Civil Engineering Infrastructures Journal, 49(2): 197 – 213, December 2016
Print ISSN: 2322-2093; Online ISSN: 2423-6691
DOI: 10.7508/ceij.2016.02.002

Mechanical Behavior of Self-Compacting Reinforced Concrete Including Synthetics and Steel Fibers

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Received: 21 Sep. 2015; Revised: 26 Sep. 2016; Accepted: 04 Oct. 2016

ABSTRACT: This paper investigated the effects of combining fibers with self-consolidating concrete (SCC). 12 series of test specimens were prepared using three kinds of fibers including steel, polyphenylene sulfide (PPS) and glass fibers with four different volumes fractions and one specimen without fibers as a reference sample. All plans were subjected to fresh concrete tests. For mechanical behavior of concrete, compressive, tensile and flexural strength, toughness, fracture energy and force-displacement curves has been studied. Fresh (rheological) properties were assessed using L-Box, Slump flow and T-50 tests. results show that concrete workability is reduced by increasing fiber volume fraction; among different fibers the PPS fibers have less negative effects on rheology. On the contrary, these fibers can improve the splitting tensile, flexural strength, toughness and fracture energy of SCC significantly; however strength of compressive is decreased by increasing the amount of fibers. Adding steel fibers to SCC increases energy absorption eminently.

Keywords: Glass Fibers, Mechanical Behavior, PPS Fibers, Rheological Characteristics, SCC, Steel Fibers.

INTRODUCTION

In order to improve stability and durability of concrete construction in Japan in 1998, Self Compacting Concrete (SCC) was first constructed (Ozawa and Okamura, 1996b). The preliminary researches about the workability of Self Compacting Concrete were done by Okamura (1993) and Ozawa (1989) in University of Tokyo (Okamura and Ouchi, 1998; Okamura and Ozawa, 1996a). Under its own weight, SCC needs little vibration or no vibration in order to be placed and, also, there will not be any segregation.

SCC is commonly used to ensure suitable filling and well performance in limited areas and extremely reinforced structural members. These advantages made SCC to play the role of an important building material. In recent years SCC has obtain wider use in lots of industrialized countries

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for various applications and constructional configurations.

Another remarkable advantage of SCC is providing a transcendent working environment by reducing vibration noise. These concretes need a high slump that super plasticizers plus a good concrete mix can easily provide that. In order to reduce bleeding, Segregation and settlement SCC often contains a large amount of powdered materials that help concrete to hold sufficient yield value also viscosity of fresh mix. By increasing cement quantity the costs and temperatures increases, thus the use of additions like fly ash, blast furnace slag and limestone filler good improve the properties of concrete mix sans increasing its cost (Aslani and Nejadi, 2012a,b,c,d, 2013).

Concrete has some disadvantages, including: low tensile strength, weak ductility and high brittleness, these properties make concrete not suitable for structures like bridges, dams and airports. Steel bars are usually used to overcome these barriers of concrete.

Reinforcing concrete with steel bars removes above problems, but they are prohibitive and cannot be practical in some areas like surface of the canals or airports overlays (Beigi et al., 2013). During the last decades using string fibers in concrete has helped to solve the problem.

Fibers improve engineering performance of structural and non-structural concrete. The workability of Fiber reinforced concrete is dependent to length, content, aspect ratio and shape of the fibers. Using Fibers improves strength and resistance to impact, resistance against strikes and growth, and increases ductility, fracture energy absorption and ductility of concrete. By all advantages Fiber Reinforced Concrete (named above, FRC) plays excellent role in technology of concrete, and makes it a affordable material in engineering (Bencardino et al., 2010; Kang et al., 2010; Meddah and Bencheikh, 2009; Zuccarello and Olivito, 2010; Shah and Ouyang, 1995).

FRC usually needs to be fluid enough to improve fiber dispersion, provide sufficient compaction and reduce entrapping voids, high workability also reduces the need for vibration and further facilitate placement. The most important properties of Fiber Reinforced Self Consolidating Concrete (FRSCC) are spreading into place under its own weight, providing consolidation with no internal or external vibration, undergoing minimum entrapment of air voids and loss of homogeneity, and ensuring appropriate dispersion of fibers.

Any failure in self-compaction may end up in structural defects (micro or macro defects) that can affect performance and durability of the structure. FRSCC is a partly new composite material that has the benefits of both SCC technology and fiber addition to a brittle made of cement matrix (Khayat and Roussel, 2000).

Over the last few years, many studies have been conducted to obtain concrete properties (Arefi et al., 2016; Salehjalali and Shadafza, 2016; Dadash and Ramezanianpour, 2014). Here are some examples of studies done on SCC (Tavakoli et al., 2015; Tavakkoli et al., 2014). El-Dieb (El-Dieb and Taha, 2012; El-Dieb, 2009) has studied mechanical and durability properties of FRC with ultra-high strength and self-compacting characteristics (UHS-FRC), he also studied the effect of fibers on rheological characteristics. Siddique (Siddique, 2011) evaluated attributes of SCC by changing the amount of fly ash. The results of studies of Fava et al (Fava et al., 2012) ground-granulated blast furnace slag (GGBFS) can increase the strength of SCC.

Cattaneo et al. (2012) studied the flexural performance of beams made by reinforced pre-stressed and composite self-compacting concrete. Soutsos and Lampropoulos (2012) investigated flexural performance of two kinds of fiber reinforced concrete (steel fiber, synthetic fiber). Khaloo et al. (2014) studied the mechanical performance of SCC reinforced with steel fibers. Najim and Hall had done some researches about dynamic and mechanical properties of self-compacting crumb rubber modified concrete (Najim and Hall, 2012).

Most of the researches have been done on steel fiber reinforced concrete, but these kinds of fibers cause a sharp drop in fresh properties of concrete and reduce its performance. The present research is done to investigate the influence of PPS, Glass and steel fibers on mechanical and rheological properties of SCC.

A comprehensive experimental program is performed to evaluation the rheological and mechanical properties of 13 mixes of SCC. The rheological properties of fresh concrete include Slump flow time and diameter and L-Box tests. The mechanical Characteristics of hardened FRSCC include compressive, splitting tensile and flexural strength, flexural toughness, and fracture energy of SCC beams. Also the developments of mechanical properties with Increase the amount of fiber are investigated.

EXPERIMENTAL PLAN

Material

Materials used in the provided study: super plasticizer (SP) based on carboxylic ether (P10-3R) with 1.1 gr/cm^3 specific gravity (at 20 °C), and three kinds of fibers including: steel, PPS and glass fibers. See Table 1.

