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Experimental investigation on self-compacting concrete reinforced with steel fibers

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Abstract. Self-Compacting Concrete (SCC) has been originally developed in Japan to offset a growing shortage of skilled labors, is a highly workable concrete, which is not needed to any vibration or impact during casting. The utilizing of fibers in SCC improves the mechanical properties and durability of hardened concrete such as impact strength, flexural strength, and vulnerability to cracking. The purpose of this investigation is to determine the effect of steel fibers on mechanical performance of traditionally reinforced Self-Competing Concrete beams. In this study, two mixes Mix 1% and Mix 2% containing 1% and 2% volume friction of superplasticizer are considered. For each type of mixture, four different volume percentages of 60/30 (length/diameter) fibers of 0.0%, 1.0%, 1.5% and 2% were used. The mechanical properties were determined through compressive and flexural tests. According to the experimental test results, an increase in the steel fibers volume fraction in Mix 1% and Mix 2% improves compressive strength slightly but decreases the workability and other rheological properties of SCC. On the other hand, results revealed that flexural strength, energy absorption capacity and toughness are increased by increasing the steel fiber volume fraction. The results clearly show that the use of fibers improves the post-cracking behavior. The average spacing of between cracks decrease by increasing the fiber volume fraction. Furthermore, fibers increase the tensile strength by bridging actions through the cracks. Therefore, steel fibers increase the ductility and energy absorption capacity of RC elements subjected to flexure.

Keywords: self-compacting concrete; steel fibers; flexural strength; mechanical performance; fracture energy

1. Introduction

Self-Compacting Concrete (SCC) does not need to vibrate due to the compacting ability by its own weight without vibration. In addition, SCC reduces construction time, noise level and labor cost and improves durability (Malhotra *et al*. 1994). The SCC has been developed originally in Japan in 1980s to reduce the usage of a growing shortage of skilled labors (Nanni 1988). The use of fibers in SCC improves the mechanical properties and durability of hardened concrete such as impact strength, flexural strength, and vulnerability to cracking, resistance to fatigue, toughness

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and spelling (ACI Committee 544 1990, Nehdi and Ladanchuk 2004, Tlemat *et al*2003, Malhotra *et al*. 1994, Nanni 1988). Initially, the idea of SCC appeared for using in inaccessible areas and underwater structures (Gaimster and Dixon 2003). Self-Compacting Concrete has been developed more in recent years, but the overall productions are still less than the conventional concrete (Sarmiento2011). In Netherland, about 70% of precast concrete was SCC in 2005. However, this proportion in Denmark was just 30% of conventional concrete (Geiker 2008).

The SCC has different applications such as cast-in-place or precast, complicated buildings or simple, small or big structures, vertical or horizontal members (Yakhlaf 2013). In the USA, the use of SCC is nearly 40% in precast productions (Daczko2012). Recently, the usage of SCC widened to repair materials in Switzerland and Canada (ACI Committee 237R-07 2007, EFNARC 2002). Fibers provide further resistance against crack development by creating bridges through cracks (Narayanan and Darwish1987, Li *et al*. 1992, Lim and Oh 1999). Therefore, steel fibers in the reinforced concrete change the behavior from brittle to ductile and increase the shear capacity (Mansur *et al.* 1986, Ramakrishnaand Sundararajan 2005). Limiting the tensile crack to a certain location and preventing of excessive diagonal tensile cracking are other advantages of steel fibers (Choiand Park 2007). There are numbers of research on rheological and mechanical properties of SCC with different steel fiber volume fractions and different concrete strength classes. Khaloo *et al.* (2014) studied mechanical and rheological properties of medium and high strength with different steel fibers volume fractions. Pajak and Ponikiewski (2013) investigated the effects of straight and hooked end steel fibers on flexural behavior of self-compact concrete. Fathi *et al.* (2014) utilized Polyvinyl Alcohol (PVA) and chopped basalt fibers and compared them with steel fibers.

