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BEHAVIOR AND STRENGTH PROPERTIES OF STEEL FIBER REINFORCED SELF-COMPACTING CONCRETE COLUMNS

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Abstract

The presence of steel fiber in self-compacting concrete mix offers many advantages to the structural elements that cast by this type of mix. Steel fiber acts inside the concrete structural elements like a bridges that delays the cracks propagations and enhances the concrete mechanical properties. Concrete containing steel fiber influences on the workability of concrete so that self-compacting concrete improves the workability of concrete. In the present study, conduct of the steel fiber reinforced self-compacting concrete columns subjected to static loading was investigated. The self-compacting concrete as limestone powder was adapted with steel fiber such as 1, 1.5 and 2%. Concrete mechanical properties such as compressive strength, splitting tensile strength and modulus of rupture were investigated. Four stub columns were tested under axial load. The test results show that there was an increase in concrete mechanical properties and load capacity of short column in presence of self-compacting concrete and steel fibers. The amount improvement resulting from use of steel fibers in a concrete (SCC) on the mechanical properties of concrete (compressive, tensile and flexural strength) based on the best steel fiber percentage (2%) is 40.00, 16.67, and 14.29% respectively and the amount of improvement in the behaviour of SFSCC columns as loading is 25.93%. the enhancements in lateral and longitudinal displacements is 20 and 24% respectively.

Keywords: Self-compacting concrete, Short column, Steel fiber, Strength capacity, Workability.

1. Introduction

The self-compacting concrete (SCC) is classified as a new material in which the concrete gets compacted under its self-weight without main contributions from mechanical vibrator. The self-compacting concrete is very useful to fill the spaces in case of heavy structural elements such as beams, slabs, columns, shear walls and foundations. Many advantages for self-compacting concrete make the structural engineering to adapt such as reduction in time of constructions, no noise, improving the capacity of the structural member by filling the spacing's and giving excellent structural behaviour.

Super plasticizer can be used in concrete mix to avoid segregations and increase the concrete workability [1]. The presences of steel fiber in concrete mix reduce cracks due to plastic [2]. Thin steel fibers are more magnificent than the thick in preventing the cracks width [3]. Presence of steel fiber in concrete reduces the concrete permeability so that reduces the bleeding [4].

Adding steel fibers to the concrete enhances the mechanical properties of self-compacting concrete [5]. Presences of steel fiber improve the strength and toughness of the concrete member by transmitting the stresses throughout [6]. Hooked steel fiber gives more strength on the structural member effects as compared with the straight. Steel fiber mix with the SCC combines the advantages of both materials [7]. Aspect Ratio of steel fiber influences on the concrete workability as increase or decrease relies on the ratio of length to the volume per unity [8]. Steel fiber contents influence upon the conduct and strength for structural member and on the mechanical properties of concrete [9]. Short reinforced normal concrete columns under the effects of axially loadings came from gravity external loads are investigated. Axial load means loads lie with centre of gravity of the column cross section [10].

Test results of steel fiber SCC revealed that the workability of SCC mixtures was reduced by increased the steel fiber content and the load-deflection capacity was increased by the addition of the steel fibers [11]. Tensile and flexural strength increased upon the used of 10% silica fume as compared with normal concrete and the ideal percentage of steel fiber was 2% of the total weight of the binder. The steel fibers generated a heightened compressive and splitting tensile strength in the self-compacting concrete mixes [12].

The interfacial bond between the concrete and the steel fibers has a significant effect on the overall performance of the strengthened concrete members [13]. Test results revealed that 30-40% replacement of coarse aggregate by pumice stone was considerable for improved density, compressive strength, split tensile strength and flexural strength development in light weight SCC [14].

The aims of present work are to investigate the behaviour and strength of steel fiber reinforced self-compacting concrete columns under the effect of axial static loadings. Different percentages of steel fiber such as (1, 1.5 and 2) % are added with self-compacting concrete limestone powder to produce a new concrete of fibrous self-compacting concrete SFSCC. The SFSCC is adapted to cast four short columns and then tested. Columns capacity, lateral and longitudinal displacements with full behaviour for all tested columns are recorded and discussed.