The gravel that was used in the mix design was crushed gravel, the aggregate size was smaller than 12.5 mm and the grade was in match with ASTM standard of grading curve. The sand that was used was river-type and selected from sieve #4 (4.75 mm) sand equivalent value was 80 % and the gradation curve was adapted to ASTM C33 standard, limits are shown in Figure 1.

The cement used, was Portland type II produced by the Mazandaran Cement Co. with properties presented in Tables 2 and 3. We used Limestone powder with the specific gravity of 2.6 g/cm^3 to make the concrete for which the chemical properties are presented in Table 2.

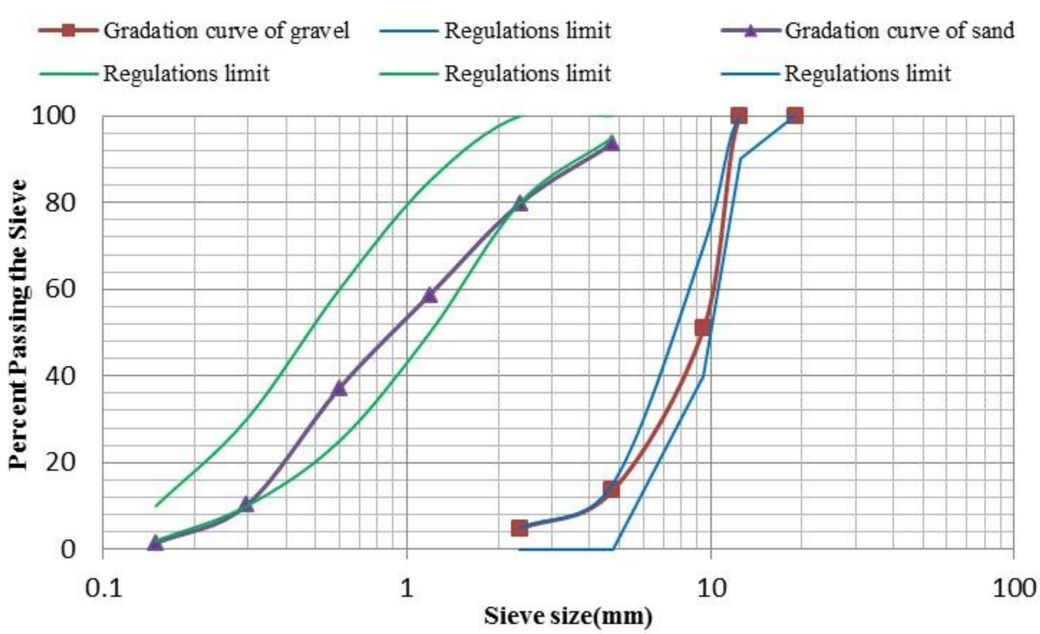

Fig. 1. Gradation curve of fine and coarse aggregates

Table 1. Characteristics of fibers investigated in this study

Fiber Type	Fiber Name	Density (Kg/m^3)	Dimention (mm) *L*	*W*	*T*	*D*	Moudulus of Elasticity (GPa)	Tensile Strength (MPa)	Geometry	Cross Section
Steel	DUOLOC 36/0.8	7850	36	-	-	0.7	160	2100	Hooked end	Circular
Polyphenylene Sulfide	PPS fiber	910	50	2	1	-	3.5	275	Rough	Rectangular
Glass	Glass fiber	2500	12	-	-	0.02	72	1400	Smooth	Circular

Table 2. Chemical compositions of cement and limestone powder (wt. %)

Items	Sio2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$CaCO_3$	L.O.I
PC	21.90	4.86	3.30	63.33	1.15	2.10	-	2.40
LS	0.45	0.33	0.02	52.35	0.02	52.35	99.3	-

PC: Ordinary Portland cement.
LS: Limestone powder.

Mixing and Testing Procedures

To achieve the aims of the study, 13 mix designs were made and tested and the results were compared. The mix designs contained 3 types of fibers: steel, PPS and Glass with volume percent of 0.1, 0.2, 0.3, 0.4 and one mix design without fibers as reference concrete. In Table 4 you can see the concrete mix compositions for the samples. (V_f is the volume percentage of fiber in Table 4, i.e. fiber to ratio of concrete volume).

The same as the fiber free conventional concrete, we can make SCC with fibers by adding fibers during the mixing process. The SCC mixture was made in 3 steps. First, the aggregates and powder materials were mixed in dry form for one min. next half of the water including the whole super plasticizer was poured and mixed for three min. Following that, a 1 min dregs was allowed and finally the dregs of the water was added to the admixture and mixed for another 2 min.

To determine the rheological properties of the self-compacting concrete, fresh concrete tests were carry out just after the matters were mixed. The flow rate of SCC pertains on the viscosity of the concrete. The SCC must have 4 basic characteristics. First, it should be able to fill out the form with its weight. Furthermore, it should be of an acceptable level of resistance against segregation. Ability to go across through the spaces between bars is next important characteristic of SCC, and eventually, it needs to have a flat surface after placing. There are some tests in EFNARC and ACI 237R such as slump flow time and diameter, V-funnel flow time, visual stability index, J-ring, and L-box in order to reach these characteristics.

According to Nagataki and Fujiwara (1995), to characterize the flow characteristics of unobstructed concrete on a horizontal surface, slump flow time and diameter tests are two customary methods. In these tests, the fresh concrete is poured into a slump cone. When the cone is withdrawn upwards, the time it takes from the beginning of the upward movement when the concrete has flowed to a diameter of 500 mm is measured, called the T50 time. The greatest diameter of the flow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump-flow diameter.

Table 3. Analysis of physical properties of cement

Blaine (cm^2/g)	Expansion (autoclave) (%)	Compressive strength (kg/cm^2)		
		3 Days	7 Days	28 Days
3050	0.05	185	295	397

Table 4. The mix designs concrete samples used in this study

Concrete Mixture	Fiber V_F (%)		(Kg/m³) Gravel	Sand	Limestone Powder	Cement	Water	SP
Control	-		722	826	288.9	413.1	162	7
PPS10	PPS	0.1	722	826	288.9	413.1	162	7
PPS20	PPS	0.2	722	826	288.9	413.1	162	7
PPS30	PPS	0.3	722	826	288.9	413.1	162	7
PPS40	PPS	0.4	722	826	288.9	413.1	162	7
Glass10	Glass	0.1	722	826	288.9	413.1	162	7
Glass20	Glass	0.2	722	826	288.9	413.1	162	7
Glass30	Glass	0.3	722	826	288.9	413.1	162	7
Glass40	Glass	0.4	722	826	288.9	413.1	162	7
Steel10	Steel	0.1	722	826	288.9	413.1	162	7
Steel20	Steel	0.2	722	826	288.9	413.1	162	7
Steel30	Steel	0.3	722	826	288.9	413.1	162	7
Steel40	Steel	0.4	722	826	288.9	413.1	162	7

The test of L-box is used to determine the passing capability of SCC to flow through tight openings including spaces among reinforcing bars and other obstructions sans segregation or blocking. Accordingly, the concrete is decant from the container into the filling hopper of the L-box. Next the gate is lifted so that the concrete flows into the horizontal part of the box.

