Effects of steel fibers on flexural strength and impact resistance for self-consolidating concrete plates

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Abstract

Self-Consolidating Concrete (SCC) can be considered as a major innovative satiric expansion in the future of concrete materials and technology during the recent three decades. It has evolved to make adequate compaction with easy concrete placement in constructions, which have overcrowded the restricted zones and reinforcement. This research aims to experimentally study the effect of steel fibers volumetric ratio ($V_f$) and effect of chicken wire in enhancement of the behavior of the normal strength SCC. Two types of SCC concrete mixes were prepared and cast for this purpose. One of them was normal strength SCC to serve as a reference mix, while 0.75% of steel fibers was used in the second one. Slump-flow test, L-box, J-ring and V-funnel tests had been done to investigate the properties of fresh SCC. Compressive strength of the reference SCC was about (33.5MPa) and for 0.75% steel fibers SCC was about (39.7MPa). In addition to that, six identical plate's specimens of (400x400x20) mm were cast and tested to study the effect of steel fibers and chicken wire on the impact load resistance and flexural load of SCC. Results show that the impact load resistance for steel fibers SCC concrete had been increased by about 60% compared with the reference normal strength SCC mix, while an increase in impact load resistance for SCC of about 50% was gained by using chicken wire mesh. It was noted that the use of 0.75% steel fibers-SCC and chicken wire-SCC plates show an increase in impact resistance and flexural strength by about 20% and 2% compared to the reference normal strength SCC, respectively. The results also indicate that using steel fibers is useful in holding up the formation of transverse cracks and providing affirmative restraint to the successive growth of cracks of plate's specimens.

Keyword
Impact load Resistance, self compacting concrete, Flexural Behavior, steel fibers.

1. Introduction

SCC or Self Consolidating concrete is considered as a major innovative improvement in concrete knowledge for the recent decades. SCC is a unique type of concrete, which can run throughout and block up the gaps between reinforcement bars and corners of moulds with no more requirement for shaking and compaction through the casting procedure. SCC results in long-lasting concrete structures, and spares labour and consolidation racket. SCC is like ordinary concrete in being a fragile material with low elasticity and tensile strength and poor crack vitality inspite of its high performance; thus, SCC mixes can be provided by steel fibers in order to increase its tensile potency and improve its stiffness, fracture capacity and maximize its load carrying capacity.
Few researches presented deal with using steel fibers to enhance the properties of SCC, some of these researchers studied the structural behavior of SCC, while the others deal with the mechanical behavior of it. Spearheading deals with Self Compacting Concrete comes back to 1980s in Japan. Okamura and Ozowa[1] studied the mechanism for accomplishing self-compatibility, which prevents segregation between gravel and mortar when the concrete moves through the confined region of steel reinforcing bars in addition to involve high deformability of mortar or paste. The occurrence of collision and contact between the particles of aggregate may be raised with the decrease in comparative distance between the particles, subsequently; the interior particles’ stresses could be raised with the deformation of the concrete, predominantly close to obstacles. It was concluded that the required flowing energy is consumed with increase in the internal stress, resulting in blockage of aggregate particles. Restricting the coarse aggregate crashing (whose energy utilization is principally powerful) to less than normal level is effective in avoiding that kind of blockage.

Sonebi et al. [2] studied the compressive strength of SCC. Five mixes were used in the investigation with cement content ranging between (280-515) kg/m³ and with water to cement ratios between (0.43-0.68). Superplasticizer admixture was used in the investigation. Results indicated that all mixes were highly flowable, with slump flow ranging between (650-690) mm and flow times ranging between 2.3 and 4 sec. The 28 days compressive strength ranged between 47-79.5 MPa. Koning et al. [3] and Hauke[4] suggested an acceptable strength increase by 13.5% and 9.1%, respectively in SCC made with addition of 15% of fly ash material.

Al-Jabri [5] investigated the properties of SCC produced using locally available materials in Iraq and the influence of dosage and fineness admixture of High Reactivity Metakaolin (HRM) on the properties of SCC in fresh and hardened state. Concrete mixes containing (500 kg/m³) cement with (0.34-0.36) water to cement ratio. The results show that the slump diameter was greater than or equal to 650 mm, filling height ranged between 0 to 50 mm and flow times ranged between 3 and 9.5 sec. The compressive strength was upto 85 MPa, and the splitting tensile strength was upto 6.1 MPa. HRM improved the compressive, splitting tensile, and modulus of rupture strengths upto 23.9 %, 4.26% and 4%, respectively.