2. Materials

All raw materials that used to cast the short column specimens were tested. The materials such as cement, aggregates, limestone powder (LSP) as a filling materials for self- compacting concrete and steel fiber are as follows:

2.1. Cement

Ordinary Portland cement- Type I had been utilized, the testing result complies to Iraqi standard specification IQS No.5-1984 [15].

2.2. Fine aggregates

Natural sands having max size of 4.75 mm were utilized; the fine grading shows agreements with the Iraqi Specifications No.45-1984, Zone 2 [16].

2.3. Coarse aggregates

Crushed gravels having a maxi size of 12 mm were utilized, the testing results shown that the sulphate content and grading of coarse aggregate comply with the Iraqi specifications IQS No.45,1984 [16].

2.4. Limestone powder

Limestone powder (LSP) had been utilized as a filling materials for self-compacting concrete. Tables 1 and 2 indicate the chemical and physical composition of limestone powder.

Table 1. Chemical composition of limestone dust.

Oxide	%Content
CaO	60.1
Al_2O_3	0.61
Fe_2O_3	0.2
SiO_2	1.22
SO_3	0.1
MgO	0.32
L.O.I	36.5

Table 2. Physical composition of limestone dust.

Physical form	Fine aggregate gradation zone (2)
Color	White
Fineness (Blain) (m^2/kg)	315

2.5. Super-plasticizer

A chemical admixture (Glenium 51) had been utilized as a high range water reducing agent. It has no chlorides and meets with ASTM C-494 specification [17]. The description of type F high range water reducing super-plasticizer admixture is listed in Table 3, which is issued by the producer.

Table 3. Technical description of Glenium 51.

Specific gravity	1.1 at 20 ºC
Ph.	6.6
Viscosity	128 ± 30 cps @ 20 ºC

2.6. Micro steel fiber

Steel fiber properties with dimensions are listed in Table 4 according to the supplier, Fig. 1 shows the steel fiber properties.

Table 4. Micro steel fiber properties.

Length, (mm)	15
Diameter, (mm)	0.25
Aspect ratio	60
Tensile strength, (MPa)	2000

Fig. 1. Micro steel fiber.

3. Concrete Mixtures

Many mixing trials were done to reach the required compressive strength. The final mix proportion is given in Table 5. Slump Flow, T50, L-box and V-funnel testing were conducted to ensure that the concrete working as self-compacting concrete. Moreover, a comparison was done between the findings and the limit of EFNARC-2002 [18] along with ACI 237R-07 [19] as pointed to in Table 6. The utilized potable water was taken from the water-supplying network system (tap water).

Figures 2, 3 and 4 show the slump test, L box test and the self-compacting concrete mix that adopted in concrete mix design, respectively.

Table 5. Self-compacting concrete mixing proportions.

Cement, (kg /m^3)	430
Water, (kg/m^3)	185
Limestone powder, (kg /m^3)	120
Water, (kg /m^3)	185
Fine aggregate, (kg /m^3)	830
Coarse aggregate, (kg /m^3)	830
Super plasticizer, (l /m^3)	5

Table 6. Fresh self-compacting concrete testing result.

Test method	Result	EFNARC-2002 [18]	ACI-237R-07 [19]
Slump flow,(mm)	710	650-800	450-760
L- box, (H2/ H1)	0.8	0.8- 1	0.8-1
T500, (sec)	2	2-5	2-5
V- funnel, (sec)	9	6-12	-

Fig. 2. Slump flow test.

Fig. 3. L-box test.

Fig. 4. Self-compacting concrete mixing.

4. Steel Reinforcements Bars

Main and tie reinforcements with yield stress of main reinforcement (ϕ10) and the stirrup (ϕ4 mm) are 612 MPa and the ultimate tensile strength is 720 MPa based on the tensile test of rebar and according to ASTM A996M-05 [20].

5. Experimental Program

A total of four RC square column specimens were cast and tested to examine the effect of steel fiber proportion on the conduct of SCC reinforced concrete columns. Twenty-four cubes with dimensions of (150x150x150) mm and twenty-four cylinders with 150 mm in diameter and 300 mm in height had been tried to measure the compressive strength and tensile strength of concrete mix, respectively. Also, twenty-four prisms were tested to measure the flexural strength with dimensions of (100x100x400) mm. The characteristics of tested specimens are presented in Table 7. Figures 5, 6 and 7 show the compressive strength, tensile test and modulus of rupture, respectively.