When the movement is ceased, the vertical distances are measured, at the end of the horizontal part of the L-box, sans the top layer of the concrete and the top of the horizontal section of the box, and at three positions equally spaced across the width of the box.

Differing from the height of the horizontal section of the box, these three measurements are used to calculate the mean depth of concrete as H2. The same procedure is followed to calculate the depth of concrete immediately behind the gate as H1. The value of H2/H1 as blocking ratio is then reported.

Once the mixing process was completed, after the completion of fresh concrete tests, the fresh concrete was poured into the oiled molds immediately. The samples were kept under laboratory condition for 24 hours.

The samples were de-molded after 24 hours and then cured in a water tank (at 20 ± 2 °C) for 28 days. Each mixing design included three 100×100×100 mm cubic molds for compressive strength testing, three 300×150mm cylindrical molds for splitting tensile strengths, three 500×100×100 mm prism beam for flexural strength and three 840×100×100 mm prism beam for toughness testing at 28 days.

According to standard B.S1881 Part116, compressive strength test was conducted. During these assessments, curing conditions and experimental and the sample production parameters was the same. The splitting tensile test, was in accordance with the ASTM C496 tests of splitting tensile strength of cylindrical concrete specimens, although ACI committee 544.2R hardly recommends the use of the test on FRC.

The running arose because the ratio of fiber length to the cylinder diameter took a low value of 0.3 in the work and because some investigators have shown that the ASTM C496 test is applicable to FRC specimens.

To determine the flexural properties, we use beams. According to the standard ASTM C1018-94b, Tests like Flexural strength (modulus of rupture), Flexural toughness (FT), Fracture energy (G_f), Three-point bending tests were performed on beams, using a hydraulic Universal Testing Machine (UTM) equipped with displacement speed Control mechanism (displacement rate of 0.5 mm/min). Flexural moment in the middle of the span was also obtained, and the flexural strength.

The maximum tensile stress in maximum bending load, was calculated according to ASTM C78. One of the characteristics of reinforced concrete with fibers is its high flexural toughness property. This property of concrete can decrease the risk of concrete elements failure, especially under dynamic load. Flexural toughness properties of fiber-reinforced concrete can be measured by a toughness test (ASTM, 1997).

In this research, in order to determine the flexural toughness notch beams with dimensions of 100×100×840 mm were used. Flexural toughness is the area under the load– deflection curve of concrete in flexure up until a deflection of 1/150 times the span, which corresponds to 5.33 mm for the used specimens (JSCE, 1984). The maximum loading capacity of the machine is 150 KN. In the center of each prismatic specimen, we cut a notch with 50 mm deep and 3 mm wide with a concrete saw.

EXPERIMENTAL RESULTS AND DISCUSSION

Result of Fresh Concrete Test

The mixes samples were designed such that the concrete possesses the FRC properties notwithstanding the presence of fiber. Based on the rate, which is at least 0.8, L-box and slump flow test was performed to evaluate the thermal conductivity, strength and deformation or flowing and blocking of the concrete can be estimated. The results of physical property assessments of the concrete are presented in Figures 2-4.

