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Experimental and Numerical Study of Energy Absorption Capacity of Glass Reinforced Self-compacting Concrete Beams

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ABSTRACT

Various experimental studies have been carried out on glass fiber reinforced concrete (GFRC), but in limited studies, the behavior of this type of concrete is evaluated using finite element method (FEM). In this study an analysis model is presented for predicting energy absorption capacity of glass fiber reinforced self-compacting concrete (GFRCSCC) beams and the results are compared with experimental study. For this purpose, the investigations are conducted in two experimental and numerical sections. In experimental section, the characteristics of fresh and hardened concrete have been evaluated using slump flow, V-funnel, L-box, T50, compressive strength, tensile strength and flexural strength tests. In numerical section, ABAQUS software has been used to simulate GFRCSCC beams. The concrete damage plasticity model has been used to simulated concrete material. The fiber contents are 0, 0.25, 0.75 and 1% of the mixed concrete by volume. The results show that the maximum increase in energy absorption capacity of beams compared to the plain concrete for 25, 35 and 45 concrete grade was 29, 33.2 and 53.75%, respectively. At last, the ultimate loads corresponding to the FEM are found to hold good agreement with experimental ultimate loads which validates the FEM.

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1. INTRODUCTION

Concrete is one of the most consumed construction materials all over the world. However, the weakness of its tensile strength leads to sudden failure in concrete structures during an earthquake [1, 2]. Different fibers can be used to eliminate the brittleness of concrete and improve the mechanical properties. Currently, different types of fibers such as carbon, asbestos, cellulose, steel, polypropylene and glass are used to reinforce concrete and cement [3–8]. However, each of them has some advantages and disadvantages. Steel fibers increase the compressive strength and the hardness of concrete. On the other hand, it can increase concrete weight and the dead weight of structure and it also increases the final cost. Steel reinforced concrete performance decreases due to the possibility of steel corrosion and it increases the maintenance costs [9–11].

From economic point of view, the use of fibers depends on the application and project conditions. Nowadays fiber has become more used in construction projects. Economic assessment is more about the type of fiber and how it is used. The cost equality between fiber and steel is not the only problem, when fiber is used instead of steel mesh, but also the materials, skilled manpower, equipment and materials storages are significant. Maintenance costs, weather conditions and future uses of building are the factors that can justify the use of fibers economically. Also, in some cases, the project scheduling may be very important and the use of fibers will speed up the construction process and this leads to saving in economic.

Various studies have been carried out to investigate the use of glass fiber [12–14]. Sadrmomtazi et al. [15] investigated glass fiber reinforced concrete in an experimental study. The results showed that by increasing the fiber to cement ratio in the range of zero to one, the compressive strength of concrete increases and in the range of one to five, the compressive strength decreases and the flexural strength of concrete specimen

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increases. Raj et al. [16] investigated self-compacting concrete containing glass fiber. The fiber length added to the mixture was 1.2, 1.8 and 2.4 mm, and the fiber content was 0%, 0.25%, 0.5%, 0.75% and 1%, respectively. The maximum compressive strength was in a case with 2.4 mm in length and containing 1% fiber. Kwan et al. [17] investigated the durability of self-compacting concrete specimens in corrosive environments. For this purpose, the glass fibers contents were 0.6 to 2.4%. The results showed that the specimens with more glass fiber exhibited greater strength against corrosive environments. Abhishekh Soraturet al. [18] studied the properties of concrete containing foundry sand and glass fibers. For this purpose, the compressive, tensile and flexural strength of specimens were evaluated. The results showed that the addition of glass fiber and foundry sand led to improve the mechanical properties of concrete. Alex and Arunachalam [19] examined the steel and glass fiber on mechanical properties of lightweight concrete. The results showed that the use of glass and steel fibers can have a significant effect on compressive, tensile and flexural strength of concrete specimens.

According to previous studies, fibers are suitable material to ensure optimal seismic behavior and improve seismic performance of shear and flexible structure members [20]. According to author's knowledge in the field of finite element and experimental investigations of self-compacting concrete containing glass fiber a few studies have been carried out. Therefore, in the present study, compressive stress-strain behavior and mechanical properties of this concrete were investigated. For this purpose, the present study was conducted in two experimental and numerical sections. In experimental section, the characteristics of fresh and hardened concrete have been evaluated using Slump Flow, V-funnel, L-box, T50, compressive strength, tensile strength and flexural strength tests. Also, in numerical section, ABAQUS finite element software has been used to simulate glass fiber reinforced concrete beams and the results are compared with experimental results.

2. EXPERIMENTAL PROGRAM

2. 1. The Used Material

The Used Material in this investigation are cement, coarse aggregate (gravel), fine aggregate (sand), glass fiber, water and super plasticizer. Portland cement (Type II), which is made in accordance with ISIRI 389 Iranian national standards, is used. The chemical properties of cement are presented in Table 1. River gravel is used in the concrete mix. The water absorption of gravel is 2.63% and the maximum aggregate size is 12.5 mm. The gravel gradient is presented in Figure 1. In this research, sand river was used. The sand gravel curve is in the range recommended by the ASTM-C33 [21]. The specific gravity of the sand used is 1593 kg/m^3 and the water absorption is 2.5 %. The sand gradient curve is presented in Figure 2. Fiber used type are A-glass with module of elasticity 72 GPa, tensile strength 3300 MPa, Percent elongation 4.8, density 2.44 g/cm^3 and length 30 mm. The properties of glass fiber used are presented in Table 2. Also, the glass fiber used in concrete specimens is shown in Figure 3.