Table 7. Characteristics of tested specimens.

Specimens	Compressive strength f_{cu} (f_c') (MPa)	% Steel fiber ratio
C1	30 (24.6)	0.0
C2	30 (24.6)	1.0
C3	30 (24.6)	1.5
C4	30 (24.6)	2.0

Fig. 5. Compressive test.

Fig. 6. Tensile test.

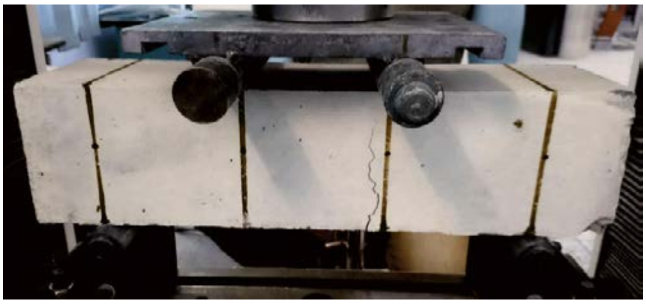

Fig. 7. Modulus of rupture test.

6. Column Specimens Description

Four tested specimens of square cross section (120 mm), total height700 mm and cover 20 mm are adopted. The columns were reinforced with 4ϕ10 mm longitudinal bars and 9ϕ4 mm stirrups distributed as shown in Fig. 8.

7. Testing Procedure

All columns are tested by a hydraulic machine capacity of 2500 kN. Thick steel plates with 7 mm thickness are fixed at top and bottom of every specimen during the test to avoid load concentration. The applied loads are recorded by a calibrated loading and LVDT-dial gages used to measure the vertical and horizontal displacements at the top of specimen. The applied vertical load is increased incrementally with 10 kN. Figure 9 shows the test setup and specimen before test.

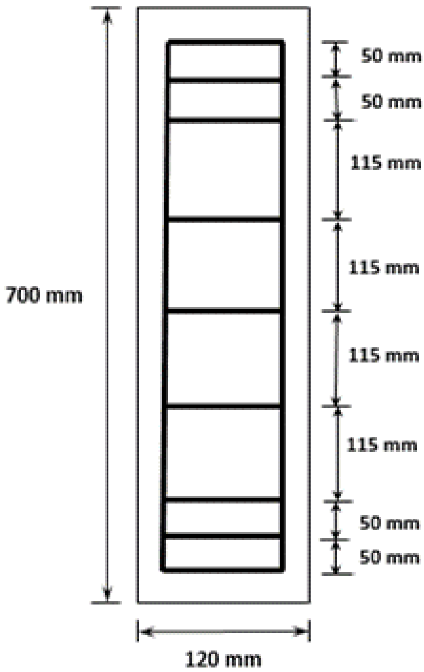

Fig. 8. Tested columns layout.

Fig. 9. Test setup.

8. Test Results and Discussions

Mechanical properties of a new concrete as SFSCC are investigated for compressive strength, splitting tensile strength and modulus of rupture. As structural tests, the major parameters that were noticed in the course of testing are the ultimate capacity of the columns, longitudinal displacements and lateral displacements for all columns.

8.1. Mechanical properties

Mechanical properties for SFSCC are founded by test cubes, cylinders and prisms to find out the compressive strength, splitting tensile strength and modulus of rupture respectively.

8.1.1. Compressive strength

The compressive strength of cubes is tested based on the BS1881-116 [21]. Test results are listed in Table 8. Figure 10 shows the failing mode of some samples. The Compressive strength increased as the percentage of steel fiber increased due to the fact that steel fiber was acts as bridges to connect the whole specimen from inside so that the cube becomes more resisting to applied loads. Table 8 presents the comparisons between all specimens that show the effect of presence of steel fiber. Modes of failure are shown in Fig. 10.

8.1.2. Splitting tensile strength

Indirect tensile test of SFSCC is conducted based on ASTM C496 [22]. Table 8 lists the splitting tensile strength. Figure 11 shows the mode of tensile failure of cylinder. The splitting tensile strength increase when the percentage of steel fibers increase due to enhancement in tension in ductility in the range of elastic deformation and the specimen becomes more resisting to applied loads. Table 7 presents the comparisons between all specimens that show the effect of presence of steel fiber, modes of failure shown in Fig. 11.