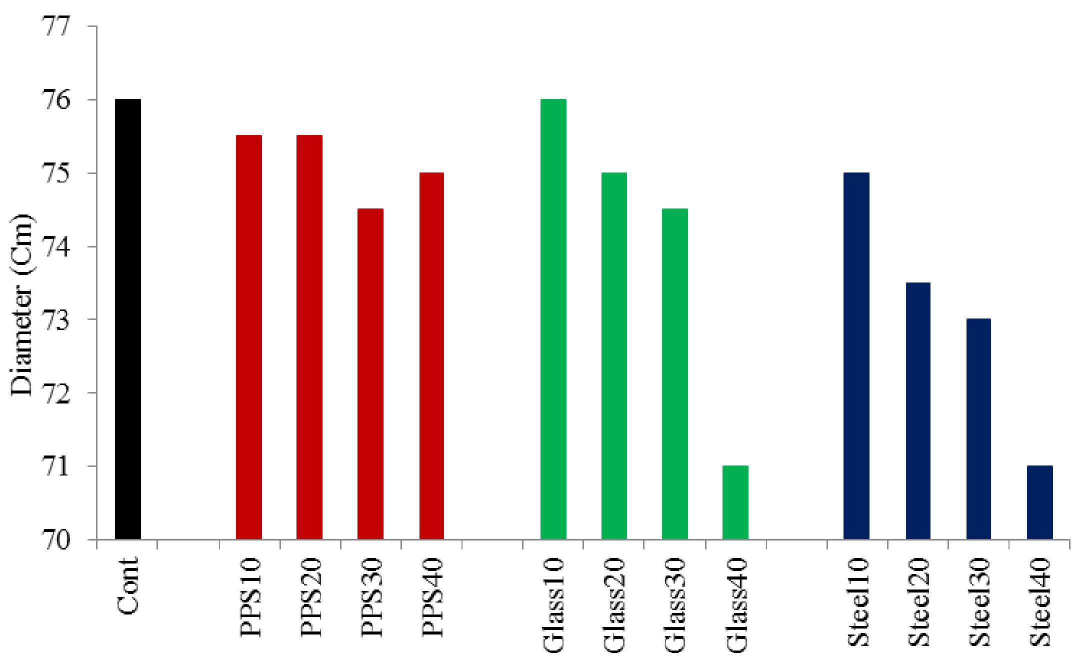

Fig. 2. Slump flow test

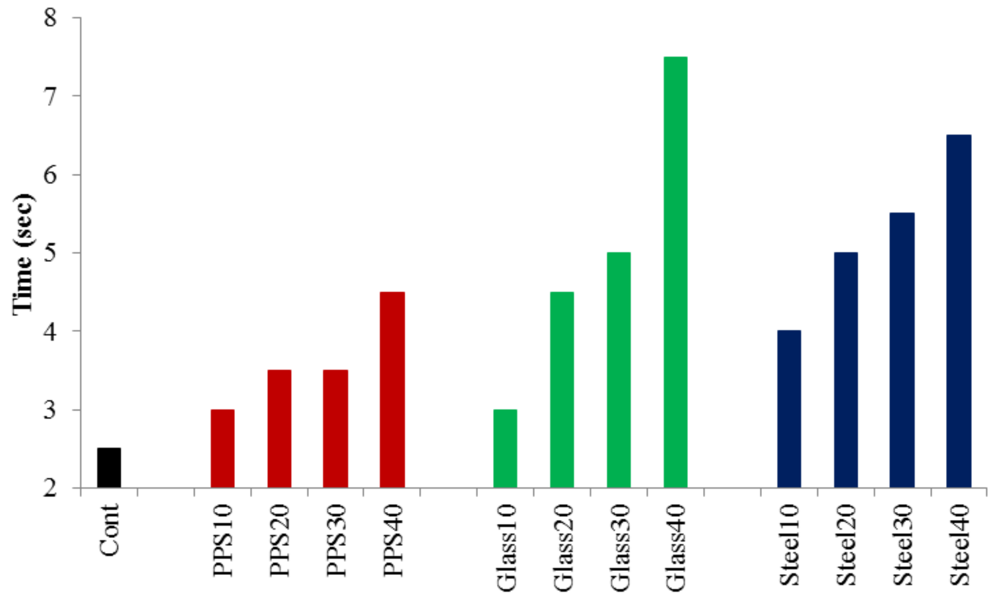

Fig. 3. Slump flow test (T50)

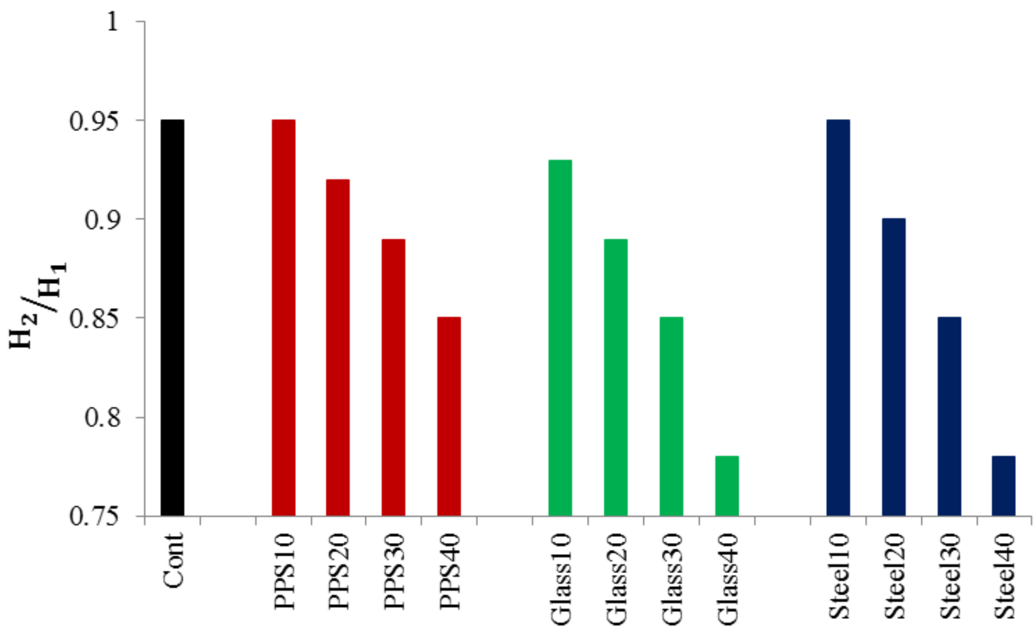

Fig. 4. L-Box test

The findings of the fresh concrete assessments show adverse effects of fibers on rheological properties of SCC. Fibers decrease the performance of SCC. As it can be seen from these Figures, the higher the percentage of fiber, the lower the performance of the concrete is resulted. The rate of this reduction in the higher values of fiber percentage was very high. But the reduction is acceptable based on the limitations of the regulations. Also negative effects on the rheology of samples with PPS fibers are less than two other fibers, so generally PPS fibers are the best choice when less reduction in workability is needed. Additionally, not in any of the sample, was detected any sign of aggregates–cement matrix separation.

Hardened Concrete Test

Compressive Strength

The results gained from the compressive strength test at 28 days, and with different fiber volume fractions is shown in Figure 5. It can be seen that compressive strength decreases with increasing the volume percentages of fibers. This reduction might be because of decreasing of the workability of the concrete.

Increasing fibers in mix design, decreases the workability of concrete which causes reduction in compaction levels of vibrated concrete (Mohammadi and Kaushik, 2008). This issue is highlighted in SCC mixtures when no vibration is applied for molding them and the compaction is only gained by their own weights. In this regard, according to a great reduction in compressive strength by using high steel fiber volume fractions, we should be careful about the application of these types of SCCs for heavily reinforced structural sections.

The average compressive strength of reference mix (Control) was equal to 70.2 MPa which for other mix designs (PPS40, Glass40 and Steel40) has reached to 67.5, 67.2 and 65.4 MPa, respectively.

As shown in Figure 5 percentage changes are compared to the reference design. As can be observed in this figure, the percentage reduction for mix designs (PPS10, PPS20, PPS30 and PPS40) has been equal to 1%, 1%, 3% and 4%, respectively; While the reduction for Steel10, Steel20, Steel30 and Steel40 has been 0%, 3%, 5% and 7%, respectively, in comparison to the plain concrete.

In examples containing glass fibers, we observed that by increasing fiber content the strength slightly increased and then resistance decreased. By addition of fiber volume fractions of 0.1% to 0.4% causes the compressive strength for 28-day specimens to be equal 70.3, 70.6, 69.4 and 67.2 MPa, respectively. The decrease in compressive strength for samples containing synthetic fibers is less than samples that contain steel fibers, and it may be because of that, samples containing synthetic fiber are more workable than plans that contain steel fibers. Also, fiber effects were not significant on compressive strength.

