International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 2 (2018) pp. 1344-1353
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Experimental and Numerical Study on the Effects of Size and type of Steel Fibers on the (SIFCON) Concrete Specimens

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Abstract

The steel fiber reinforced concretes have different sizes as dimensions are typically put together by incorporate the fiber as a partner with the other concrete mixing. The maximum volume friction (Vf) of steel fiber not more than by (2%) volume, but in case of greater than this limit the concrete becomes strenuous to mix. In recent years, the quantities percent of steel fibers increased to procedure a new concrete with excellent mechanical properties. The new concrete called slurry infiltrated fiber concrete composites (SIFCON) have more strength, ductility, and crack resistant properties. In present paper, experimental and numerical studies of sullary infiltrated fiber reinforcement testing specimens. The laboratory works consists of twelve specimens with dimension of length 1250 mm and height 150 mm and depth 100 mm specimens who had the same length, geometry and reinforcements of longitudinal and stirrups were designed to fail in flexural mode. The total specimens are classified four as reference and eight specimens were the steel fiber percentages different as (6%) and (8%). The load applied for all specimens up to failure with mid deflections for each test. The numerical method was finite elements approach by ANSYS (16.2) the adopted to simulate all models and compared the analysis results with that from experimental tests. Also exanimate (12% Vf) specimens numerically .The test results showed close with that from numerical analysis and indicated that the increased in steel fiber percentages lead to increasing in mechanical properties of concrete, strength capacity of specimens and reducible in deflection.

Keywords: Steel fiber, Slurry infiltrated specimen, Numerical approach, ANSYS.

INTRODUCTION

Slurry Infiltrated Fibrous Concrete (SIFCON) was first adopted since forty years ago in the north of America, by merge large rate of SF in cement mortar that used by Lankard, D.R., 1984 [1]. The SIFCON as components when steering uniformly and distributed within mortar gave enhance in tensile strength of concrete because of have high tensile strength. In case of presence of SF on the cement matrix that limited up to (2%) from the total volume of concrete mix and above this limit the behavior of concrete behave different and mainly the workability affected. The SF percentage in case of SIFCON reach in the range (5- 30%), Lankard, D.R. and Homrich, J.R. in 1984, 1987 [1],[2]. The steel fiber ratio relay on the aspect ratio of the SF, so that when the percentages of SF increase that is mean either the length increased or the diameter decreased that is useful because of the long SF give the more connections between concrete particles. The composition of the test sample that includes SIFCON need of special treatments relay on to prevent the un regularly of the SF allocation to shun of unsuitable SF orientation. In 2015, Rakesh Kumar Chaudhary and R.D.Patel [3], studied the SIFCON concrete in case of partial replacement of cement by steel fiber. The steel fiber percentages are (6, 12 and 18%) and the specimens that casted are cube. The test results are visible that the compressive strength increased with increased in percentage of SF. In 2015, Rakesh Kumar Chaudhary and Raghvendra Gupta [4], investigated the SIFCON that produced by low steel fiber. The cube with (150 mm) was used for tests with different steel fiber ratio such as (6, 12 and 18%). The test results indicated that the optimum compressive strength at (12%) of steel fiber. In 2010, Y. Farnam et al [5], look out on the behavior of SIFCON subjected to triaxial compression loading. The specimen was concrete cylinder with (75x150 mm) in dimensions and the steel fiber (0, 2, 5 and 10%). The results showed that increased in strengths in case of steel fiber increased. In 2013, K. Parthiban et al [6], explored the flexural behavior of (SIFCON) specimens. Total of (13) specimens with span (1000 mm) were tested with (10, 20, 30, 40 and 50%) of steel fiber. Test results are obvious improved in flexural and reduced in deflections when the steel fiber percentages increased. In 2015, Pradeep.T and Sharmila. S [7], investigated the SIFCON specimens under the effects of cyclic loading. The steel fiber with (8%) was used and the specimen dimensions as (1200 mm x 150 mm x 100 mm). from the test results, the SIFCON specimen as compared with the control specimen was better as strength capacity. In 2014, Arun Aniyan Thomas and Jeena Mathews [8], investigated the strength of SIFCON taking into accounts various fiber types. The specimen dimensions was (100x100x500 mm) and the steel fiber ratio as (4, 5, and 6%). Results indicated that the optimum steel fiber ration was (5%) in flexural and increased in tension resistance of concrete. In present paper, experimental and numerical study on the effects of volume friction (Vf) fibers type ,and mix type of sullary infiltrated fiber reinforcement concrete (SIFCON) on the behavior of reinforce concrete specimens are discussed.