8.1.3. Flexural strength-modulus of rupture

The modulus of ruptures test of SFSCC is based on ASTM C78/ C78M-16 [23]. Table 8 lists the flexural strength and Fig. 12 shows the flexural failure of prism. Modulus of rupture also increase when the percentage of steel fiber increase due to the enhancement in concrete properties that reduce the brittle of SFSCC which is a result of an increase in tensile strength because of the presence of steel fibers. Table 8 lists the comparisons between all specimens that show the enhancement of modulus of rupture is due to the presence of steel fiber. A mode of failure in Fig. 12 shows the cracks at ultimate stage.

Table. 8. Hardened mechanical properties test results.

% Steel fiber	Average compressive strength at 28 days (MPa)	% Increase of compressive strength	Average tensile strength at 28 days (MPa)	% Increase of tensile strength	Average modulus of rupture at 28 days (MPa)	% Increase of modulus of rupture
0	30	--	3.0	--	4.2	--
1	35	16.67	3.2	6.67	4.5	7.14
1.5	38	26.67	3.3	10.00	4.6	9.50
2	42	40.00	3.5	16.67	4.8	14.29

Fig. 10. Failure mode of some cubes.

Fig. 11. Failure mode of some cylinder.

Fig. 12. Failure mode of prisms.

8.2. Axial load capacity of the square column

The ultimate load capacity for each column is listed in Table 9. The maximum longitudinal and lateral displacements is given in Table 10. A comparison is made between the mechanical properties of SFSCC with those of normal concrete as suggested by ACI-318M-2014 [24], Table 11 shows the comparisons between the mechanical properties of normal concrete and SFSCC. The concrete column is (315 kN) as ultimate strength capacity based on the ACI-318M-2014 [24].

Table 9. Ultimate load capacity of tested columns.

Column	%Steel fiber	Ultimate load (kN)	% Increase of load capacity
C1	0	540	--
C2	**1**	**600**	**11.11**
C3	**1.5**	**630**	**16.67**
C4	**2**	**680**	**25.93**

Table 10. Maximum longitudinal and lateral displacements of tested columns.

Column	Maximum longitudinal displacement (mm)	Maximum lateral displacement (mm)	% Decrease of longitudinal displacement	% Decrease of lateral displacement
C1	5.00	0.90	---	---
C2	**4.8**0	**0.86**	4.00	4.44
C3	**4.3**0	**0.76**	14.00	15.56
C4	**3.8**0	**0.72**	24.00	20.00

Table 11. Comparisons between normal concrete mechanical properties and SFSCC.

% Steel fib	Average compressive strength at days (normal concrete)(MPa)	Average Modulus of rupture at 28 days (MP	Average tensile strength at 28 days (MPa)
0	30 (24.6)	4.2 (3.07)	3.0 (2.78)
1	**35** (24.6)	**4.5** (3.07)	**3.2** (2.78)
1.5	**38** (24.6)	**4.6** (3.07)	**3.3** (2.78)
2	**42** (24.6)	**4.8** (3.07)	**3.5** (2.78)

Figure 13 shows the failure modes for all columns that designed previously according to ACI Committee 318M-14 [22]. The columns fail when the applied loads reach and over the ultimate load capacity which was calculated based on the methodology suggested by ACI Committee 318M-14 [24]. As shown in Fig. 13, the column C1 spalling near the middle and high cracks propagated from the top starting from the location of the applied load. The Column C2 spalling at middle with less cracks near the applied load, but in the column C3 and C4 there are some spalling that occurs at middle due to an increase in the applied load in which column C4 has little diagonal cracks.

Figures 14 and 15 show the full behaviour of load verses the longitudinal and lateral displacement, respectively. The first crack load for specimens are 45, 53, 63 and 70% from the ultimate loads that represent the inflections points for all columns which are approximately linear, and then after that they become nonlinear for columns C1, C2, C3 and C4, respectively. The curves of all columns after the inflection point become less slope, that means the stiffness of the columns becomes less due to an increase in loads and displacements. The full behaviour of the SFSCC in case of short columns are similar to the normal concrete short column but there are differences in full strengths capacities and displacements. As shown in Figs. 14 and 15, the load required to cause longitudinal and lateral displacement in cases of SFSCC became more for the same control short column C1.