In this research, the effect of steel fibers on rheological and mechanical properties are investigated with different volume frictions of fibers. The slump flow, T50, L-box, J-Ring and V-Funnel test are conducted to determine the rheological properties of SCC containing two different volume ratios of superplasticizer (1%, 2%). To achieve the mechanical properties of SCC compressive strength, flexural strength and flexural toughness are utilized with different percentage of 0%, 1%, 1.5% and 2% of steel fibers of SCC beams.

2. Experimental tests

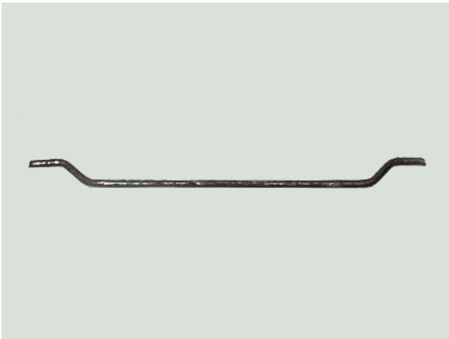
2.1 Materials and mix

In this study, different steel fiber volume fractions of 1%, 1.5% and 2% were used. The steel fibers characteristics are given in Table 1. Fig. 1 shows the steel fibers. To control the amount of aggregate size in the concrete mixture, a sieve analysis is conducted based on ASTM C33 (2003). Fig. 2 provides sieve analysis grading results for fine and coarse aggregates. The cement used was type I Portland cement. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate. The particle size and shape of coarse aggregate directly influence the flow and passing ability of SCC and its paste demand. The maximum coarse particle aggregates size must be determined with respect to reinforcement spacing. The powdered materials such as fly ash, silica fume, lime stone powder, glass and quartzite filler can eliminate segregation in SCC (Aggarwal 2008). The superplasticizer (SP) is an essential part of SCC in order to obtain high flowability and mobility. In this research, superplasticizer was used is based on chains of modified polycarbxylic. To find out the optimum percentage of superplasticizer, concretes containing

Table 1 Hooked-ended macro steel fibers characteristics

Fibers Types	Effective Length (mm)	Diameter (mm)	Tensile Strength (MPa)	Density (kg/m^3)	Aspect Ratio (l/d)
60/30	30	0.5	1345	7850	60

(a)



(b)

Fig. 1 (a) Steel fibers (b) Single steel fiber (hooked ended)

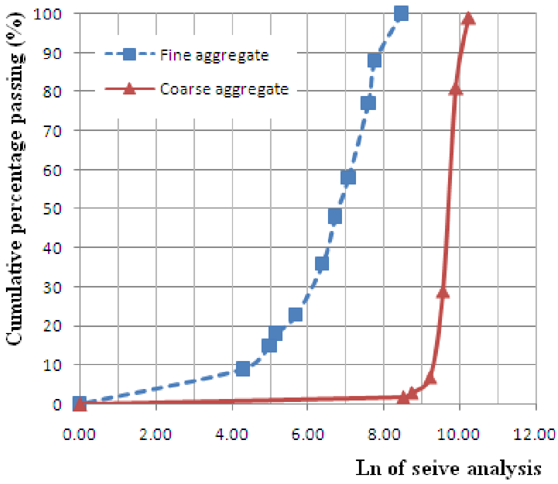


Fig. 2 Sieve analysis grading results

Table 2 Mix design for Mix 1% and Mix 2%

Concrete Class	W/C Ratio	Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Superplasticizer (kg/m^3)
Mix 1%	0.66	416.2	276.8	1224	660.6	4.16
Mix 2%	0.50	416.2	208.6	1224	660.6	8.32