EXPERIMENTAL PROGRAM

A series of twelve reinforced concrete specimens with steel fiber (Vf) rations as (2, 6 and 8%) were used in this experimental study to find out flexural behavior. Ordinary Portland Cement OPC (Type I) has been used in present work, and we used Al-Zobeer natural sand was a fine aggregate that matched with the requirements of Iraqi standard as IOS No.45/1984[9].Also we used two mix type 1:1 and 1:1.5 with w/c is about 0.4, and we used silica fume and superplastesizer in the mixes. The laboratory works first by carry out tests on fresh concrete. The V-funnel and L-box test are adopted to assess the fresh properties of (SIFCON) concrete .The results of this test are lists in Table 1.

Table 1: Mix Type of SIFCON

Mix Symbols	Mix Type	V- funnel Test	L – box Test
		T_v (sec)	(H_2/H_1)
Mix 1	1:1	8.21	0.951
Mix 2	1:1	7.42	0.932
Mix 3	1:1.5	11.61	0.901
Mix 4	1:1.5	11.1	0.811
Limits of EFNARC [50]		6-12	0.8-1

COMPRESSIVE STRENGTH

Tests were based on BS 1881: part 116:1989 [10] as standard specimen with nominal dimensions as cube (150 x150 x 150 mm) those treatments under ideal laboratory conditions (28) days. The test results for various blends are lists in Table 2 based on mix type and steel fiber (SF) ratio for average of three specimens. The compressive strength increased when the steel fiber ratio increased because of the concrete worked as reinforced concrete elements so that the steel fiber make strong bond between concrete particles that led to increasing in compressive strength.

Table 2: Compressive strength results

Mix type	Specimen type	Compressive strength (MPa) At (28) days	% Increase
1:1	(C4) Vf 2% Hook-End	43.2	-
	(A3) Vf 6% Hook-End	56.5	30.23
	(A4) Vf 8% Hook-End	76.7	35.71
	(C2) Vf 2% Straight	44.8	-
	(A1) Vf 6% Straight	59.4	34.09
	(A2) Vf 8% Straight	78.2	32.20
1:1.5	(C1) Vf 2% Straight	39.1	-0.5
	(B1) Vf 6% Straight	52.3	-
	(B2) Vf 8% Straight	65.8	33.33
	(C3) Vf 2% Hook-End	42.4	25
	(B3) Vf 6% Hook-End	50.2	13.23
	(B4) Vf 8% Hook-End	63.1	-

SPLITTING TENSILE STRENGTH

Tests were based on ASTM C496/C496M-04 [11] by tests the (150 x300 mm) cylindrical specimens at (28) days. The laboratory tests results classified as group depend on different mixtures are lists in Table 3; show that there are increases with the SF ratio. The tensile strength of concrete increased in presence of steel fiber because of the tensile strength of steel fiber more so that the cracking load becomes more.

Table 3: Splitting tensile strength results

Mix type	Specimen type	Splitting tensile strength (MPa)	% Increase
1:1	(C2) Vf 2% Straight	7.51	-
	(A1) Vf 6% Straight	12.12	61.33
	(A2) Vf 8% Straight	15.41	27.27
	(D1) Vf 12% Straight	16.21	5.19
	(C4) Vf 2%Hook-End	8.2	-
	(A3) Vf 6% Hook-End	13.1	62.5
	(A4) Vf 8%Hook-End	15.21	16.92
1:1.5	(C1) Vf 2% Straight	6.4	-
	(B1) Vf 6% Straight	12.1	84.61
	(B2) Vf 8% Straight	14.12	17.5
	(D2) Vf 12% Straight	15.91	12.76
	(C3) Vf 2%Hook-End	6.42	-
	(B3) Vf 6%Hook-End	11.71	82.81
	(B4) Vf 8%Hook-End	15.1	28.20

FLEXURAL STRENGTH (MODULUS OF RUPTURE)

This test was implement by specimens with prism in shape (100x100x400 mm) at (28) days of treatments based on ASTM C-78, 2002 [12]. A flexural strength results for different mixtures is presented in Table 4. The specimen strength results showed that there are increase in presence of steel fiber because of steel fiber enhance the tensile strength of concrete so that the load need to produce cracks become more.