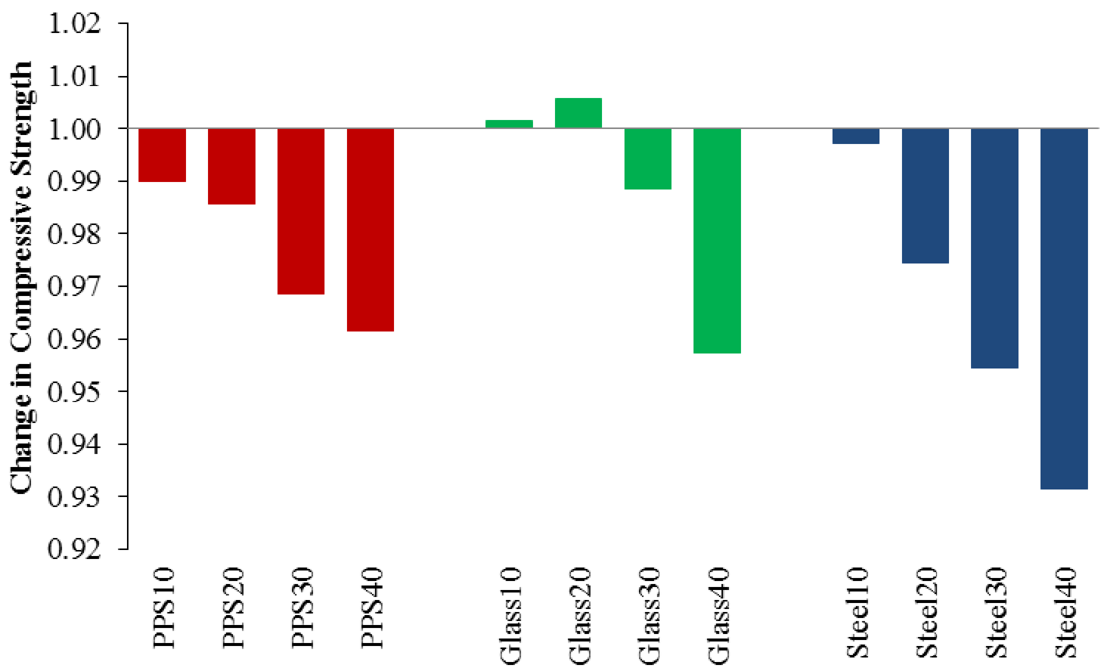

Fig. 5. Compressive strength of self-compacting concrete

Splitting Tensile Strength

Figure 6 shows the change of tensile strength behavior of concrete sample along changing contents of different fibers including PPS, Glass and steel fibers. As can be observed, splitting tensile strength increases by the using more fibers. Increasing fiber volume fractions causes more increase in splitting tensile strength.

The average Tensile strength for reference mix design was 4.2 MPa which for examples PPS40, Glass20 and Steel40 this value reached to 5, 5.58 and 5.13 MPa, respectively. In Figure 6 the percentage change in tensile strength compared with reference plan is shown by changes in fiber content. It can be seen in this figure, by increasing the fiber content, the average tensile strength of the samples containing PPS fiber, is increased by 2.7%, 7.5%, 14.5%, and 19.5% for mix designs (PPS10, PPS20, PPS30 and PPS40), respectively.

For specimens that contain glass fiber, as can be observed in Figure 6, the increase of fiber volume fractions 0.1% to 0.4% makes splitting tensile strength increase 29%, 33%, 13%, and 4%, respectively, in comparison to the plain specimen and, also average tensile strength for samples with Steel fiber (Steel10, Steel20, Steel30 and Steel40) has been equal to 16.5%, 19%, 21% and 22.5% respectively.

It can be concluded that in samples with the same amount of fibers at low volume fractions, samples that are reinforced with glass fibers show higher tensile strength while at high volume fraction samples containing steel fibers show higher tensile strength. By increasing ratio of all fibers in concrete, tensile strength goes up and this happens because of these reasons: the contact between mortar and fibers (area of fibers in contact with mortar) gets wider, the reinforcement effect of fibers gets stronger and fibers act like a bridge among micro-cracks and slow down the speed of their extension.

Load–Deflection Relationships

Different samples with different amounts and kinds of fibers have been tested, load-deflection curves for each sample were so close and for comparing different samples, representative curve was randomly chosen among available curves for each sample. Representative curves of force-deflection behavior of all the concrete mixtures are shown in Figure 7, where it can be observed that reinforced matrices show high strength and toughness in comparison to non-reinforced matrix.

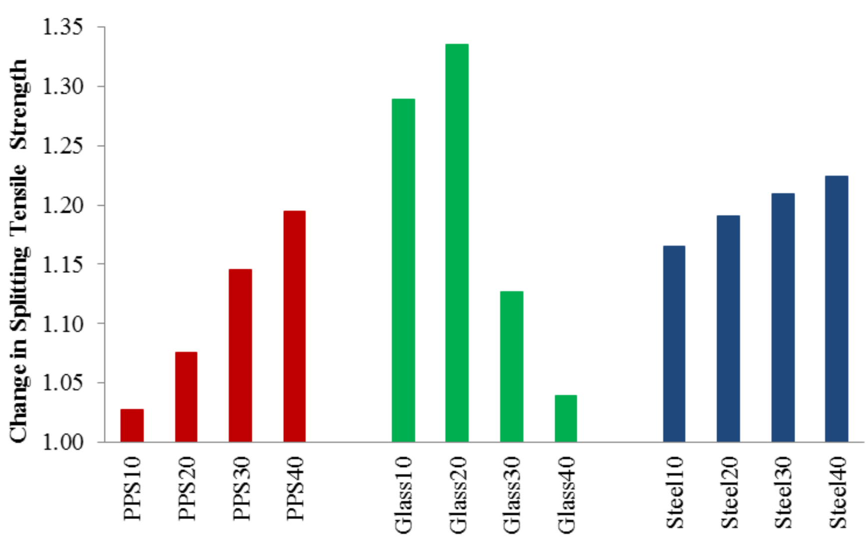

Fig. 6. Splitting tensile strength of self-compacting concrete

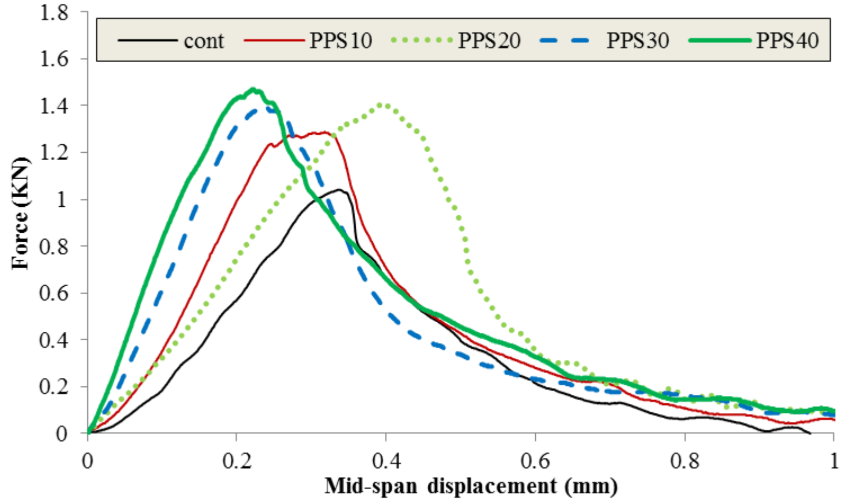

Fig. 7. a) Force–displacement curves for samples with different contents of PPS fibers