Fig. 13. Mode of failure with conventional crushed for all columns.

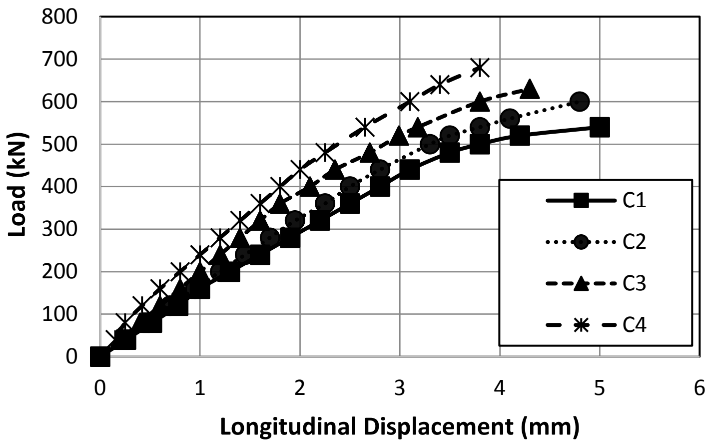

Fig. 14. load-longitudinal displacement for all columns.

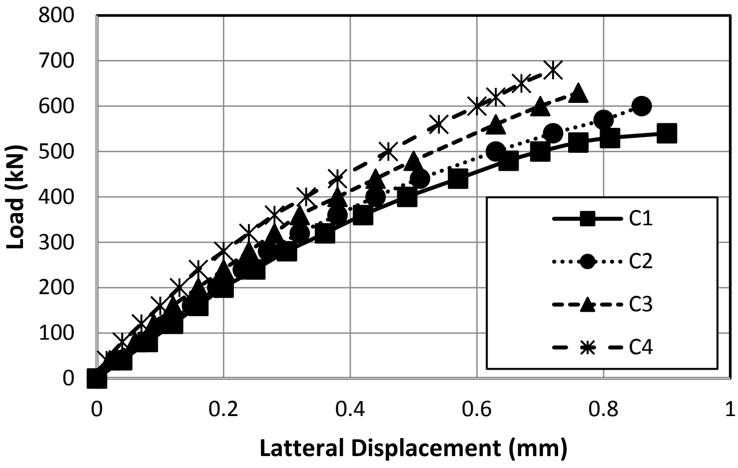

Fig. 15. Load-lateral displacement (buckling) for all columns.

9. Conclusions

The experimental results presented in this study are to evaluate the steel fiber self-compacting concrete short columns under static axial loads. The following points are concluded based on the observations and the recorded data:

- The mechanical properties of steel fiber self-compacting concrete are greater than the normal concrete due to the self-compacting concrete material increases the workability that reduces the voids. The presence of steel fiber makes connections between concrete mix particles which lead to reduce the cracks in early load stage. The presence of steel fibers makes the concrete less brittle so that the modulus of rupture becomes more.
- The increase of fine materials as self-compacting concrete will enhance its cohesiveness as well as improve the resisting against segregating.
- The short columns under axial loading fail due to crushing of concrete.
- The increase in compressive strength of steel fiber self-compacting concrete makes the columns more resistance to applied loads and improve the behaviour of columns that reflects on reduce the longitudinal and lateral displacements.
- The strength resistance of short columns mainly influences by the steel fibers percentages which make the fracture of the tested samples increase through the increase in steel fibers content.
- The amount improvement resulting from use of steel fibers in a concrete (SCC) on the mechanical properties of concrete (compressive, tensile and flexural strength) based on the best steel fiber percentage (2%) is 40.00, 16.67, and 14.29% respectively and the amount of improvement in the behaviour of SFSCC columns as loading is 25.93%. the enhancements in lateral and longitudinal displacements is 20 and 24% respectively.

Nomenclatures

f_c	Compressive strength of concrete, MPa
f_r	Flexural strength of concrete (modulus of rupture), MPa
f_t	Tensile strength of concrete, MPa

Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing Material
BS	British Standard Institution
EFNAC	European Federation for Specialist Construction Chemicals and Concrete Systems
IQS	Iraqi Specification
LSP	Limestone Powder
SCC	Self-compacting concrete
SFSCC	Steel Fiber Self-compacting concrete

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