Superplasticizer is a chemical material with high range water reduction capacity and it is one of the most important components of self-compacting concrete [22, 23]. A F-type Polycarbonxylate-based SP was used in all samples. This type of superplasticizer is in conformity with ASTM-C496 [24]. The water used in this research is drinking water according to ASTM-C190 [25].

TABLE 1. Chemical properties of cement, type II [26]

Comparison with standard	ISIRI-389 [27]	EN-197-1 (32.5R) [28]	Hegmatan cement factory
SiO_2	Min 20	***	21.27
AL_2O_3	Max 6	***	4.95
Fe_2O_3	Max 6	***	4.03
CaO	***	***	62.95
MgO	Max 5	***	1.55
SO_3	Max 3	Min 3.5	2.26
K_2O	***	***	0.65
Na_2O	***	***	0.49
LOI	Max 8	Min 5	2.11
C_3A	Max 8	***	6.30

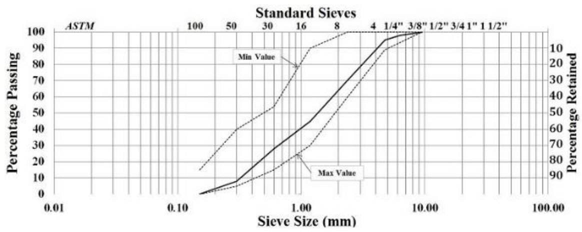


Figure 1. Gravel gradient curve according to ASTM-C33 [21]

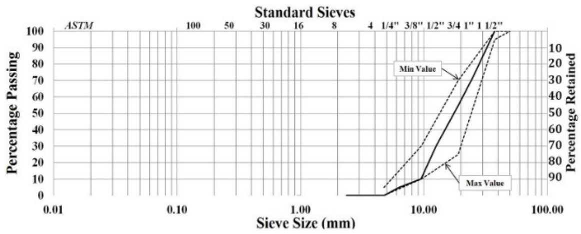


Figure 2. Sand gradient curve according to ASTM-C33 [21]

TABLE 2. Properties of glass fiber used

Type	Fiber length (mm)	Density (g/cm^3)	Fiber diameter (mm)	Percent elongation	Tensile strength (MPa)
A-Glass	30	2.44	5-20	4.8	3300

Figure 3. Glass fiber used in concrete specimens

2. 2. Mixture Details The concrete mix design has been selected according to concrete workability criteria for fresh and hardened concrete properties. The studied variables include content of glass fiber and the grade of concrete. According to this and conducted researches in the field of concrete containing glass fiber and the study of their properties, the content of glass fiber considered were 0, 0.25, 0.5, 0.75 and 1% of the mixed concrete by volume. Mix design for C25, C35 and C45 grades of concrete have been carried out using ACI-211-89 method. So, according to the mentioned values, 15 different mix designs were made.

The water to cement ratio according to the grades of strength is considered 0.61, 0.47 and 0.27, respectively. Mixture details are presented in Table 3. W, C, GF, M, G, S and SP is water, cement, glass fiber, micro silica, gravel, sand and superplasticizer, respectively.

2. 3. Experimental Procedures

2. 3. 1. Fresh Concrete Tests V-Funnel, T50, L-box and Slump flow were conducted on fresh concrete in accordance with EFNARC considerations [28] (Figure 4). Mixture details were chosen with the aim of obtaining self-compacting characteristics, despite the use of glass fiber in concrete. Therefore, self-compacting concrete tests were used to measure the workability of self-compacting concrete containing fibers. L-Box test was used to investigate different properties such as passing ability and segregation resistance of SCC and the slump test was performed to evaluate the consistency of SCC. Slump test of SCC is similar to the test that used for conventional concrete; the only difference in this test is that the spread diameter of the specimen is measured in two perpendicular directions. The average measured values express the consistency of concrete.

Also, the time to reach a diameter of 500 mm (in seconds) is recorded according to the marking inside the slump test table, which indicates the deformation rate. Fresh concrete height after passing through the specified spaces between steel reinforcements is measured using L-Box test. V-funnel test was also tested to determine the filling ability of concrete. This test can also be used as a criterion for determining the concrete segregation.

TABLE 3. Mixture details (kg/m^3)

Mix code	W/C	C	G	S	GF	SP (%)
C25G0	0.61	336	601	518	0	0.675
C25G0.25	0.61	336	599	516	6.75	0.675
C25G0.5	0.61	336	597	514	13.5	0.675
C25G0.75	0.61	336	595	512	20.25	0.675
C25G1	0.61	336	592	510	27	0.675
C35G0	0.47	436	573	494	0	0.872
C35G0.25	0.47	436	571	492	6.75	0.872
C35G0.5	0.47	436	569	490	13.5	0.872
C35G0.75	0.47	436	567	488	20.25	0.872
C350G1	0.47	436	565	486	27	0.872
C45G0	0.27	760	480	414	0	1.52
C45G0.25	0.27	760	478	412	6.75	1.52
C45G0.5	0.27	760	475	410	13.5	1.52
C45G0.75	0.27	760	474	408	20.25	1.52
C45G1	0.27	760	471	406	27	1.52

W: Water, C: Cement, G: Gravel, S: Sand,
GF: Glass fiber, SP: Superplasticizer

2. 3. 2. Hardened Concrete Tests Hardened concrete tests include compressive strength, flexural strength and tensile strength. The compressive strength test is carried out in accordance with ASTM C39 standard. This test shows the strength of concrete against the weight force. It is also one of the most important factors in controlling the concrete quality and expresses the strength of specimen against the compressive force; Concrete specimens were made in cubic moulds with dimensions of 15×15×15 cm. The cube samples were cured under standard laboratory conditions and tested after 28 days using a compression testing machine of 2000 KN capacity. In this machine a linear variable differential transducer (LVDT) is used to record displacement and strain. This feature is used to determine the compressive stress-strain curve of concrete samples.