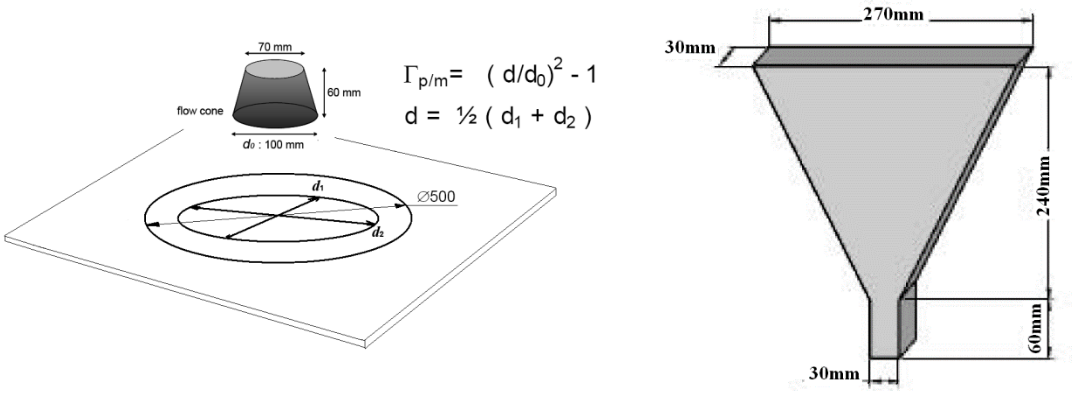
different percentage of superplasticizer were tested. For each percentage of SP and each class of concrete, three cube samples were used in the mix-design as illustrated in Table 2 (Eren and Alyousif 2010).

Table 3 Compressive strength test results for cube samples of Mix 1% with different percentage of SP

SP (%)	0%	0.3%	0.5%	0.8%	1%	1.5%	2.5%	3%
7-day	13.51	15.7	16.3	16.6	17.9	16.5	18.6	16.3
28-day	18.55	22.2	24.5	24.65	26.65	23.3	21.9	22.1

Table 4 Compressive strength test results for cube samples of Mix 2% with different percentage of SP

SP (%)	1%	2%
7-day	32.1	32.33
28-day	43.55	40.73



(a) (b)

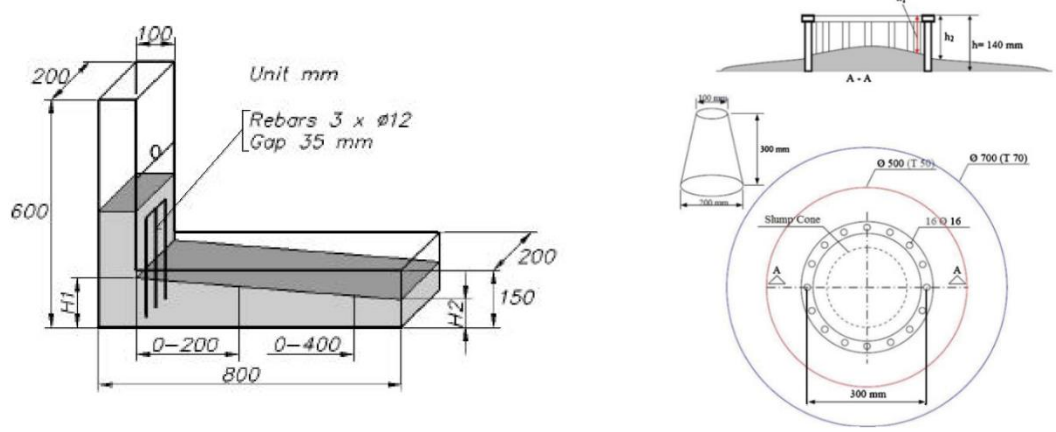
Fig. 3 (a) Flow test (b) V- funnel tests (EFNARC 2005)

Tables 3 and 4 show the compressive strength test results of the cubes (150×150×150 mm) on the 7-day and 28-day for Mix 1% and Mix 2%. Based on the compressive strength test results, the volume fraction of 1% and 2% of superplasticizer was selected for Mix 1% and Mix 2% respectively. The mixture started by adding coarse aggregate, fine aggregate and cement. After mixing dry materials in appropriate time (1 minute), water was added in two steps. In the first step, the added water was without SP and in the second step, it was with superplasticizer. Then fibers were added slowly in order to avoid segregation. For each beam specimens, three samples (cube of 150×150×150 mm size) have been taken for compressive strength test.