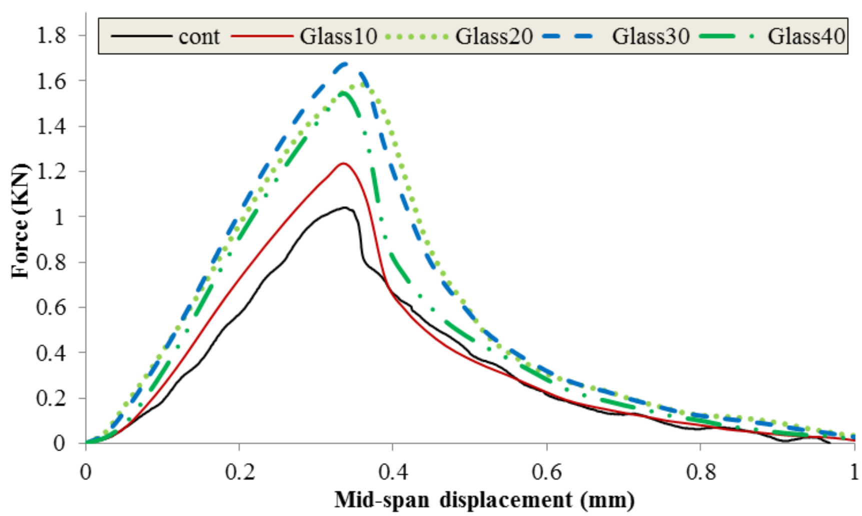

Fig. 7. b) Force–displacement curves for samples with different contents of glass fibers

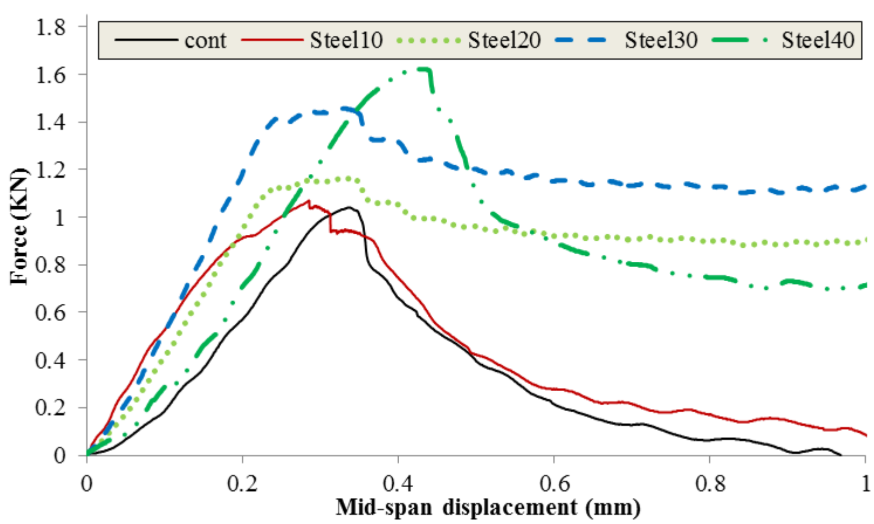

Fig. 7. c) Force–displacement curves for samples with different contents of steel fibers

As seen in the figures, with increasing fibers content, peak load has risen, and the softening branch (especially in beams containing steel fiber) is developed. This could be because of reinforcement properties and bridging fibers, and results in increasing the tensile strength and flexural strength.

It is important to mention here that each representative curve shown here is not an average of three samples. In fact, after plotting the curves of all samples of each mix design, a single representative curve was selected. However, the values of each flexural property (i.e. MOR and FT) given in the following sections are the average of all three samples of each composition.

For beams, the addition of fibers increases the maximum bending load. The addition of 0.1%, 0.2%, 0.3%, and 0.4% steel fiber volume fractions causes the maximum bending loads to increase by 3%, 12%, 40%, and 55%, respectively, in comparison to the plain SCC. For PPS fiber reinforced samples, the maximum bending loads of beam specimens containing 0.1 to 0.4% fiber volume fractions increase 23%, 35%, 34%, and 41%, respectively, in comparison with the plain beam specimen.

By Addition of 0.1%, 0.2%, 0.3%, and 0.4% glass fiber volume fractions causes the maximum bending loads to increase by 18%, 51%, 61%, and 48%, respectively, with respect to the plain SCC. The main reason for this increase is the performance of randomly distributed steel fibers which provide bridging forces across micro-cracks that prevents them from growing (Banthia et al.,1993; Rossi, 1994). As a result, by increasing the fiber volume fractions the maximum bending load of beam specimens increases.

Flexural Strength

The Flexural strength (modulus of rupture) of all samples was calculated from the maximum load attained in the test using elastic analysis. Average values for each mixture is shown in Figure 8. This figure indicates a direct relationship between the reinforcement fiber content (PPS, glass and steel fibers) and flexural strength. The Maximum increase in flexural strength equals 7.1 MPa and 7.8 MPa when there is an increase of 0.4% in PPS and Steel fibers, respectively and 8.03 MPa for 0.3% of glass fiber.

As can be seen in Figure 10, for samples contain Glass fiber, the addition of fiber volume fractions of 0.1% to 0.4% ends up to the flexural strength increase, by 19%, 52%, 61%, and 48%, respectively, with respect to the plain SCC specimen at 28 days.

Moreover, the addition of fiber volume fractions of 0.1% to 0.4% in PPS fiber reinforced specimens causes the flexural strengths increase 23%, 35%, 35%, and 41%, respectively, with respect to the plain specimen at the age of 28 days. Also, adding 0.1%, 0.2%, 0.3%, and 0.4% steel fiber volume fractions causes the maximum bending loads to increase by 5.2%, 12%, 40%, and 56%, respectively, with respect to the non-fiber reinforced SCC. This increase in flexural strength could be due to fine interlocking between fibers and concrete and increased bearing capacity of beams.

Toughness

The most important role of adding reinforcing fibers to concrete is making links between cracks produced by different causes. If the fibers in volume unit have proper density, enough strength and be well adhered to cement matrix, they can limit spread of cracks and increase the fiber-reinforced concrete against greater stresses after the appearance of cracks. This also improves the ductility of concrete after the appearance of cracks which is named toughness.

To mitigate the hazard for structures subjected to dynamic loads (such as seismic, impact and blast) high-energy absorbing materials are needed (Kim et al., 2008). Flexural toughness also exhibits the ductile behavior of the material. Flexural toughness presents the ability of concrete to absorb energy. Flexural toughness, in fact, refers to the area under the load-deflection curve. The amount of flexural toughness of a concrete beam is known as the absorbed energy of the concrete.