The purpose of the present experimental work is to investigate the possibility of utilizing locally found materials in Iraqi to create SCC that conforms to international well known specification documents. And to evaluate the filling ability, passing ability of fresh concrete, compressive strength and tensile strength for hardened SCC produced. In addition to studying the effect of adding steel fibers and one or two layers of chicken wire in the impact load resistance and flexural strength of the normal strength SCC.

2. Experimental program
An experimental program is planned and prepared in order to scrutinize the structural performance for SSC after being strengthened by adding steel fibers and one or two layers of chicken wire meshes. A lot of laboratory experiments were done in Materials and sStructural engineering laboratories of the Structural Engineering Branch / Civil Engineering Department / University of Technology/ Baghdad/ Iraq in turn to complete the present research investigational job. A total of 42 specimens have been cast to investigate the properties of SCC. Six concrete plates with dimensions of (400x400x20)mm were cast to study the impact load capacity test and flexural strength test of the SSC plates after strengthening by adding steel fibers and one or two layers of chicken wire.

18 concrete cubes (150x150x150) mm are used to determine the compressive strength of SCC concrete in accordance with B.S 1881: part 116, 1989 [6] and 18 concrete cylinders (150x300) mm are used to determine splitting tensile strength of this type of concrete in accordance with ASTM C496-04 [7]. In natural conditions, SCC does not require any compaction; therefore, the mixes
were poured into moulds till these moulds were completely filled with no compaction. Then, after casting, moulds were enclosed by polyethylene sheets for around twenty four hours to avoid loss of moisture from the specimens' top surface, which could result in plastic shrinkage cracks through the first few hours beyond concrete casting. After that, specimens were demoulded and positioned in the curing water containers. Figure 1 shows some of the specimens after being cast.

![Figure 1. Casting of specimens.](image)

3. Materials used

3.1 Concrete Ingredients

In this research, Tasluja factory ordinary portland cement has been used in all concrete mixes. This cement conformed to the requirements of Iraqi Specification No.5 /1984 [8] according to the chemical and physical test results. Natural sand (Al-Ukhaider) was used as a fine aggregate with maximum size of 4.75 mm conforming to Iraqi specifications limits (No. 45/1984 [9], it's classified as zone No.2 according to the Iraqi Specification. Locally found normal crushed aggregate of maximum size (10 mm) was utilized as gravel (Coarse aggregate). The grading and sulfate content of the adopted gravel comply with requirements of No.45/1984 Iraqi Specification [9].

In general, it is necessary to use superplasticizers in order to obtain high mobility for SCC mixes. Therefore, a high range water reducing admixture (HRWRA) was used to fabricate better performance concrete mix. HRWRA is commercially recognized as Top Flow SP703. This admixture conforms to ASTM C494 [10] requirements. Also, silica fume is used as pozzolanic admixture. Pozzolanic activity index and the chemical oxide compositions results of silica fume match to the requirements of ASTM C1240-05 requirements [11]. In addition to that, Limestone powder (LS) was utilized as a filler to increase the quantity of fine materials in the mixture in order to improve segregation resistance and upgrade its cohesiveness. The used (LS) is of 0.125 mm particle size (passing through sieve No. 200 that conforms to EFNARC 2005 recommendations [12].

3.2 Chicken Wire Mesh

The Rhombic shape meshes of reinforcement fabricated from (0.54mm) nominal diameter steel bars was used in the present work. The opining in the long and short directions were 10.6 and 7.92mm, respectively. Three samples of chicken wires with dimensions of (30x150) mm were prepared for tensile tests and mesh properties according to ACI 549- 1R-99 [13]. Figure 2 shows measured and mesh test. The test of chicken wire mesh was done by using the computerized equipments existing in Production Engineering and Metallurgy Department/ University of Technology. One or two layers of these chicken wires were used as an internal reinforcement in two (400×400×20) mm plates specimen in order to study the impact strength of SSC.
3.3 Micro Steel Fibers.

Micro straight steel fibers of 0.75% volume fraction and aspect ratio of $L/d = 75$ was used in the present work. Table 1 shows the micro steel fibers properties. This form of fibers conformed to the ASTM A820-01[14] requirements. Figure 3 shows the micro steel fibers used.

| Item                      | Value  |
|---------------------------|--------|
| volume fraction           | 0.75%  |
| aspect ratio              | 75     |
| Length (mm)               | 15     |
| Diameter (mm)             | 0.2    |
| Tensile Strength (MPa)    | 2850   |

Figure 3. The used Steel fibers.