SCC is characterized by filling ability, passing ability and resistance to segregation. There are several different methods to characterize the properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mixture has been tested by more than one test method for the different workability parameters (Aggarwal 2008). The slump flow test is intended to investigate the filling ability of SCC in the absence of obstructions. In this test, the slump cone filled by SCC is lifted up gradually until the concrete flows of a flat horizontal plate. The average of maximum diameter of the concrete circle in two perpendicular directions is a measure for the filling ability. The time *T*50 indicates the rate of deformation in a specific distance.

The *T*50 test is the period (in seconds) when the cone leaves the base plate and concrete flow touches the circle with diameter of 500 mm. T50 indicates the viscosity and stability of concrete (Fig. 3(a)). The *V*-funnel test can be used to determine the flowability or viscosity of concrete. The *V*-funnel is filled by about 12 liters of concrete and the time taken for it to flow out through the apparatus is measured (Fig. 3(b)). It is obvious that a short time for flowing out indicates more flowability of concrete. The *L*-box test investigates the passing ability of SCC and it measures the height of fresh concrete after passing over the specified openings of three smooth bars (12 mm diameter) and flowing in a defined distance. In this test, the vertical section of the *L*-box is filled with concrete, and then the gate is opened to let the concrete flow into the horizontal section of *L*-box. The ratio of the height of concrete at the end of horizontal section to that remaining at the vertical section is measured (H2/H1). The ratio of H2/H1 is called blocking ratio. During this test, the blocking or passing behaviour of fresh concrete can be assessed. The vertical part filled by 12.7 litters of FRSCC and after resting concrete for 1 minute, let the concrete flow by opening the sliding gate. After the concrete is stopped, the height of concrete in two parts starting point H1 and ending point H2 of the horizontal box was measured (ACI 237R-07 2007).

The *J*-ring test is used to assess passing ability of the concrete. In this test, a ring apparatus with a series of vertical bars is used around a circle with 300 mm diameter. The flow of mixture is obstructed by the bars, thereby creating a difference of level in the concrete. This gives an indication of the passing ability and restricted deformability of the concrete (Gencel *et al.* 2011). Furthermore, the *J*-ring test considers flow time T50J, flow spread and blocking. The *J*-ring flow test shows the restricted deformability of fresh concrete because of blocking effect of ring (reinforcement bars) and the T50J shows the rate of deformation in a defined distance (500 mm) ACI 237R-07 2007. This test is similar to slump test just a ring is added around the cone of slump. After filling the cone and placing the ring, raise the cone vertically and allow the concrete to flow out freely the cone. The time of the first touch of concrete to the circle (500 mm) should be recorded (T50J). After stopping the concrete, the final diameter of the concrete is measured in two perpendicular directions (ACI Committee 544 1990). The *J*-ring spread (SJ) is the average of the two measured diameters in mm. The difference in height of concrete level is measured just inside and outside of the bars. The blocking step (BJ) is the average of the difference in height at four locations in mm.



(a) (b)

Fig. 4 (a) *L*-Box test (EFNARC 2005) (b) *J* ring test (Gencel *et al.* 2011)

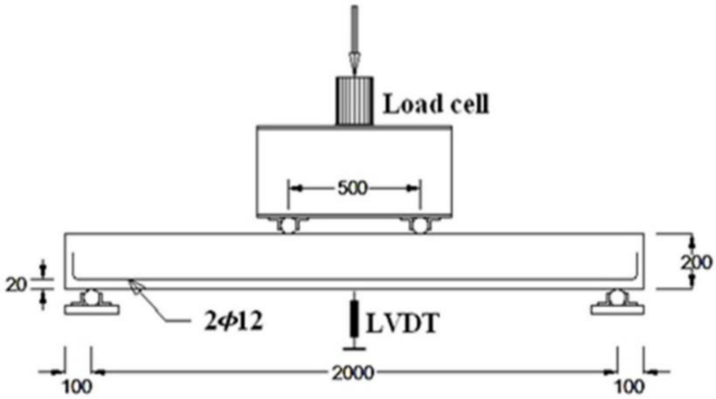


Fig. 5 Test set up

(a) (b)

