cm, while the total length of specimens between supports was 175 cm. The clear span for the test zone was 100 cm and the width of all specimens was 10 cm. The set-up of each test consisted of installing the tested beam in a horizontal position under load spreader, the machine head insured that the load eccentricity was maintained at all stages of the loading and also the bearing plates were adjusted to prevent any eccentricity could result from any misalignment position. All beams were tested using 100-ton capacity hydraulic Jacks machine in the reinforced concrete laboratory at the Housing and Building National Research Center (H.B.R.C.), Egypt.

![Figure 2: Test set-up and loading arrangement](image)

3. Test results and discussion

3.1 Failure modes and crack patterns of test specimens

Standard concrete cubes were taken from each mixture to measure the compressive strength at 28-days. Table (1) shows the standard cube compressive strength at 28 days for each beam and its description.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Symbol</th>
<th>Description</th>
<th>( f_{cm} ) 28 day (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>OC</td>
<td>Ordinary Concrete</td>
<td>30</td>
</tr>
<tr>
<td>B2</td>
<td>SCC</td>
<td>Self-Compacting Concrete</td>
<td>44</td>
</tr>
<tr>
<td>B3</td>
<td>HSCC</td>
<td>High strength Self Compacting concrete</td>
<td>82</td>
</tr>
<tr>
<td>B4</td>
<td>SCC, ( V_f 0.75% )</td>
<td>SCC with steel fiber 0.75%</td>
<td>55</td>
</tr>
<tr>
<td>B5</td>
<td>HSCC, ( V_f 0.75% )</td>
<td>HSCC with steel fiber 0.75%</td>
<td>86</td>
</tr>
<tr>
<td>B6</td>
<td>HSCC, ( V_f 1.5% )</td>
<td>HSCC with steel fiber 1.5%</td>
<td>90</td>
</tr>
</tbody>
</table>
The failure mode of all tested specimens was brittle failure (BF), brittle failure occurred by crushing of the concrete in the compression zone before yielding of both longitudinal steel and stirrups. Table 2 shows the test results of all tested specimens including; specimens’ description, ultimate loads, and failure modes. All tested specimens were designed to fail under torsional moment. Generally, all cracks occurred in the clear span, between the two short cantilevers. The initial hair inclined cracks were observed on the top surface of most of the specimens, and then followed by increasing the number of diagonal cracks as the load increase. Typical torsional spiral cracks developed around the circumference of all beams are shown in Figure 3. The average inclination angle of the cracks was 40° to 60°. After the maximum load was reached, the width, number and length of cracks were increased when the concrete reached the ultimate strength till failure. The concrete cover spalling was not observed till the ultimate load is reached. The torque at failure was calculated to insure that the beam failure was due to torsional moment not flexural moment. All beams with steel fibers failed also in a brittle mode but was not severing as the conventional ones. The steel fiber reinforced beams showed typical cracking patterns on the perimeter of the clear span between supports. Cracks were formed uniformly with smaller width due to the bridging effect of steel fibers. From the observed test results, it can be concluded that the steel fibers improve concrete brittleness. Figure 3 shows the failure modes and crack patterns of the tested specimens.

Table 2: Test results

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Concrete properties</th>
<th>Compressive strength, ( F_{cu} ) (MPa)</th>
<th>Fiber volume fraction, ( V_f ) (%)</th>
<th>Ultimate load, ( P_u ) (KN)</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Ordinary Concrete</td>
<td>30</td>
<td>0.0</td>
<td>32.1</td>
<td>BF</td>
</tr>
<tr>
<td>B2</td>
<td>SCC</td>
<td>48</td>
<td>0.0</td>
<td>38.3</td>
<td>BF</td>
</tr>
<tr>
<td>B3</td>
<td>HSCC</td>
<td>84</td>
<td>0.0</td>
<td>53</td>
<td>BF</td>
</tr>
<tr>
<td>B4</td>
<td>SCC</td>
<td>54</td>
<td>0.75</td>
<td>44.3</td>
<td>BF</td>
</tr>
<tr>
<td>B5</td>
<td>HSCC</td>
<td>87</td>
<td>0.75</td>
<td>57.2</td>
<td>BF</td>
</tr>
<tr>
<td>B6</td>
<td>HSCC</td>
<td>90</td>
<td>1.5</td>
<td>69.5</td>
<td>BF</td>
</tr>
</tbody>
</table>
3.2 Torsional behavior of test specimens

Based on the experimental results, the behavior of the tested beams is discussed in terms of observed behavior, concrete type, ultimate load, load-deflection relationship, and failure modes as shown in table 2 and figures from 4 to 7. Figures 4 to 7 indicate the relationship between the applied load and deflection was typical for all the tested beams, an approximate linear increase behavior followed by a nonlinear behavior until failure is observed for all beams.