Figure 9 shows that increasing the percentage of fibers increases toughness. Flexural toughness for different fiber volume fractions of steel fiber (0.1% to 0.4%), was 1.58, 12.9, 16.3, and 12 times, respectively, higher than the plain beam specimen (Flexural toughness for SCC without fiber was 0.33 N.m). For beam samples with PPS fiber, flexural toughness for different fiber volume fractions from 0.1% to 0.4% was 1.37, 1.7, 1.82, and 1.96 times, respectively, more than the plain sample.

Also for beam specimens with glass fiber, flexural toughness for different fiber volume fractions from 0.1% to 0.4% was 1.13, 1.72, 1.75, and 1.41 times, respectively, more than the plain specimen.

Obviously metal fibers play more crucial role in increasing toughness. Pull-out strength between fibers and matrix is so much that delays pulling-out mechanism and causes absorbing more energy by the fiber reinforced concrete.

Fracture Energy

More reports from measurement of toughness are the indices without foundation energy dimension, particularly laboratory experiments of such indices with the introduction of a toughness index ACI (Committee 544, 1983) based on Henegar work was begun. Japan´s Concrete Institute JCI define toughness index for a beam with a standard size, area under curve (force-displacement) to range (L/150). Standards from Belgian (IBN, 1992), Germany (DBV, 1992), RILEM (RILEM, 1984) and Spain (AENOR, 1989) also suggest a same trend and test.

Energy absorption capacity, defined as the amount of absorbed energy in per basal area unit of sample in a certain deformation. In this present study, in order to determine the fracture energy through the force-displacement curve has been used HillerBorg working method accepted by RILEM (RILEM, 1988). Figure 10 shows the fracture energy of fiber-reinforced samples which are studied.

As can be observed in figure, with increasing percentage of fiber, fracture energy increased; while this increase for samples contain a different fiber volume fraction of steel fiber (0.1% to 0.4%) was 5.35, 26.6, 29.6 and 27.6 times, respectively, compared to the reference sample (Fracture energy for SCC without fiber was (143.1 j/m^2).

This increase is due to that, by increasing percentage fiber, the descending branch of the reference beam curve, found significantly strain softening; that this behavior in the beams containing steel fibers significantly amended as softer failure and created more area under the curve of force–displacement which mainly has been after the peak of the curve, so the energy absorption capability of reference concrete has shifted up.

For beam samples with PPS fiber, fracture energy for different fiber volume fractions from 0.1% to 0.4% was 1.3, 1.59, 1.61, and 1.65 times, respectively, more than the non-reinforced specimen. Also for beam specimens with Glass fiber, fracture energy for different fiber volume fractions from 0.1% to 0.4% was 1.1, 1.37, 1.39, and 1.23 times, respectively, more than the plain specimen.