Table 4: Flexural strength results

Mix type	Specimen type	Flexural strength (MPa)	% Increase
1:1	(C2) Vf 2% Straight	11.41	-
	(A1) Vf 6% Straight	14.82	29.82
	(A2) Vf 8% Straight	19.71	33.10
	(D1) Vf 12% Straight	12.51	-
	(C4) Vf 2%Hook-End	15.62	24.8
	(A3) Vf 6% Hook-End	20.43	30.76
	(A4) Vf 8%Hook-End	10.41	-
1:1.5	(C1) Vf 2% Straight	13.74	31.73
	(B1) Vf 6% Straight	18.45	34.30
	(B2) Vf 8% Straight	11.12	-
	(D2) Vf 12% Straight	13.18	18.73
	(C3) Vf 2%Hook-End	18.13	37.32
	(B3) Vf 6%Hook-End	11.41	-
	(B4) Vf 8%Hook-End	14.82	29.82

YOUNG'S MODULUS

The test based on ASTM C469-02[13] by tests cylinder with dimensions (150 x 300mm). Test results lists in Table 5. Modulus of elasticity become more in case of presence steel fiber because of the modulus of elasticity as function of compressive strength and the compressive strength as mentioned above increased in presence of steel fiber that lead to increasing in modulus of elasticity.

Table 5: Static modulus of elasticity

Mix type	Specimen type	Modulus of elasticity(GPa)
1:1	(C2)Vf 2% FINE SF	32.14
	(C4)Vf 2% COURSE SF	32.61
	(A1)Vf 6% FINE SF	38.54
	(A3)Vf 6%COURSE SF	38.78
	(A4)Vf 8% COURSE SF	41.14
	(A2)Vf 8% FINE SF	41.98
1:1.5	(C1)Vf 2% FINE SF	30.23
	(C3)Vf 2% COURSE SF	31.12
	(B1)Vf 6% FINE SF	36.67
	(B3)Vf 6% COURSE SF	37.16
	(B2)Vf 8% FINE SF	39.45
	(B4)Vf 8% COURSE SF	39.79

SPECIMEN'S TESTS

As mentioned above, twelve specimen specimens with same geometry as (1250x150x100 mm), was designed to fail in flexural. The main and stirrups reinforcements bars are the same for all tested specimens except that the steel fiber ratios and/or steel fiber geometry and classified as groups. Top and bottom main reinforcement by two (6 mm) in diameter while the stirrups (4 mm) with (110 mm) center to center. The reference four specimens with (2%) of SF in which classified as (2) specimens have straight and the remaining had hook end. The remaining (8) specimens mix SF (6%) and (8%) respectively, (4) specimens arranged in straight and four hooked end SF in which all specimens were tested up to failure. The test results were classed and categorized according to the load caused cracks, failure load, maximum deflection, and cracks configurations. GroupsG1 and G2 specifications are lists in Table 6.

Table 6 : Groups G1 and G2

G1				G2			
Mix type	Specimen symbols	% S.F Vf	Type of SF	Mix type	Specimen symbols	% S.F Vf	Type of SF
1:1	C2	2	Straight	1:1.5	C1	2	Straight
	C4	2	Hook-End		C3	2	Hook-End
	A1	6	Straight		B1	6	Straight
	A2	8	Straight		B2	8	Straight
	A3	6	Hook-End		B3	6	Hook-End
	A4	8	Hook-End		B4	8	Hook-End

TEST RESULTS

Load – deflection behavior for all tested specimens are presented in Figures (1) to (12), for groups G1 and G2, respectively. The behaviors of all specimens are nonlinear and at a certain point of load the specimen fail and then the load drop down. Table 7 lists the test results for all specimens that represents the load cause first crack and the corresponding deflection in addition of failure load with maximum central deflection for each specimens. Figures (13) to (24) show the cracks pattern for all tested specimens as G1 and G2 at failure load. The cracks propagations for all tested specimens shown in Figures (13) to (24). These Figures show that the cracks classified as flexural. As shown in Figures that represents the full behavior of G1 and G2 specimens, the deflection decrease as the steel fiber increase and the strength specimens capacity increased because of the presence of steel fiber increased the mechanical properties of concrete and these reflect to increase in specimen capacity, reduce cracks and decrease in deflection because of increased in modulus of elasticity.