4. Concrete mix properties

Two types of concrete mix were used in the present work. A number of trial mixes were prepared and made so as to acquire the most appropriate mix design for normal strength SSC. The final mix proportions was 1:2:2 (cement: sand: gravel) by weight of cement. Totally of 18 standard cubes of (150 x150 x150) mm were cast and tested at 28 days to determine the concrete compressive strength according to BS 1881-1983 [6] in a rate of six standard cubes for each batch (a batch has an adequate amount of concrete for casting two plates specimens for each working day). In addition to that, 18 cylinders of 150 mm in diameter and 300 mm in length were cast and tested from the same batch to calculate concrete strength in tensile. The mix design compositions are listed in table 2.

| Table 2. Present Work Concrete Mixes. |
In turn to confirm that the concrete used in the present experimental work has the properties of SCC, the new fresh normal strength concrete of separate mix was verified according to four typical SCC tests procedures, which are: T50 cm slump flow, Slump flow, V-Funnel test, L-box, and J-Ring Test. The tests are all performed at the Concrete Laboratory/ Civil Engineering Department/ University of Technology. These tests were carried out according to EFNARC. Details of each test are being listed below:

5.1 Slump-flow and T500 test.

Slump flow test deals with the measuring of horizontal free flow for SCC using a regular slump cone. The experimental values of slump flow and T500 tests were 720 mm and 3.8 sec, respectively. Hence, all mixes are considered to have an excellent consistency and workability from the filling ability point of view. The results of fresh properties test for the mix were listed in table 3 that shows the time required for the concrete flow to reach a circle with 500mm diameter. Figure (4-a) shows the slump flow test.

5.2 L-Box test.

The L-Box test values were between 0.91 and 0.96. The obtained results achieved the acceptable criteria for SCC. The mix shows no blockage throughout the strictly spaced obstacles, as a result, it was assumed to have a good passing ability from the passing ability point of view. The results of fresh properties test for the mix was listed in table 3. Figure (4-b) shows the L-Box test.

5.3 V-Funnel test

Concrete Flowability o was measured through V-funnel test. The V-Funnel test values were between 6.2 and 7.5 sec. These results are within the acceptable criteria for SCC. No segregation behavior is observed for all mixes. The V-funnel time results of fresh concrete of the mix were listed in table 3.

5.4 J-Ring Test

J-Ring test is represented by the values of (D), which can be defined as the highest spread slump of low final diameter in the J-ring. The obtained J-Ring test results ranged between 716 and 755mm; these results are inside the satisfactory criteria of SCC. Thus, all of mixes are assumed to have an excellent passing ability. Results of the J-Ring test for fresh properties for the mix was shown in table 3. Figure (4-c) shows the J-Ring test.

| Mix Type  | Steel fiber % | Slump-flow D (mm) | J-Ring D (mm) | L – Box H1/H2 | V-Funnel (sec.) |
|-----------|---------------|-------------------|---------------|--------------|----------------|
| SCC (Ref.) | 0             | 720               | 3.8           | 755          | 0.96           | 6.2            |

Cement content =400 kg/m³ for all concrete mixes, Water cement ratio of (0.48) for all concrete mixes.
6. Mechanical properties of hardened SCC

6.1 Compressive and tensile strength

Standard Concrete cubes and cylinders were used to measure the compressive strength and tensile strength for the SCC concrete as mentioned previously. The specimens were tested at the age of (28) days using hydraulic jacks machine of 3000 kN, which was available in Concrete Laboratory/ Civil Engineering Department/ University of Technology (figures 5 and 6). The test was completed in accordance to BS 1881-part 116:1983[6] for cube compressive strength and ASTM C496/C496M-11 [7] for tensile strength. Results of these tests are shown in table 4. The results show that compressive and tensile strength of plain concrete had increased by adding steel fibers by 19% and 10%, respectively.

|SF-SCC| 0.75| 719| 3.8| 716| 0.91| 7.5|
|---|---|---|---|---|---|---|
|Range| 650-800 mm| 2-5 sec| 600–750| 0.8–1.0| 6–12 sec|

![Slump-flow test](image1)
![L-Box test](image2)
![J-Ring test](image3)

**Figure 4.** Fresh normal strength SCC tests.

**Table 4.** Hardened Mechanical Properties for SCC Mixes.

| Mixes Type | Steel fibers Content (%) | compressive strength (MPa) | tensile splitting strength (MPa) |
|---|---|---|---|
| SCC (Ref.) | 0 | 33.5 | 3.1 |
| SF-SCC | 0.75 | 39.7 | 3.4 |
6.2 Flexural test
Two standard test methods are available to find out the flexural strength of a concrete beam according to C78/C78M-16 specifications [15]:

Center point loading: In this test method, the total loads are applied at the center of the span length of the beam. The maximum stress is present at the center of the beam.