The flexural strength test was performed by simple supported beams subjected to a central load in accordance with ASTM-C78 standard [29]. Prismatic specimens with dimensions of 400×100×100 mm were prepared for point loading till failure of specimen. Also,

L-box test SCC mix during slump flow test V funnel test

Figure 4. SCC tests

the deflection at the center of the beam is measured with LVDT (Figures 5 and 6). The flexural strength is calculated by the following expression:

$$S_f = \frac{3pl}{2bh^2} \quad (1)$$

where S_f is the flexural strength in newton per square millimeter, P is the applied force in the middle of the span in newton, b is the cross section in mm, h is the height of the section in mm, and L is the distance between the two supports in millimeters. The distance between two supports is 300 mm.

The most common method for measuring the tensile strength of concrete is splitting tensile method in accordance with ASTM-C496 [24] standard. Cylindrical samples 15 cm in diameter and 30 cm in height were used in splitting tensile strength test.

Conditions for preparation and curing of specimens are such as compressive specimens (Figure 7). The splitting tensile strength is calculated by the following expression:

$$T = \frac{2p}{\pi Ld} \quad (2)$$

where T is splitting tensile strength in MPa, P is the maximum applied load showed by the testing machine in N, l is length in mm and d is diameter in mm.

The tensile strain capacity can also be estimated from the flexural strength and modulus of elasticity Houghton showed that the tensile strain capacity can be determined

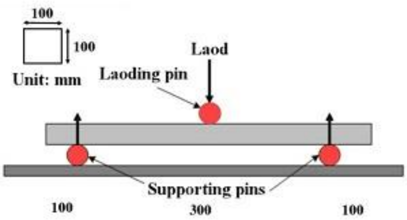


Figure 5. Schematic illustration of flexural strength test

Figure 6. Flexural test set-up

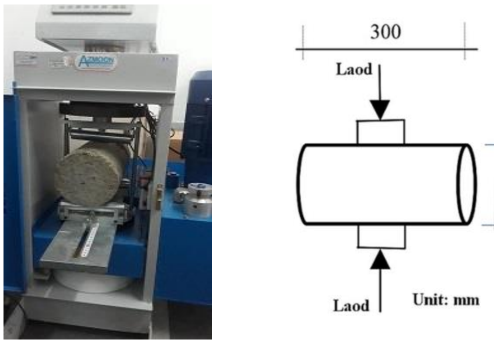


Figure 7. Set-up splitting tensile strength test

according to flexural strength (fr) and elasticity modulus of concrete in comparison (EC) [30, 31]:

$$\varepsilon_{tsc} = \frac{f_r}{E_C} \quad (3)$$

3. RESULTS AND DISCUSSION

3. 1. Fresh Concrete Properties

Fresh SCC tests were performed for each mixture design. Controlling the properties of SCC is shown in Table 4. The results of fresh concrete tests show that all specimens have self-compacting conditions in accordance with EFNARC considerations. In order to investigate the results of SCC tests, linear diagrams for slump flow, T50, V-funnel and L-box tests are shown in Figures 8 to 11.

TABLE 4. Fresh properties of mixes

Mix code	Slump flow		V-funnel flow time (s)	L-box (H_2/H_1)
	D (mm)	T_{50} (s)		
C25F0	692	2.92	7	0.81
C25F0.25	685	3.28	7	0.84
C25F0.5	679	3.73	9	0.86
C25F0.75	675	4.57	9	0.88
C25F1	662	4.58	10	0.89
C35F0	677	3.29	8.3	0.85
C35F0.25	674	3.7	9.4	0.87
C35F0.5	669	4.21	9.8	0.87
C35F0.75	669	4.81	10.1	0.89
C35F1	662	4.82	10.8	0.91
C45F0	669	3.78	8.6	0.92
C45F0.25	668	4.24	10.2	0.95
C45F0.5	667	4.83	10.9	0.95
C45F0.75	653	4.91	11.5	0.97
C45F1	651	4.95	11.8	0.99
EFNARC recommended values for fresh state of SCC				
Min.	650	2	6	0.8
Max.	800	5	12	1

In these diagrams, EFNARC allowed range is also shown. The range of slump flow should be between 650 and 800 mm. All the specimens in this study are in this range. Also allowed range of H_2/H_1 ratio in L-box test is between 0.8 and 1 and the V-funnel allowed range is between 6 and 12 according to EFNARC, which the study specimens are in this range. So, concrete specimens are self-compacting with regard to mentioned values.

According to Figure 8, it is observed that by increasing the glass fiber volume content, the slump flow decreases. The lowest slump has been created in C45F1 mixture design; so that in this specimen the slump has decreased by 40% compared to control specimen.

On the other hand, the results of T50 test indicated that T50 is increased by increasing glass fiber volume content. Also, by increasing cement content, T50 is increased; so that, depending on fiber content, T50 corresponding to C45 is 8-29 percent higher than T50 corresponding to C25 (Figure 9).

As mentioned above, the V-funnel time for all specimens is in the range of 6 to 12 seconds (Table 4). As shown in Figure 10, the V-funnel flow time increased by increasing glass fiber content compared to control specimens which have no fibers. This increase in specimens containing 1% glass fiber (C45F1) is higher than other specimens. Therefore, it can be stated that the use of glass fibers increases the time of V-funnel significantly. The reason for this is that the specific surface area and density of concrete containing glass fiber has increased. The values obtained from L-box are in the range of 0.80 to 0.99 (Table 4). Also, according to Figure 11, by increasing the glass fiber content, blocking ratio is increased.