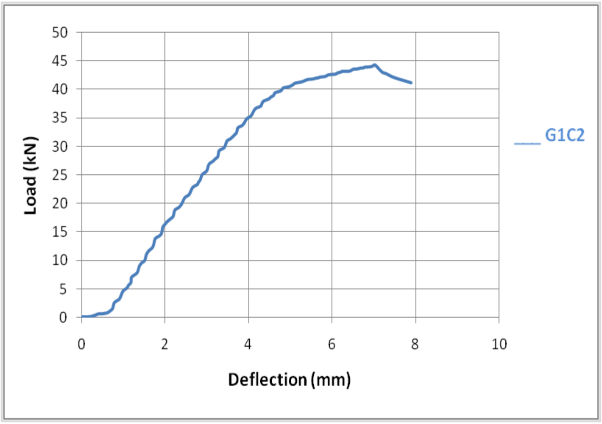

Figure 1: Specimen G1 C2

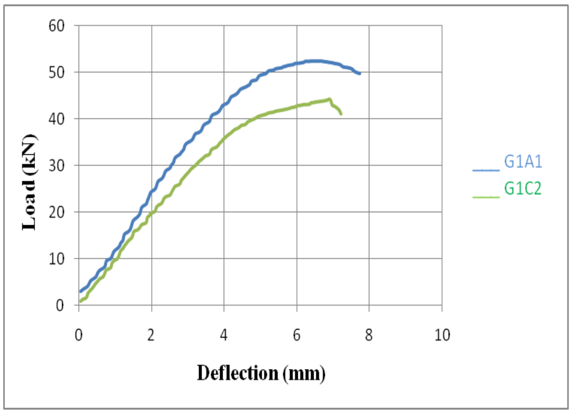

Figure 2: Specimen G1 C2 and A1

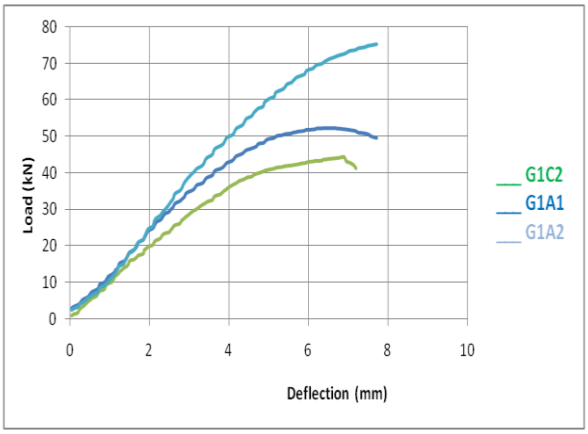

Figure 3: Specimen G1 C2, A1 and A2

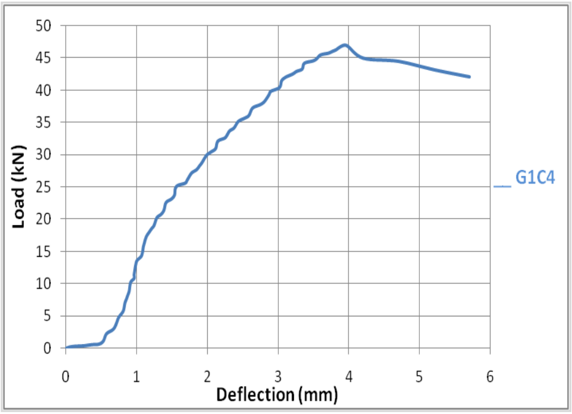

Figure 4: Specimen G1 C4

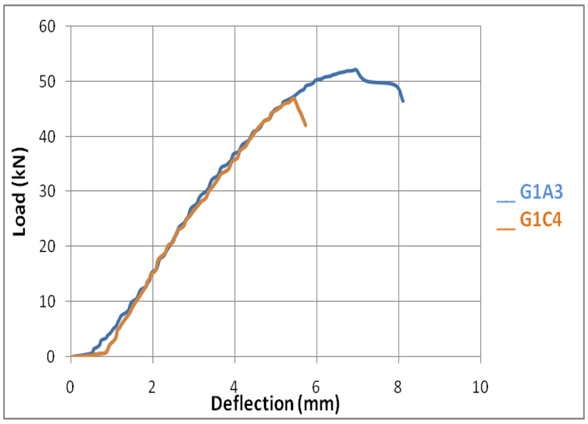

Figure 5: Specimen G1 A3 and C4

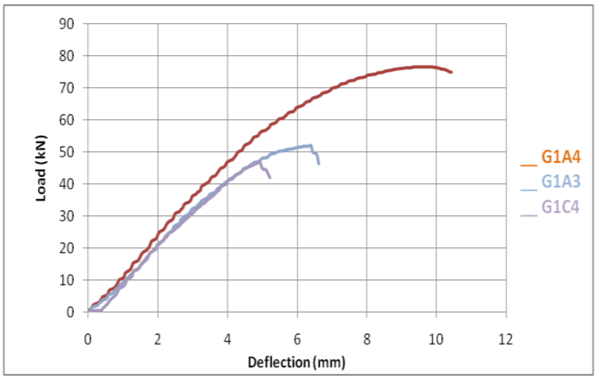

Figure 6: Specimen G1 A4, A3 and C4

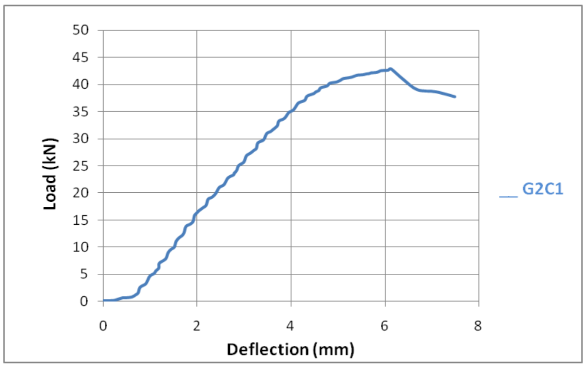

Figure 7: Specimen G2 C1

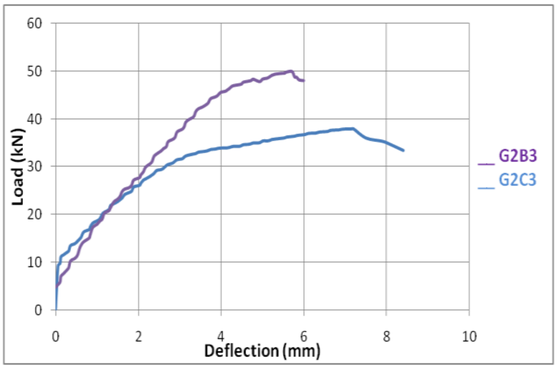

Figure 8: Specimen G2 B3 and C3

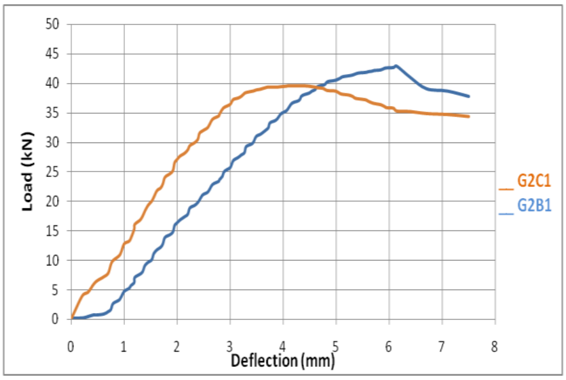

Figure 9: Specimen G2 C1 and B1

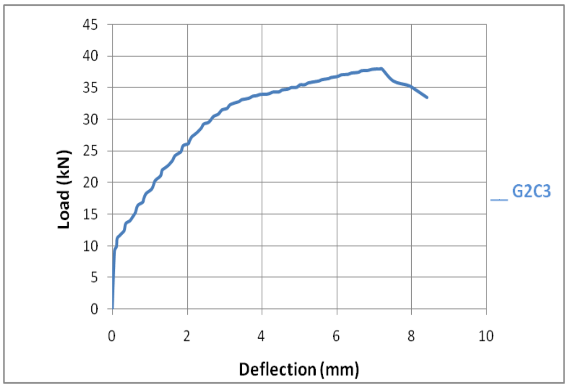

Figure 10: Specimen G2 C3

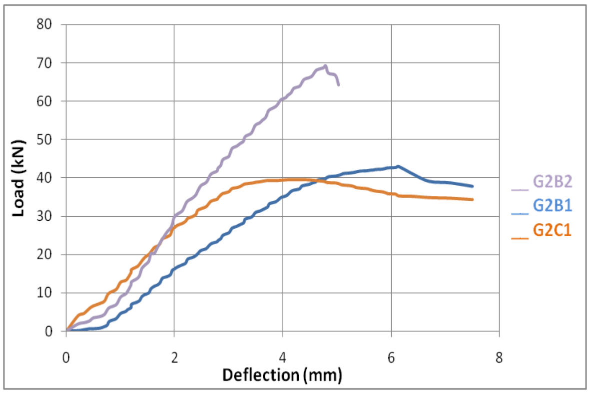

Figure 11: Specimen G2 C2, B1 and C1

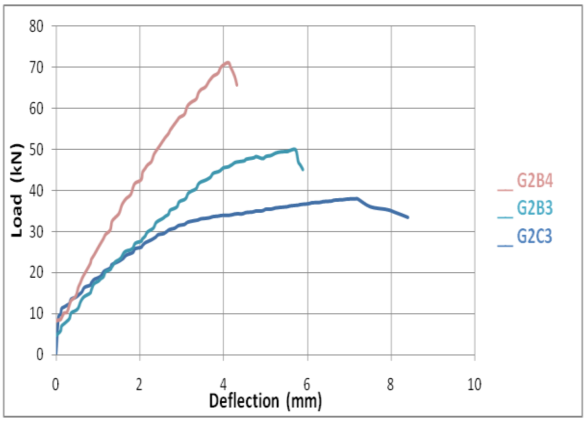

Figure 12: Specimen G2 C3 B3 and B4

Table 7: Test results for tested specimens, Straight, Hook-End

Mix type	Specimen mark	% S.F	SF configuration	P First crack (kN)	Deflection at first crack (mm)	P ultimate load (kN)	Deflection at ultimate load (mm)