Fig. 6 Test set up (a) front view (b) side view

The standard three point loading test for flexural performance of fibre reinforced concrete was conducted in current research. The beams specimen's dimensions were 200×300×2200 mm (Fig. 5). Totally 8 beams was tested by different steel fibers volume frictions. All beam specimens were reinforced by 2ϕ12 (two longitudinal rebar with diameters of 12 mm) with a yield stress of 420 MPa and material Grade 60. All beams specimens were cured in laboratory conditions and were tested at the age of 28 Days. A hydraulic jack applied load in the middle of a rigid steel beam and a load cell send applied load to the data logger model TDS-303. The applied load was divided in two points load with distance of 500 mm. A 100 mm linear variable displacement transducer (LVDT) was used for measuring displacement placed at the bottom middle of the beams as shown in Figs. 5 and 6.

3. Results and discussion

3.1 Workability tests results

Table 5 Workability test results of Self-Compacting Concrete

	Fiber	T50	Slump Flow Dia.	*L*-Box	*V*-Funnel	*J*-Ring		
	%	(sec)	(mm)		(sec)	T50J (sec)	SJ (m)	BJ (mm)
Mix 1% (1%SP)	0	0.63	685	0.9	7.4	0.87	645	54
	1	1	615	1	12.9	2.12	600	52.2
	1.5	1.43	600	0.2	18.4	2.47	540	53.5
	2	1.56	574	0.09	23.5	2.73	515	46.2
Mix 2% (2%SP)	0	0.41	920	0.29	9	0.55	870	49.2
	1	1.01	615	0.22	48.8	1.88	565	42.5
	1.5	3.2	550	0	51.3	3.65	510	39.5
	2	3.48	495	0	60.6	3.9	420	38.3

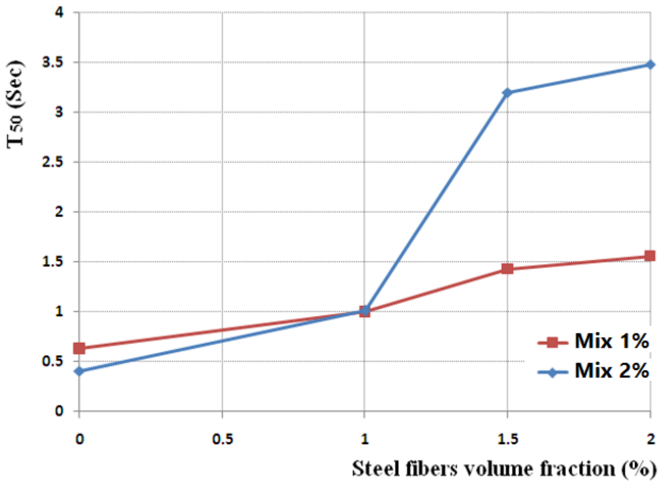


Fig. 7 T50

The result tests of workability of SCC are illustrated in the Table 5. The slump flow times results (T50) are from 0.41s for Mix 2% without fiber to 3.48s for Mix 2% with 2% fibers and for all mixture the slump flow time increases by increasing of volume fraction of fibers (Fig. 7). The slump flow times are 0.63s and 0.41s for Mix 1% and Mix 2% without fibers, which show more workability for Mix 2% without fibers mixture. The recommended ranges for T50 are 2s to 5s by EFNARC (2005). The effect of increasing of fibers on the slump flow times (T50) are more significant in Mix 2% in comparison to Mix 1%. It can be concluded that Mix 1% mixtures with fibers are more workable in comparison to Mix 2% with fibers. The results revealed slump flow diameters decrease by increasing of steel fibers volume ratio. These effects are more significant in Mix 2% in compare to Mix 1%. The results slump flow diameters, like the slump flow times results (T50), indicate more workability for C20 Mix 1% mixture with the same fibers in comparison to Mix 2%mixtures .The recommended slump flow diameters are 650 to 800mm by EFNARC (2005) (Fig. 8).