![Figure 4: Beams of different concrete types without steel fibers](image)

![Figure 5: Effect of steel fibers on SCC](image)
Using self-compacting concrete (SCC) changed the behavior of the tested beams and improved the torsional resistance as shown in Figure 4. Steel fibers increased considerably the torsional strength of self-compacting concrete beams and that increase is because of the addition of steel fibers. The addition of steel fibers helped to bridge cracks in the whole concrete matrix and transferred tensile stresses through two opposite faces of cracks until the fibers are totally pulled-out or broken. The beams produced using the steel fibers showed more ultimate load and improved ductility, which is totally reflected on the increase of the tensile strength and the torsional resistance. Figure 5 shows clearly the effect of steel fibers on the torsional capacity of conventional self-compacting concrete beams, and for steel fibers self-compacting concrete beams SFRSCC. The torsional capacity increased by 15.7% at fiber volume fraction of 0.75% in comparison with self-compacting concrete beams without steel fibers as given in table 3.

Inclusion of steel fibers in concrete improved the ultimate torsional strength and imparts significantly to the post-cracking ductility and toughness of all beams however, it did not have any influence on the mode of failure. Steel fibers self-compacting concrete (SFRSCC) specimens exhibited considerable post-cracking ductility before collapse. It can be noticed from test results that, the torsional capacity in terms of ultimate load increased with the corresponding increase in the concrete compressive strength.

The torsional capacities of SFRHSCC increased by 31% using a fiber volume fraction of 1.5% in comparison with that of high strength self-compacting concrete beams (HSCC) without steel fibers as given in table 3. In contrast, torsional capacities increased slightly by about 8% at fiber volume fraction of 0.75% in comparison with that of high strength self-compacting concrete beams (HSCC) without steel fibers as given in table 3. The torsional behaviors of SFRHSCC beams were almost identical close to the maximum load as shown in Figure 6, though the fiber volume fraction was varied. The maximum loads did not linearly increase with increasing the fiber volume fraction. They showed that the increase of the torsional capacity of SFRHSCC beams became sensible from the fiber volume fraction over 0.75% to 1.5%.

4. Finite element analysis

4.1 Modeling

4.1.1 Concrete elements
SOLID 65 element was used to model the concrete. SOLID 65 element is an eight node solid element and has 3 displacement and 3 rotation degrees of freedom at each node. The element has the shape of a rectangular prism. Solid 65 has the capability to simulate the linear and nonlinear behavior of concrete material. The typical behavior expressed in the stress-strain relationship for concrete subjected to uniaxial loading is shown in Figure 8. SOLID 65 element considers smeared crack in tension and crushing in compression, and its failure criterion is given by:

\[ \frac{F}{f_c} - S \geq 0 \]  \hspace{1cm} (1)

Where \( F \) is a function of the principal stresses, \( S \) is the Willam and Warnke failure surface, and \( f_c \) is the material compressive strength. When eq.1 is satisfied, the material will crack if the principal stresses exceed its tensile strength and will crush when the compressive principal stresses are exceeded. The Willam and Warnke failure surface used in ANSYS® [30] is defined by five parameters, which are the concrete uniaxial compressive strength \( f_c \), concrete tensile strength \( f_t \), concrete biaxial compressive strength \( f_{cb} \), concrete biaxial compressive strength superimposed on a hydrostatic stress state \( f_{1h} \), concrete uniaxial compressive strength superimposed on a hydrostatic stress state \( f_{2h} \), ANSYS®.

The material model in ANSYS® considers perfect bond between reinforcement and concrete. Moreover, ANSYS® allows the definition of two shear transfer coefficients, one for opened cracks and the other for closed cracks.. Concrete cracking is represented by modifying the stress-strain relationship through the introduction of a failure plane normal to the crack surface, ANSYS [30]. The shear transfer coefficient represents a reduction on the material shear strength that introduces slip through the crack surface. Apart from cracking and crushing, SOLID 65 can also represent plasticity and creep, and allows the introduction of a reinforcement material in up to three directions.. The elastic modulus of concrete was calculated by using the slope of the initial tangent to the stress–strain curve The Poisson ratio is taken as 0.2. The ultimate uni-axial compressive and tensile strengths of concrete were implemented in the code from the laboratory test results. The crack interface shear transfer coefficient \( \beta_t \) for open cracks was assumed to range from 0.1 to 0.5 while for closed cracks \( \beta_c \) was assumed to range from 0.7 to 0.9. The higher range of values were assumed for steel fiber reinforced concrete as it was expected that the fibers would contribute significantly to shear transfer across a crack.