1:1	C2	2	S	22.2	3.51	44.2	7.11
	C4	2	H	20.1	2.32	46.3	4.1
	A1	6	S	33.3	3.11	52.4	6.91
	A2	8	S	54.1	3.5	75.1	7.72
	A3	6	H	31.6	4.12	52.2	7.4
	A4	8	H	50.1	4.71	76.4	9.81
1:1.5	C1	2	S	20.05	3.21	42.1	6.13
	C3	2	H	21.4	3.32	37.9	7.21
	B1	6	S	28.3	3.51	40.4	5.74
	B2	8	S	38.2	4.4	69.3	5.91
	B3	6	H	34.1	4.23	49.3	5.21
	B4	8	H	41.6	4.2	71.6	6.1

Figure 13 : Cracking of failure specimens for group 1 (C2,C4,A1,A2,A3,A4)

Figure 14: Cracking of failure specimens for group 2 (C1, C3, B1, B2, B3and B4)

NUMERICAL ANALYSIS

The numerical method using finite elements approach (FEA) by ANSYS package is adopt to simulate all models. SOLID65is (3d) structural elements used to simulate the concrete with eight nodes. LINK180is used to simulate the steel reinforcing bars for stirrups and main reinforcements with three degrees of freedom at each node. SOILD185 is used to model steel supporting plates in the specimen models. The element is defined by eight nodes having three degrees of freedom at each node translations