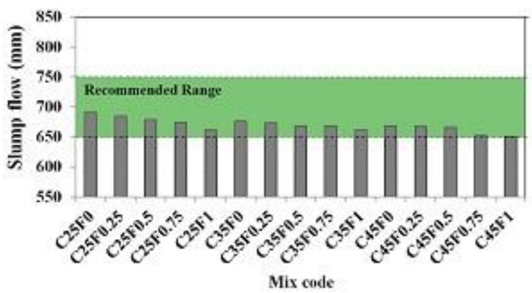


Figure 8. Slump flow results

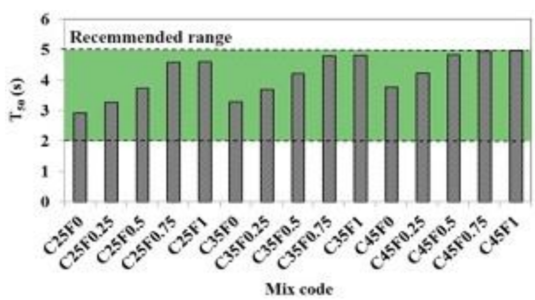


Figure 9. T50 results

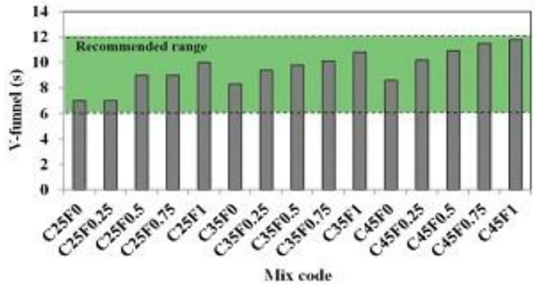


Figure 10. V-funnel values for different mixes

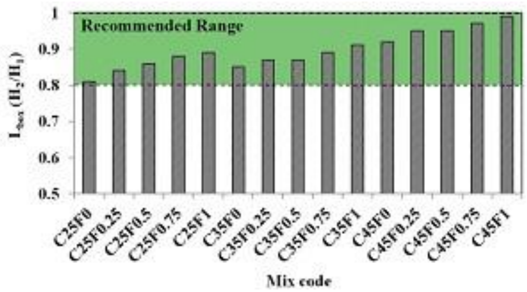


Figure 11. L-box blocking ratio for different mixes

3. 2. Hardened Concrete Properties

3. 2. 1. Compressive Strength

The effect of glass fiber on 28-days compressive strength of all concrete specimens is shown in Figure 12. Addition of glass fiber to concrete in some cases leads to an increase and in some cases leads to a decrease in compressive strength. For each of three intended compressive strengths, the most negative effect of glass fiber was found in specimens, which used 0.25% glass fiber. Also, the use of glass fiber at the dosages of 0.75% by volume of concrete led to 6.3% and 1.6% increase in compressive strength of C35 and C45 specimen, respectively. The use of glass fiber at the dosages of 0.50% by volume of concrete led to 8.8% increase in compressive strength of C35. The changes of compressive strength in glass fiber reinforced concrete specimens of the present research and lack of a specific process were observed by Choi et al. [12].

Stress-strain curves obtained from compressive strength test are presented in Figures 13 to 15. As it is seen, the use of glass fiber has led to increase in ultimate strain of concrete (or strain corresponding to compressive strength) in compare to control specimen for all three strengths. In the other words, general behavior of stress-strain curve of glass fiber reinforced concrete is different from conventional concrete curve due to significant behavior after yielding. It should be noted that by increasing cement content, the effect of glass fiber on ultimate compressive strain in concrete has decreased; So that in C25 grade concrete specimens, the ultimate strain corresponding to the use of 0.75% glass fiber is increased by 11% compared to control specimen; However, in C45 concrete specimens, the ultimate strain corresponding to the use of 0.75% glass fibers increased by 4%.

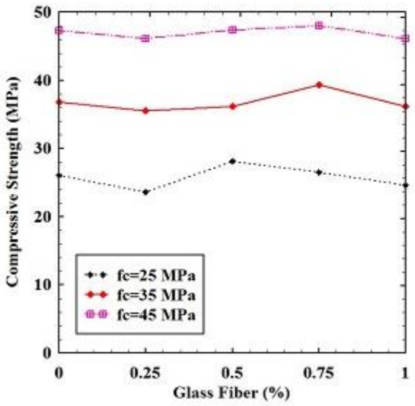


Figure 12. Compressive strength test results

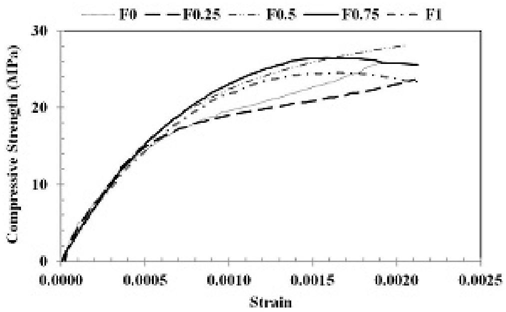


Figure 13. Compressive stress-strain curves (fc=25 MPa)

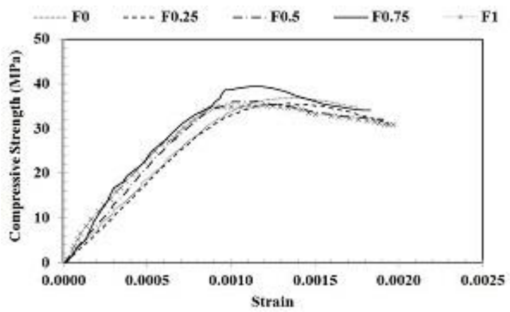


Figure 14. Compressive stress-strain curves (fc=25 MPa)