### 4.1.2 Steel fiber elements

The effectiveness of steel fibers in increasing the flexural and tensile strength of concrete, at least partially, depends on the number of fibers per unit cross-sectional area of concrete. The fraction of the entire volume of the fiber was modeled explicitly as it was expected to contribute to the mobilization of forces required to sustain the applied loads after concrete cracking and provide resistance to crack propagation. The number of fiber per unit area was calculated in this study, based on the probability approach given by Parviz and Lee. The equations given by to predict the number of fibers per unit crosssectional area of concrete are:

\[ N_f = \alpha^d \nu f / N_f \]  \hspace{1cm} (2)

where \( \alpha^d \) is the orientation factor which ranges from 0.41 to 0.82.
Orientation of these fibers in concrete and consequently the number of fibers per unit cross-sectional area is affected by the boundaries restricting the random orientation of fibers, and by the fact that the fibers tend to settle down and reorient in horizontal planes during concrete vibration. As a result of vibration, the random orientation of fibers in concrete moves away from the three-dimensional state to a two-dimensional state. Hence, the value $\alpha'$ was taken based on the 2D orientation of the fibers and was taken qual to 0.645 (average value of 0.55–0.74 proposed by Parviz and Lee). Thus the number of fibers per concrete element is given by:

$$A_f = \alpha' \mu_f A_e$$  \hspace{1cm} (3)

Where $A_e$ is the cross-sectional area of a concrete element. Thus knowing $\alpha'$, the number of fiber in each element was calculated. The elements lying at the boundary carry half of the area of the fibers used in interior of the FE mesh. The equivalent fiber reinforcement is considered smeared in the finite element in three orthogonal directions that coincide with the cartesian directions. The equivalent fiber reinforcement parameters were implemented as: Young’s modulus $E_s = 2000000$ MPa, Poisson ratio $\nu = 0.3$, and equivalent tensile strength $f_s = 1500$ MPa.

4.1.3 Reinforcement steel elements

Modeling of reinforcing steel in finite elements is much simpler than the modeling of concrete. LINK 8 element was used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom – translations in the nodal x, y, and z directions. LINK8 element is also capable of simulating plastic deformation. A perfect bond between the concrete and steel reinforcement is considered. However, in the present study the steel reinforcing was connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes. Steel reinforcement in the experimental work was constructed with typical steel reinforcing bars. The elastic modulus and yield stress for the steel reinforcement used in the FE study were adopted from the material properties used for the experimental work. The steel for the FE models is assumed to be an elastic-perfectly plastic material as shown in Figure 9. The steel Poisson’s ratio of 0.3 is used for all the simulated beams.

![Figure 8: Typical Uniaxial Compressive and tensile Stress-Strain Curve for Concrete.](image-url)
4.2 Nonlinear analysis in ANSYS

The transition of concrete from an uncracked to cracked stage and the nonlinear material properties of concrete in compression cause the nonlinear behavior of the structures under loading. In the present study, the nonlinear analysis was performed by dividing the load into a series of load increments called load steps. At the completion of each incremental solution, the stiffness matrix of the model is adjusted to reflect the nonlinear changes in the structural stiffness before proceeding to the next load increment. The Newton–Raphson equilibrium iterations option for updating the model stiffness were used in the nonlinear analyses. Prior to each solution, the Newton–Raphson approach assesses the out-of-balance load vector, which is the difference between the restoring forces (the loads corresponding to the element stresses) and the applied loads, ANSYS. Subsequently, the program carries out a linear solution using the out-of-balance loads and checks for convergence. If convergence criteria are not satisfied, the out-of-balance load vector is re-evaluated, the stiffness matrix is updated, and a new solution is carried out. This iterative procedure continues until the results converge, ANSYS.

In this study, convergence criteria for the reinforced concrete solid elements were based on force and displacement, and the convergence tolerance limits were initially selected by the software. It was found that, the convergence of solution was difficult to achieve due to the highly nonlinear behavior of reinforced concrete. Therefore, the convergence tolerance limits were increased to a maximum of five times the default tolerance limits (0.5% for force checking and 5% for displacement checking) in order to achieve the required accuracy. In order to verify the test results, the finite element was performed to simulate same models that were experimentally tested. A uniform square and rectangular mesh is used in th emodeling of all beams as shown in Figure 10. Figure 10 also shows the reinforcement, the boundary conditions, and applied loads.