in x; y and z directions.Linear and nonlinear analysis relies on the experimental test results of stress – strain are adopt for each specimen according to the laboratory tests for concrete and steel reinforcements using Newton-Raphson equilibrium iterations. All required parameters that used in ANSYS from experimental tests such as mechanical properties for all materials and loadings. The modeling and meshing of the reinforced concrete specimen is shown in Figure (15).

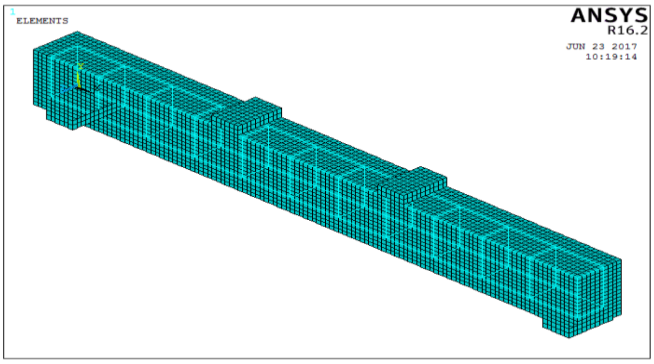

Figure 15: The three dimensional finite element model

The Poisson's ratio for concrete and steel is (0.15) and (0.3) respectively. The modulus of elasticity for reinforcement and steel plate the represents the supports and plate loading is (200000 MPa) and for nonlinear, the steel reinforcement assumed linear perfectly plastic, while for concrete based on the stress – strain tests for each specimen types. The numerical results compared with that of experimental tests shown in Figure (16) to (21) and all results lists in Table 8.