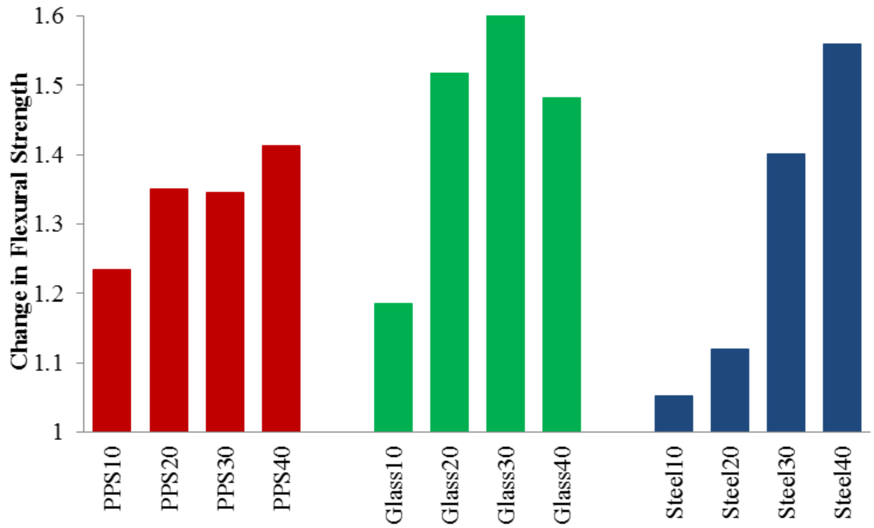

Fig. 8. Flexural strength of self-compacting concrete

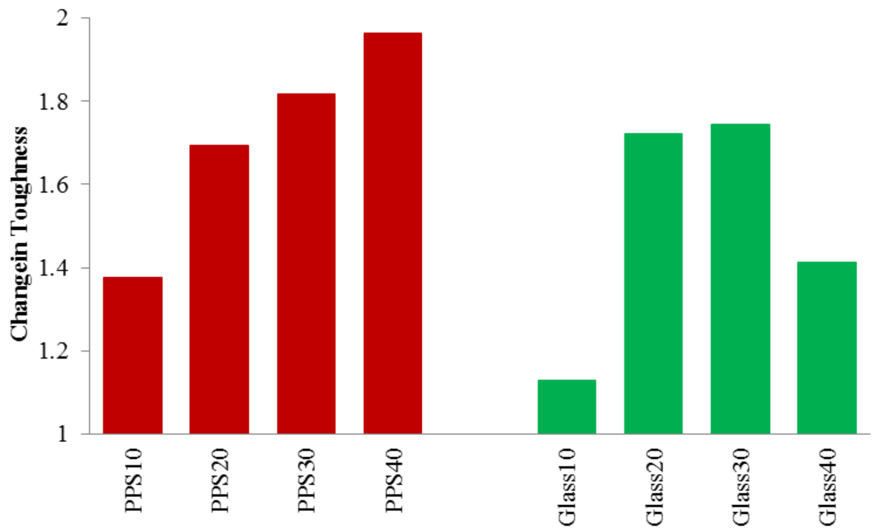

Fig. 9. a) Flexural toughness of SCC with PPS and glass fibers

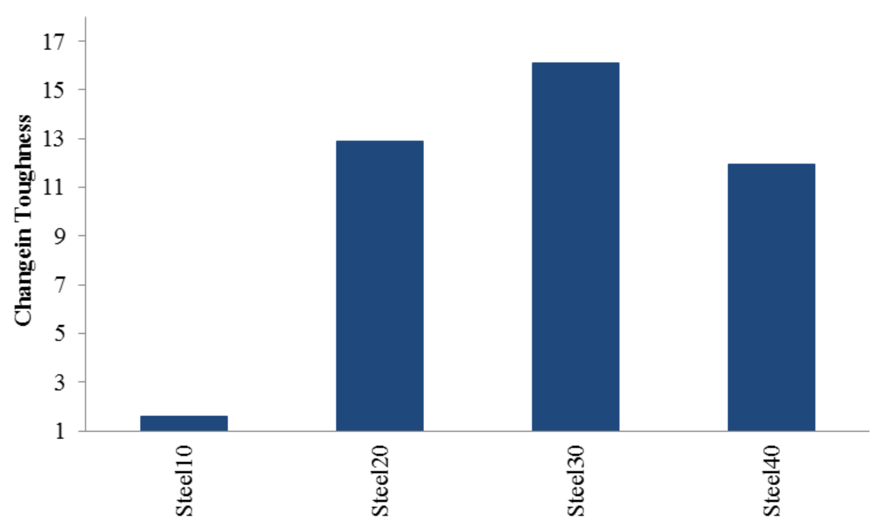

Fig. 9. b) Flexural toughness of SCC with steel fibers

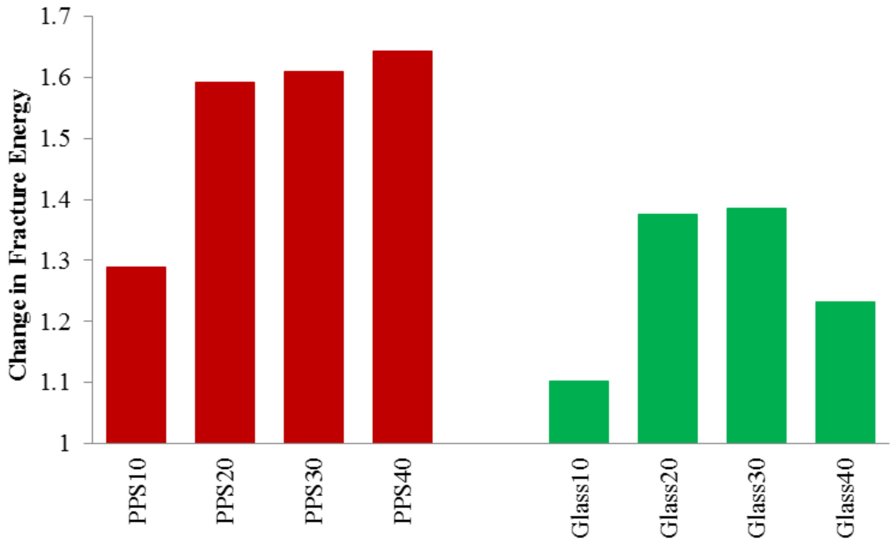

Fig. 10. a) Fracture energy of samples with PPS and glass fibers

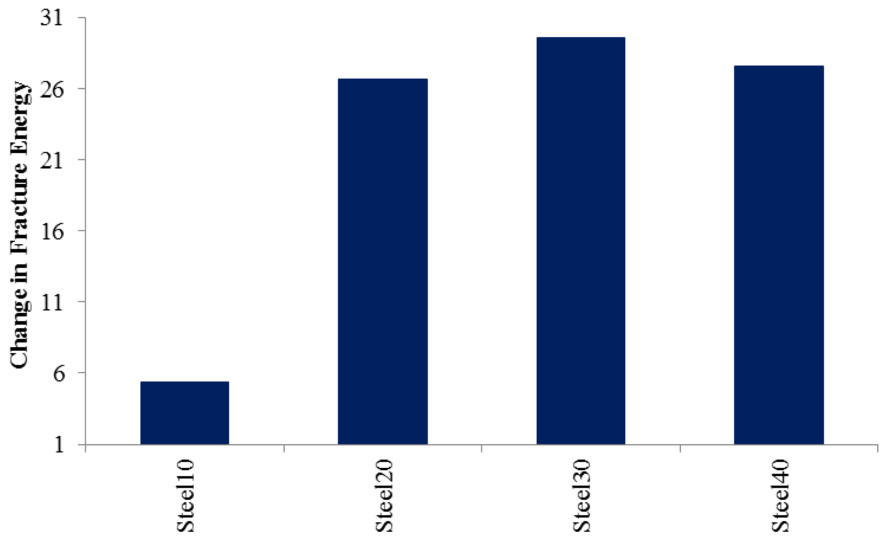

Fig. 10. b) Fracture energy of samples with steel fibers

CONCLUSIONS

This study, experimentally evaluated the effects of fibers on the rheological and mechanical properties (compressive strength, splitting tensile strength, flexural strength, flexural toughness and fracture energy) of self-compacting concrete reinforced with fibers. From this case, some conclusions can be summarized as below:

- Evaluating the results of SCC durability assessments, it has been concluded that using different types of reinforcing fibers, can adversely influence the rheological properties of fresh SCC. Also negative effects on the rheology of mixtures contain PPS fibers is less than steel fibers. Additionally, in any of the sample any sign of aggregates–cement matrix separation was detected. Addition of fibers decreases the compressive strength of the SCC. It can be because of a decrease in the workability of self-compacting concrete. For 28-day specimens, the addition of 0.4% fiber volume fraction at SCC contain PPS, Glass and Steel fiber led to 4%, 4% and

7% decrease with respect to the non-reinforced concrete, respectively.

- Fibers are very strong under tension or bending-induced tension. Presence of fibers in SCC samples enhances the splitting tensile strength. Fibers increase the splitting tensile strength through bridging the gap between two sides of a crack opening.
- Behavior (force-displacement curve) of self-compacting concrete without fibers under bending force is nearly vertical after the maximum stress and in the descending branch is without softening. This increasing in frangibility causes sudden failure during earthquake. This behavior with using fibers considerably improved as softer failure and take over their energy absorption capability.
- By surveying graphs of force-displacement shown that with reinforcing concrete with fiber, failure mechanism is changed from brittle and sudden to ductile. Bridging fibers which begin after cracking, will cause much Ductility in the samples of fibrous concrete and with increase percentage fiber will enhance Maximum tolerable displacement and crack width of prismatic beams.
- Testing the flexural assessments among the mixtures showed that increasing the content of fibers, especially metal fiber, increases Mechanical properties such as flexural and tensile strength and therefore, the consequent ductility significantly increased. Addition of fibers improves the ultimate load capacity of the SCC beams, and it leads to an increase in the flexural strength.
- Evaluating the results of toughness estimations in different mixing designs, showed that increasing the fiber contents significantly increases the toughness of concrete. Steel, PPS and Glass fibers can enhance toughness in fiber concrete, up to 16 and about 2 and 2 times, respectively. It shows that steel fibers have better performance with relation to energy absorption capacity.

The main influence of fiber in concrete is increasing fracture energy and it's ductile. So in this study, in self-compacting concrete samples containing steel fiber has increased fracture energy up to 30 times than reference concrete.

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