4.3 Finite element results

The ANSYS postprocessing subroutine was used to obtain the stresses and deformations at each load step. Therefore failure capacity and deflection levels can be determined. The ultimate loads in the finite element models are considered the last applied load step before the solution diverges due to numerous cracks and large deflections. A comparison between
experimental and finite element results is summarized in table 4 in terms of ultimate load. It is clear from the results that the finite element analysis underestimates the ultimate loads of the tested beams by ratios ranged from 0.86 to 0.93 compared to the experimental values.

**Figure 10:** Finite element mesh for a typical beam model

**Table 4:** Comparison between experimental and finite element results

<table>
<thead>
<tr>
<th>Model</th>
<th>Finite Element Ultimate Load $P_{uf}$ (KN)</th>
<th>Experimental Ultimate Load $P_{ue}$ (KN)</th>
<th>$P_{uf} / P_{ue}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>30</td>
<td>32.1</td>
<td>0.93</td>
</tr>
<tr>
<td>B2</td>
<td>33.1</td>
<td>38.3</td>
<td>0.86</td>
</tr>
<tr>
<td>B3</td>
<td>47.1</td>
<td>53</td>
<td>0.89</td>
</tr>
<tr>
<td>B4</td>
<td>40.7</td>
<td>44.3</td>
<td>0.92</td>
</tr>
<tr>
<td>B5</td>
<td>51.6</td>
<td>57.2</td>
<td>0.90</td>
</tr>
<tr>
<td>B6</td>
<td>64</td>
<td>69.5</td>
<td>0.92</td>
</tr>
</tbody>
</table>

**Figure 11:** Comparison of load-deflection curves for beam (B1).
Comparison of load-deflection curves for beam (B2).

Comparison of load-deflection curves for beam (B3).

Comparison of load-deflection curves for beam (B4).
Figure 15: Comparison of load-deflection curves for beam (B5).

Figure 16: Comparison of load-deflection curves for beam (B6).

Figures from 11 to 16 show the finite element load-deflection curves compared to the experimental results, the comparison shows that the ratio of ultimate loads predicted by finite element to experimental values ranged from 0.86 to 0.93. The curves show good agreement of the finite element analysis with the experimental results throughout the entire range of behavior and failure mode. It can be seen that, the finite element models are almost stiffer than the actual beams in the linear range.

Several factors may cause the higher stiffness in the finite element models. The bond between the concrete and steel reinforcement is assumed to be perfect (no slip) in the finite element analyses, but for the actual beams the assumption would not be true as slip occurs, therefore the composite action between the concrete and steel reinforcement is lost in the actual beams. Also the microcracks produced by drying shrinkage and hardling are present in the concrete to some degree. These would reduce the stiffness of the actual beams.

5. Conclusions

Based on the results obtained from study, the following conclusions can be drawn:

1. Using self-compacting concrete (SCC) causes a difference in the behavior of the tested beams compared to the conventional concrete beams and improves the torsional resistance.

2. Inclusion of steel fibers in concrete improves the ultimate torsional strength and imparts significantly to the post-cracking ductility and toughness of beams.

3. Torsional capacity of steel fibers self-compacting concrete beams (SFRSCC) increased by 15.7% at fiber volume fraction of 0.75% in comparison with concrete beams without steel fibers.

4. Torsional capacity in terms of ultimate load increased with a corresponding increase in the concrete compressive strength.

5. Torsional capacities of steel fibers high strength self compacting concrete beams (SFRHSCC) increased by 31% at fiber volume fraction of 1.5% in comparison
with high strength self-compacting concrete beams (HSCC) without steel fibers. In contrast, torsional capacities increased slightly by about 8% at fiber volume fraction of 0.75% in comparison with high strength self-compacting concrete beams (HSCC) without steel fibers.

6. Torsional behaviors of SFRHSCC beams were almost identical close to the maximum load, though the fiber volume fraction was varied. The maximum loads did not linearly increase with increasing the fiber volume fraction. They showed that the increase of the torsional capacity of (SFRHSCC) beams became sensible from the fiber volume fraction over 0.75% to 1.5%.

7. The finite element analysis underestimates the ultimate loads of tested beams by ratios ranged from 0.86 to 0.93 compared to experimental values.

8. The closeness of the experimental and the finite element results indicate that ANSYS® can be used to model the torsional behavior of steel fibers reinforced high strength self-compacting concrete (SFRHSCC) beams and predict the maximum load carrying capacity as well.

6. References


10. H.K.Shehab et al., (2005), Strengthening of R.C. Beams under Torsion, Structural
composites for infrastructure applications, Alexandria, Egypt, MESC-4.


27. American Standard specifications for Fly Ash, ASTM C618 class F.