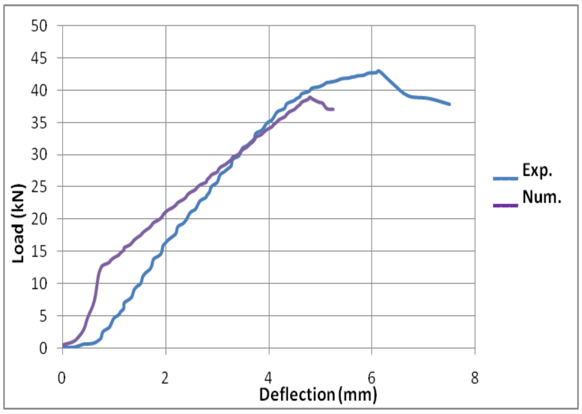

Figure 16: Load - deflection curves for specimen (C1)

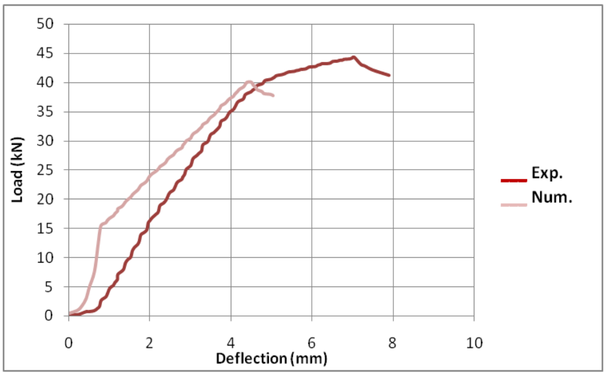

Figure 17: Load - deflection curves for specimen (C2)

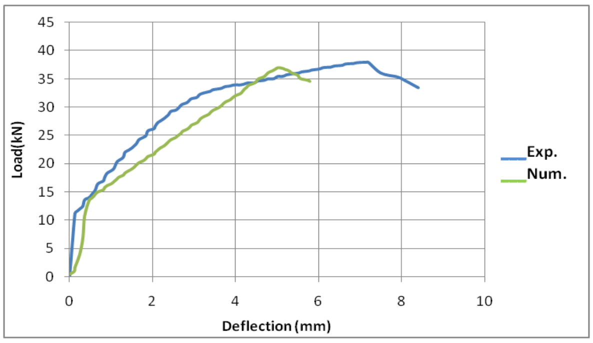

Figure 18: Load - deflection curves for specimen (C3)

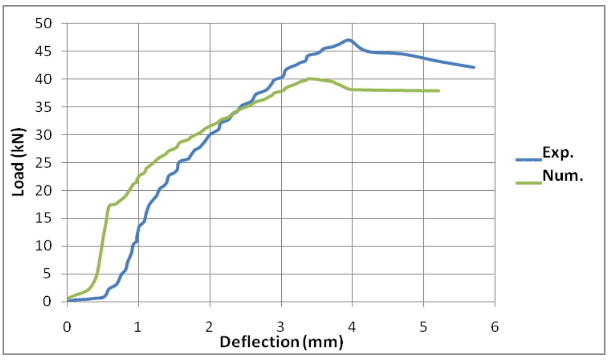

Figure 19: Load - deflection curves for specimen (C4)

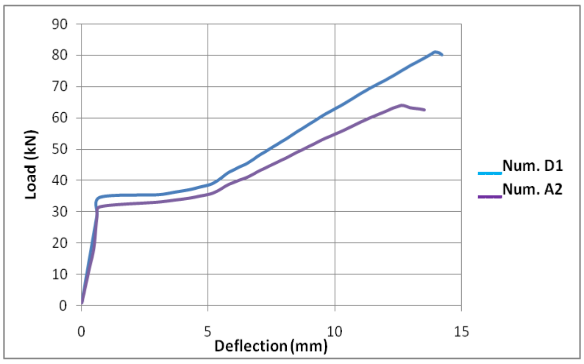

Figure 20: Load - deflection curves for specimens (A2) and (D1)

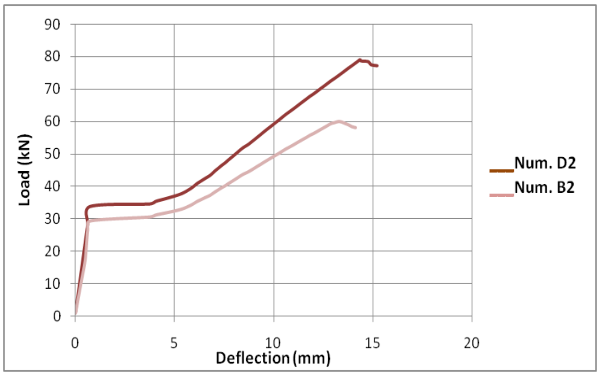

Figure 21: Load - deflection curves for specimens ((B2) and (D2)