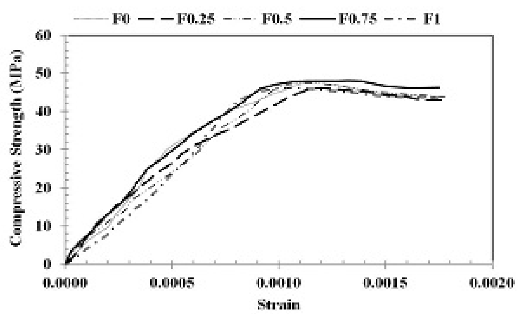


Figure 15. Compressive stress-strain curves (fc=25 MPa)

An electronic microscopic photograph of one of the specimen is shown in Figure 16 to verify the surface of the concrete specimen. The concrete mixture containing glass fiber is well-connected and coherent.

3. 2. 2. Flexural Strength The effect of glass fiber on 28-day flexural strength of concrete specimens with C25, C35 and C45 strength grades is shown in Figure 17. As can be seen in C35 and C45 concrete specimens, the highest flexural strength was obtained for dosages of 0.75% glass fiber by volume of concrete. Also, in C25 concrete specimens, the highest flexural strength was obtained for using 0.50% glass fiber by volume of concrete. In general, the use of glass fibers has increased the flexural strength of SCC specimens by 2 to 11 percent. The important thing about this is that the glass fibers have better effect on flexural strength in lower volumes.

One of the main purposes of the addition fiber is improving the energy absorption capacity of concrete (the area under the load-deflection curve), which has been studied in this study. For this purpose, the load-deflection curves of concrete beams examined in 15 different modes are shown in Figure 18. As it is seen, the

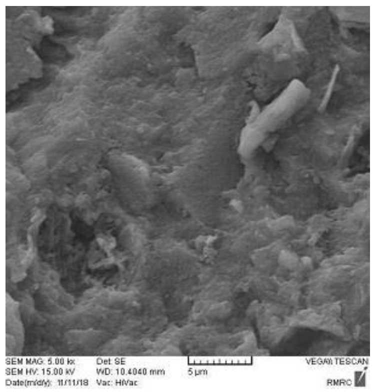


Figure 16. Electronic microscopic photograph of one of the specimen (C25F0.50)

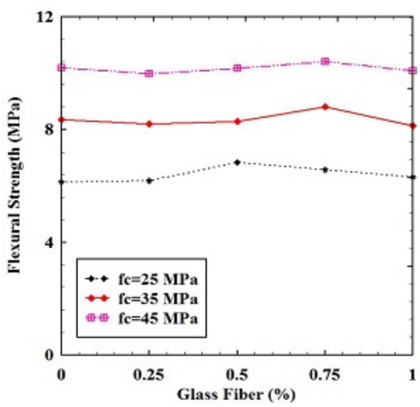


Figure 17. Flexural strength of all mixes

use of glass fibers has led to improve the energy absorption capacity of the beams in all cases compared to the plain beam; So that the maximum increase in the energy absorption capacity of beams compared to the plain concrete for 25, 35 and 45 concrete grade was 29, 33.2 and 53.75%, respectively. Also, the use of 0.5% glass fiber in beams with 25 and 35 strength grades has led to longest increasing. Whereas the use of 0.75% glass fiber in beams with 45 strength grade has led to longest increasing (Figure 19).

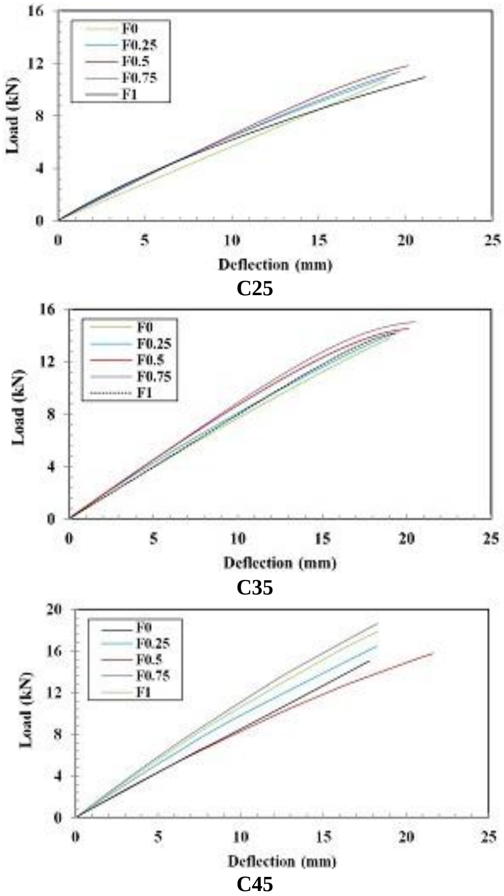


Figure 18. Load-Deflection curves from flexural test for all specimens

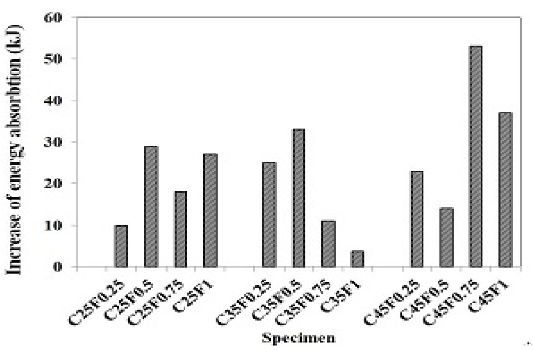


Figure 19. Increase of energy absorption

3. 2. 3. Tensile Strength

The effect of glass fiber on 28-day splitting tensile strength of SCC specimens with three different strength grades (C25, C35 and C45) is shown in Figure 20. Also, the percentage increase in tensile strength with respect to control specimens is shown in Figure 21. As it is seen, the use of glass fiber in C25 strength grade concrete specimens is more effective than C35 and C45 grades; So that the use of 0.5% glass fiber increased the tensile strength of concrete specimens by 37%. Also, compared to control specimen, the tensile strength of glass fiber reinforced concrete with C35 and C45 strength grades in most cases increased by 11 and 15%, respectively.