The passing ability of SCC was measured in *L*- box tests. In comparison with acceptable ranges of 0.8 to 1 by EFNARC (2005) just Mix 1% with 0% and 1% are in the range (Fig. 9). None of

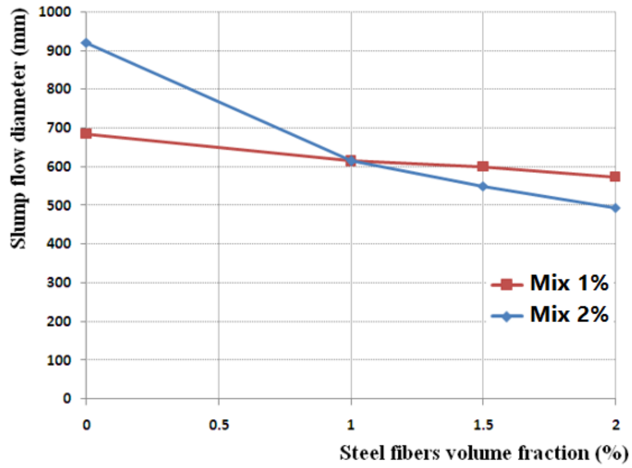


Fig. 8 Slump flow diameter

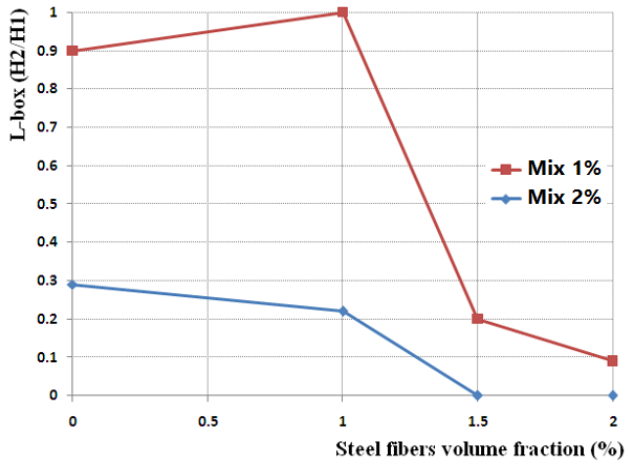


Fig. 9 *L*-box (H2/H1)