Table 8: Comparisons of numerical analysis with test results

Modeled Specimens	P_u (kN)			Deflection Δ_u(mm) at center		
	Exp.	Numerical	Diff.%	Exp.	Numerical	Diff. %
Specimen (C1)	42.1	39.1	-7.14	6.14	5	-18.56
Specimen (C2)	44.2	40.3	-9.09	7.04	7.47	6.11
Specimen (C3)	37.8	37	-2.36	7.2	6.9	-4.15
Specimen (C4)	46.2	40.1	-13.14	4	3.6	-12.4
Modeled Specimens	P_u(kN)			Deflection Δ_u(mm) at center		
	Numerical D1	Numerical A2	Diff%	Numerical D1	Numerical A2	Diff. %
Specimen (A2) and Specimen (D1)	81.2	64.4	-20.96	13.7	10.7	-0.21
Modeled Specimens	P_u (kN)			Deflection Δ_u(mm) at center		
	Numerical D2	Numerical B2	Diff%	Numerical D2	Numerical B2	Diff. %
Specimen (D2) and Specimen (B2)	79.3	60.3	-24.03	15.3	10.7	-29.6

DISCUSSIONS

According to the experimental investigation and finite elements analysis results, the following points are observed and discussed (based on the Figures and Table of results that mentioned and symbolic above):

1. The presence of steel fibers and the ratio of sand to Mix3 and Mix4 listed in Table 1 decreases the workability of the concrete mixes in which less than that of non- fibrous concrete because of regard to the presence of SF that hinder or impede the movement or progress of the motion of the mix.
2. The values lists in Table 2, the (8%) of SF is gave higher compressive strength than other mixes, and the result of mix 1:1 is better than of mix 1:1.5 because of the amount of sand is increase in this mix that lead to weak the strength of the cubes.
3. The presence of SF makes strong connection to prevent micro cracks to develop and delayed the specimen's expansion. The presence of SF effectively prevents the propagation of micro cracks and improves the tensile strength of concrete at tension zone because of the resistance of crack propagation by SF which enhances the concrete cracking resistance and tensile strength during loading progress. The enhancements of tensile strength that lists in Table 3 and 4.
4. In comparison with 2% steel fibers concrete, increase the Vf steel fibers to 6% and 8% volume fraction actually increases the modulus of elasticity (E_c) by (19.9 and 28%), respectively in mix 1:1.5. Inserting steel fiber into the concrete mix leads afterwards to elevating in the elastic modulus value.
5. Increase in the maximum load at failure for control specimen (G1C2). An increase steel fiber to (6%) was observed that the width of the crack was less than that in (G1C2). This is due to the increase in steel fibers lead to reduce the numbers of the crack, and width of the crack by bridging action between the two sides of a crack.
6. Specimen G1A2 is more ductile than the other specimens because of have more steel fibers.
7. Specimen G1C4**,** the change in ultimate load and deflection is few as compared with specimen (G1C2) because of SF distribute by hand and randomly in to the mold.
8. Specimen G1A3, the mode of failure changed from brittle to ductile because of. The presence of SF the ductility increase of the specimen that loads at first crack.
9. Specimen G1A4 becomes more ductile than other specimens due to increase percentage of SF (8%) so that the increase in SF leads to increase in ultimate load.
10. Specimen G2C1, results very converged to the mix of G1 but different in deflection because of the properties of this mix contain more sand than others mix.
11. Specimen G2B1, the ultimate load increase and the deflection was decrease because of the percentage of SF makes the specimen become more ductile than specimen G2C1, and increase in SF to (6%) increase the shear capacity of the concrete section.
12. Specimen G2B2, crack intensity and distribution decrease because of presence of silica fume in the specimen.
13. Specimens G2C3, fail with low ultimate load and high deflection as compared with others specimens because of the type of mix is different that effects on the behavior of the specimen.
14. Specimen G2B3, increased in ductility and increased in the ultimate load as compared with (G2C3) specimen, because of increased in SF that increased in concrete confinement, reducing the cracks width and increasing the ductility.
15. Specimen G2B4, has more ductile than others specimens G2 such as B3 and C3 because of a high amount of steel fibers than others.
16. Behavior of tested specimens with (2%) SF was brittle and stiff compared with others specimens which contain more SF.
17. The increase in SFs to tested specimens with different volume fraction (6% or 8%) by volume of mold used it was observed increasing in cracking load for the specimens and ultimate load and the failure changed from brittle material to ductile material that was clear in specimens (A1, A2, A3, A4, B1, B2, B3, and B4).
18. Numerical analysis results that compared with that from experimental tests showed close as shown in Figures (16) to (21) with maximum central deflections and the corresponding ultimate loads listed in Table (8).

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