Another result, which can be mentioned in Figure 21, is that in glass fiber reinforced concrete with lower cement content, the tensile strength decreased with increasing glass fiber. The concrete specimens with more cement content, the tensile strength increased with increasing glass fiber. This model is based on damaged assumptions and is designed for situations in which concrete is loaded under arbitrary conditions.

4. NUMERICAL SIMULATIONS

After presentation of laboratory test results, this section presents a finite element method with the aim of

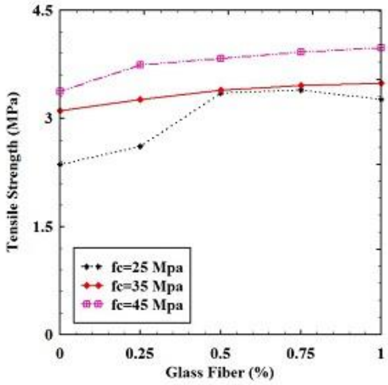


Figure 20. Tensile strength of all mixes

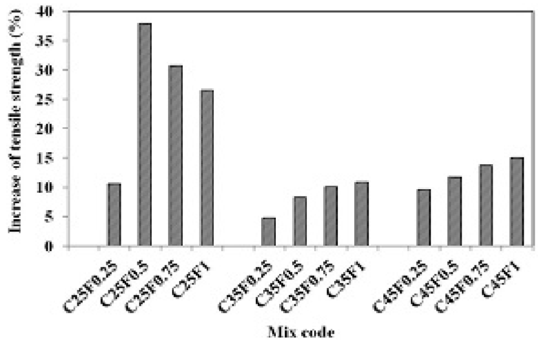


Figure 21. The percentage increase in tensile strength compared to control specimen

predicting the flexural behavior of concrete beams reinforced with glass fiber. For this purpose, the concrete beams which manufactured in flexural test were simulated in 15 different modes using ABAQUS software [32]. The load-displacement curves of experimental and numerical investigation were compared with each other. For this purpose, in part module 3D space, deformation behavior and continuum (solid) element was used to simulate concrete beam (Figure 22).

One of the important parts in ABAQUS software modeling is definition of the behavioral model for the correct estimation of the materials. In this section, to define the properties of concrete containing glass fiber, the behavioral model of concrete damage plasticity was used in ABAQUS [32]. For this purpose, defining the characteristics of the damage index in compression (d_c) and (d_t) tension, the effect of concrete behavior under damage due to crushing in the pressure and cracking in the tension is considered. Theses parameters are shown in Figure 23.

Three-point loading was applied at the center of the beam span. The load was gradually applied to the center of beam with 0.2 second time increment. The model available has been used to simulated concrete material by using C3D8 element (Cube Three Dimensional eight-node reduced integration with 3 degrees of freedom). This model takes into account the effect of reducing the elastic hardness as a result of plastic strain, both in tension and compression. Analytical evaluation of the beams conducted using non-linear static analysis. All the experimental material data of GFRC reported earlier were used for simulating the beams. Simply support was considered for the two ends of the beam. The boundary condition in support was applied at a distance of 5 cm from two ends of the beam. In order to obtain the optimum number of meshes, a mesh sensitivity analysis was performed to evaluate the effect of smaller elements on the load-displacement curve of the middle point of the beam. Meshing dimension selected is sufficiently good enough to ensure that the forces applied are calculated accurately. The mesh model and stress distribution of one of the beams are presented in Figure 24. Also load-displacement curves of the finite element models are presented in Figure 25.

The Comparison between the numerical and experimental ultimate loads is presented in Table 5. It can be seen that the difference between the values of the loads corresponding to the FEM and experimental is between 0.62 and 13.8 percent.

On the other hand, according to Table 6, the difference between the energy absorption capacity of the finite element models and the experimental specimen is between 0.18 and 16.84%. So, with respect to the mentioned values, it can be concluded that the simulation method used in this study has a good fairly agreement with the experimental results and can predict the maximum loads and energy absorption capacity of the beams reinforced with glass fibers.

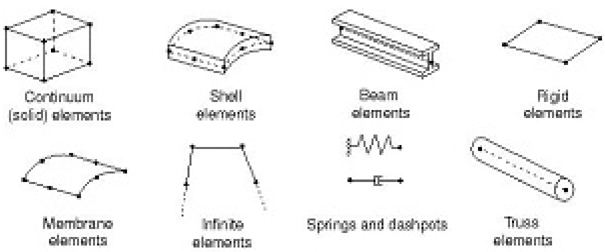


Figure 22. ABAQUS element laboratory [32]