Third point loading test: this technique depends on applied half of the load at each third of the beam’s span length. The flexural strength or modulus of rupture by center point loading is higher than the modulus of rupture of the third point loading.

In present work, the maximum stress is present over the center one-third portion of the loaded plated. The load must be continuously applied with no shock at all. Moreover, the applied load should be placed at a steady rate until the breaking point without shock or disruption. Figure 7 indicates failure modes of SCC plates. The use of 0.75 % steel fibers and two layers of CHW plate show an increase in flexural strength by about 20% and 3%, respectively compared with the normal strength SCC mix. The results for flexural strength test at 28 day are shown in table 5.

6.3 Impact load test.
Six (400×400×20) mm plate specimens were used for impact resistance test. This test was done in accordance with the procedure proposed by the ACI Committee 544.2R-89[16], which has been used by several researchers [17, 18]. The impact load is applied using hammer of 4.45 kg ball of 60.2 mm in diameter, which was dropped repeatedly and directly from a 457 mm height on the center point of the specimen’s top surface (figure 8). The plates were simply supported along all edges. The number of required blows to construct the initiation of crack (first crack) was recorded and remarked to be as initial crack strength (N1), while, the number of blows that caused specimens breakdown or failure is recorded and remarked as the strength of failure (N2). Shear cracking load can be defined as the load at which a considerable change in the load carrying mechanism take place, resulting in a redistribution of the stresses within the plates [19].

Generally, it was found that concrete is an exceptionally stain rate sensitive material. Both the peak bending loads and the fracture energies were higher under dynamic load conditions than static load conditions. Steel fibers were found to be considerably increase the ductility and the impact load resistance of the SCC. Results of impact test on plates are presented in table 6. It is well indicated that the distributed micro steel fibers gave a significant increase in number of blows by about 40% to produce cracks and 50% to failure compared with SCC without steel fibers, this increase could be because of the uniformly distributed steel fibers in the concrete mix and its effectiveness in 3Dimension inverse the chicken wires, which its effective in 2Dimension, so that the steel fibers enhanced the impact behavior of specimen more than chicken wires. For more illustration, results of table 6 are shown graphically as illustrated in figure 9. Figure 10 indicates the failure modes of tested SCC plates.
7. Conclusions

The following points are concluded depending on the test results in the present investigation:

1- It is well indicated that the distributed micro steel fibers gave a significant increase in the number of blows by about 40% to produce cracks and 50% to failure compared with SCC without steel fibers, this increase could be because of the uniformly distributed steel fibers in the concrete mix.

2- Steel fibers have a definite adverse effect on all workability properties of fresh SCC. Consequently, demand of higher water, or chemical admixture dosages could be added to keep the targeted workability values within the suitable ranges.

3- All SCC mixes that incorporated steel fibers have slightly higher compressive strength and splitting strength than reference normal strength SCC mixes.

4- Impact results indicated that presence of fibers cause more cracks and energy absorption.

![Figure 7](image1.png)

*Figure 7. Flexural test failure for SCC plates (a): Ref. Plate (b): with Steel fibers (c): with Chicken wire.*

![Table 5](image2.png)

**Table 5.** Results for flexural strength test

| Mix Type  | Steel fibers Content (%) | Strength Test(MPa) |
|-----------|--------------------------|--------------------|
| SCC (Ref) | 0                        | 410                |
| Sf – SCC  | 0.75                     | 490                |
| CHW plate | -                        | 420                |

![Figure 8](image3.png)

*Figure 8. Impact resistance testing device.*

![Table 6](image4.png)

**Table 6.** Results for Impact Load Test

| Mix Type  | Steel fibers Content (%) | Number of blows to initiate first cracks (N1) | Number of blows to failure(N2) |
|-----------|--------------------------|-----------------------------------------------|-------------------------------|
| SCC (Ref) | 0                        | 1                                             | 2                             |
| SF-SCC    | 0.75                     | 7                                             | 15                            |
| CHW Plate | 1 layer                  | -                                             | 5                             |
|           | 2 layers                 | -                                             | 5                             |
Figure 9. No. of blows at first cracks and failure stages.

Figure 10. Impact test failure for SCC plates.

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