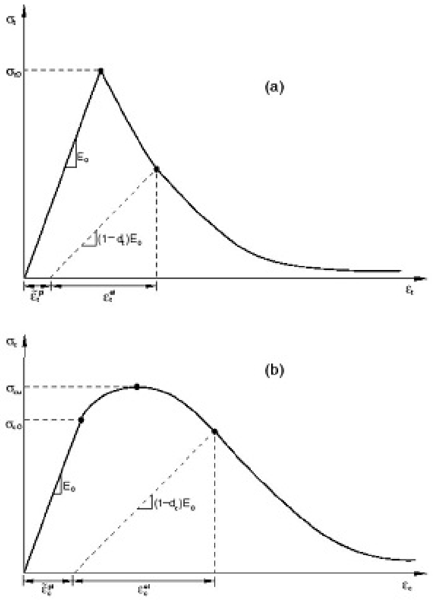
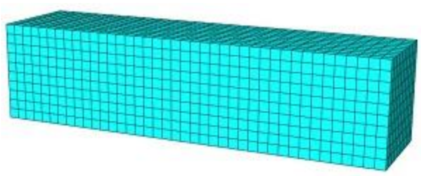
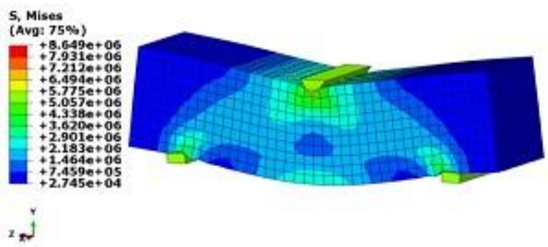


Figure 23. Concrete damage plasticity parameter a: damage compression, b: tension compression [32]



a



b

Figure 24. a: Mesh model b: The stress distribution

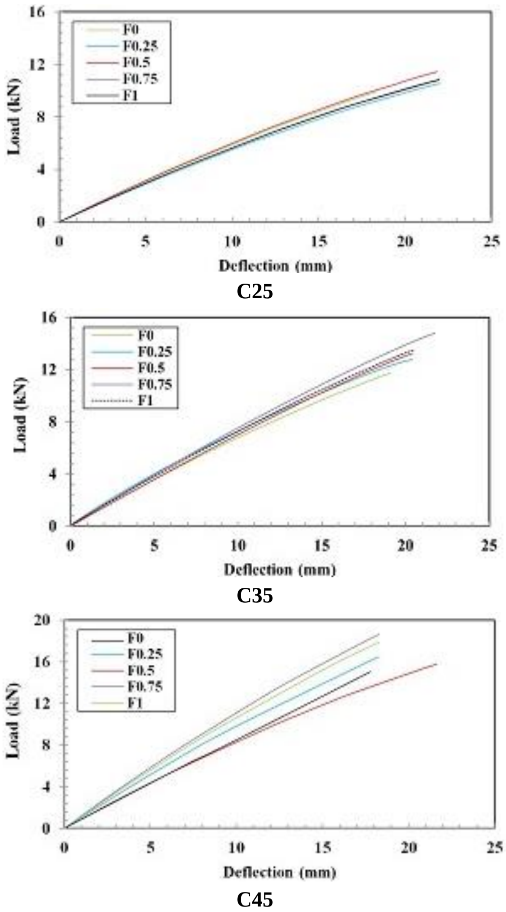


Figure 25. Load-displacement curves

TABLE 5. Comparison between the numerical and experimental ultimate loads

Beam	Ultimate load (kN)		% Difference with respect to experimental
	Experimental	FEM	
C25G0	10.25	9.91	3.32
C25G0.25	10.3	10.56	2.52
C25G0.5	11.38	11.45	0.62
C25G0.75	10.98	10.87	1
C25G1	10.52	10.8	2.66
C35G0	13.55	11.68	13.8
C35G0.25	13.68	12.7	7.16
C35G0.5	13.82	12.9	6.66
C35G0.75	14.68	14.56	0.82
C350G1	13.93	12.93	7.18
C45G0	16.65	15.06	9.55
C45G0.25	16.98	16.47	3
C45G0.5	16.95	15.77	6.96
C45G0.75	17.35	18.63	7.38
C45G1	16.82	17.9	6.42

TABLE 6. Comparison between the numerical and experimental energy capacity absorption

Beam	Energy capacity absorption(kJ)		% Difference with respect to experimental
	Experimental	FEM	
C25G0	100.25	97.4	2.84
C25G0.25	111	126.8	14.23
C25G0.5	129.33	136.3	5.39
C25G0.75	118.34	130.4	10.19
C25G1	128.14	129.7	1.22
C35G0	133.04	119.75	9.99
C35G0.25	146.66	142.34	2.95
C35G0.5	167.18	141.54	15.34
C35G0.75	177.2	170.78	3.62
C350G1	148	147.73	0.18
C45G0	138	134.96	2.20
C45G0.25	170	158.41	6.82
C45G0.5	158.3	184.95	16.84
C45G0.75	212.18	179.36	15.47
C45G1	190.05	171.58	9.72

5. CONCLUSIONS

In this study an analysis model is presented for predicting energy absorption capacity of glass fiber reinforced self-compacting concrete (GFRCSCC) beams and the results were compared with experimental study. For this purpose, the investigations are conducted in two experimental and numerical sections. Slump flow, V-funnel and L-box tests are performed to investigate the properties of fresh concrete. Also hardened concrete properties are investigated using compressive strength test, tensile strength test and flexural strength test. The fiber contents considered in this investigation were 0, 0.25, 0.75 and 1% of the mixed concrete by volume. The compressive stress-strain curves of specimens were determined. Finally, a finite element model with the purpose of predicting the energy absorption capacity of concretes containing glass fiber was developed and the results were compared with experimental study. The most conclusions derived from present study can be summarized as follow:

1. The results of fresh concrete tests show that all specimens have self-compacting conditions in accordance with EFNARC considerations.
2. By increasing the glass fiber volume content, the slump flow decreases. The lowest slump has been created in C45F1 mixture design; so that in this specimen the slump has decreased by 40% compared to control specimen.

3. The results of T50 test showed that T50 is increased by increasing glass fiber volume content. Also, by increasing cement content, T50 is increased; so that, depending on fiber content, T50 corresponding to C45 is 8-29 percent higher than T50 corresponding to C25.
4. The V-funnel flow time increased by increasing glass fiber content compared to control specimens which have no fibers. This increase in specimens containing 1% glass fiber (C45F1) is higher than other specimens. Therefore, it can be stated that the use of glass fibers increases the time of V-funnel significantly. The reason for this is that the specific surface area and density of concrete containing glass fiber has increased.
5. Addition of glass fiber to concrete in some modes leads to an increase and in some modes leads to a decrease in compressive strength. For each of three intended compressive strengths, the most negative effect of glass fiber was found in specimens, which used 0.25% glass fiber. Also, the use of glass fiber at the dosages of 0.75% by volume of concrete cause to 6.3% and 1.6% increase in compressive strength of C35 and C45 specimen, respectively. The use of glass fiber at the dosages of 0.50% by volume of concrete led to 8.8% increase in compressive strength of C35. The changes of compressive strength in glass fiber reinforced concrete specimens of the present study and lack of a specific process were observed.
6. The use of glass fiber has led to increase in ultimate strain of concrete (or strain corresponding to compressive strength) in compare to control specimen for all three strengths. In other words, general behavior of stress-strain curve of glass fiber reinforced concrete is different from conventional concrete curve due to significant behavior after yielding.
7. By increasing cement content, the effect of glass fiber on ultimate compressive strain in concrete has decreased; So that in C25 grade concrete specimens, the ultimate strain corresponding to the use of 0.75% glass fiber is increased by 11% compared to control specimen; However, in C45 concrete specimens, the ultimate strain corresponding to the use of 0.75% glass fibers increased by 4%.
8. In C35 and C45 concrete specimens, the highest flexural strength was obtained for dosages of 0.75% glass fiber by volume of concrete. Also, in C25 concrete specimens, the highest flexural strength was obtained for using 0.50% glass fiber by volume of concrete. In general, the use of glass fibers has increased the flexural strength of SCC specimens by 2 to 11 percent.
9. The use of glass fibers has led to increase the energy absorption capacity of beams in all cases compared to the plain beam; So that the maximum increase in the energy absorption capacity of the beams compared to the plain concrete for 25, 35 and 45 concrete grade was 29, 33.2 and 53.75%, respectively.
10. The use of 0.5% glass fiber in beams with 25 and 35 strength grades has led to longest increasing. Whereas the use of 0.75% glass fiber in beams with 45 strength grade has led to longest increasing.
11. The use of glass fiber in C25 strength grade concrete specimen is more effective than C35 and C45 grades; So that the use of 0.5% glass fiber increased the tensile strength of concrete specimens by 37%. Also, compared to control specimen, the tensile strength of glass fiber reinforced concrete with C35 and C45 strength grades in most cases increased by 11 and 15%, respectively.
12. In glass fiber reinforced concrete with lower cement content, the tensile strength decreased with increasing glass fiber; this is while in concrete specimens with more cement content, the tensile strength increased with increasing glass fiber.
13. The difference between the values of the ultimate loads corresponding to the FEM and experimental is between 0.62 and 13.8 percent.
14. The difference between the energy absorption capacity of the finite element models and the experimental specimen is between 0.18 and 16.84%. So, and with respect to the mentioned values, it can be concluded that the simulation method used in this study has a good fairly agreement with the experimental results and can predict the maximum loads and energy absorption capacity of the beams reinforced with glass fibers.

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Experimental and Numerical Study of Energy Absorption Capacity of Glass Reinforced Self-compacting Concrete Beams

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چکیده

مطالعات آزمایشگاهی مختلفی در زمینه بتن‌های مسلح به الیاف شیشه انجام شده است، اما در مطالعات محدودی رفتار این نوع از بتن با استفاده از روش اجزاء محدود مورد بررسی قرار گرفته است. در این مطالعه، یک مدل تحلیلی به منظور پیش‌بینی ظرفیت جذب انرژی تیرهای بتنی خودتراکم حاوی الیاف شیشه معرفی شد و نتایج حاصل با نتایج آزمایشگاهی مورد مقایسه قرار گرفت. برای رسیدن به این هدف، بررسی‌ها در دو بخش آزمایشگاهی و عددی انجام شد. در بخش آزمایشگاهی خواص بتن تازه و سخت شده با بررسی آزمایش‌هایی نظیر قیف V، جعبه L، T50، مقاومت فشاری، مقاومت کششی و مقاومت خمشی انجام شد. در بخش عددی از نرم افزار ABAQUS به منظور شبیه‌سازی تیرهای بتنی خود تراکم حاوی الیاف شیشه استفاده شد. از مدل پلاستیسیته خرابی بتن به منظور شبیه‌سازی بتن استفاده شد. از الیاف شیشه به مقدار ۰، ۰/۲۵، ۰/۷۵ و ۱ درصد حجمی بتن استفاده شد. نتایج حاصل نشان داد که بیشترین افزایش ظرفیت جذب انرژی در تیرهای بتنی حاوی الیاف شیشه با رده C25، C35 و C45 نسبت به نمونه شاهد به ترتیب برابر ۲۹، ۳۳/۲ و ۵۳/۷۵ درصد شده است. در انتها بارهای نهایی بدست آمده از نتایج آزمایشگاهی و مدل اجزاء محدود با یکدیگر مقایسه شد و تطابق مناسبی بین نتایج حاصل مشاهده گردید.

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