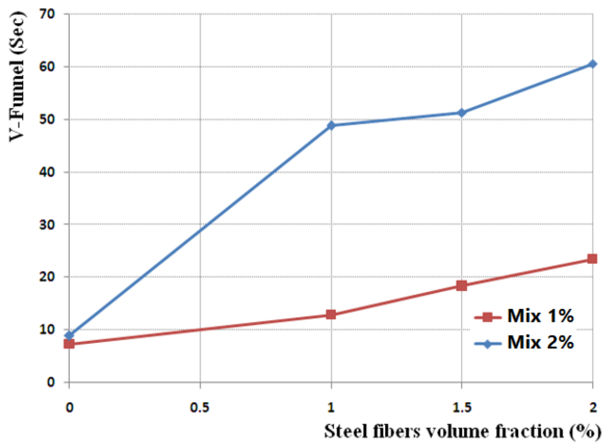


Fig. 10 *V*-Funnel

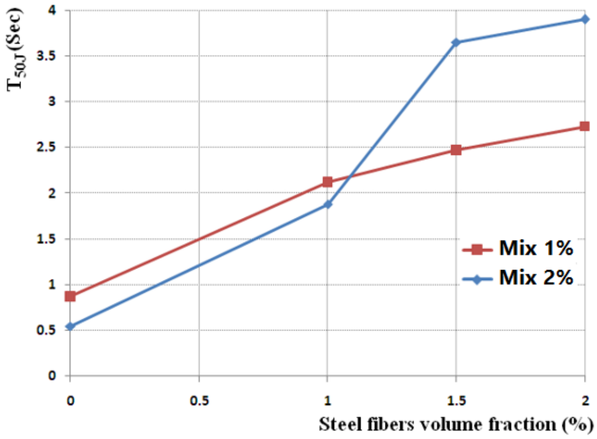


Fig. 11 *T*50 time in *J*-Ring tests

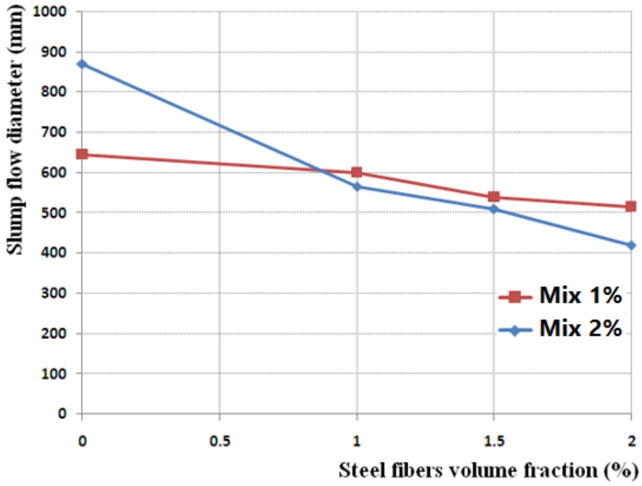


Fig. 12 *SJ* diameter in *J*-Ring tests

Mix 2% mixturesand Mix 1% mixtures with 1.5% and 2% fibers were an acceptable mixture because of their less blocking ratio than 0.8. Fig. 10 shows the results of *V*-Funnel test. The lowest *V*-Funnel flow time was 7.4s measured for Mix 1% without fibers, while the highest V-funnel flow time was 60.6 s for Mix 2% with 2% fibers. The acceptable times are between 6 s to 12s by EFNARC (2005). Based on results just two mixtures fell into the range. The *J* ring tests results are shown in Fig. 11. The lowest T50 time in *J*-ring tests was 0.55s measured for Mix 2%without fibers while the Mix 2% with 2% fiber had the highest *J*-ring time of 3.9s. The *J*-ring spread (SJ) test results are shown in Fig. 12. The results revealed the spread diameters (SJ) decrease by increasing of the volume ratio of fibers in both Mix 1% and Mix 2%. The blocking step (BJ) in *J*-ring tests results are shown in Fig. 13. According to the results, the blocking step (BJ) decreases by an increase of the volume ratio of fibers in both Mix 1% and Mix 2%. Based on the above mentioned results, the workability of mixtures decreases by increasing the volume ratio of steel fibers. The effect of increasing fibers in the reduction of workability in Mix 2% mixtures was

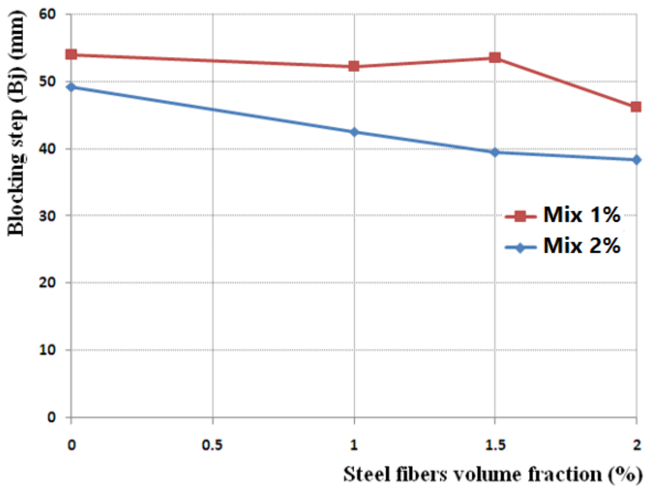


Fig. 13 Blocking step *BJ* in *J*-Ring tests

Table 6 Compressive strength results of cubes (MPa)

	7-day				28-day			
Fiber	0%	1%	1.5%	2%	0%	1%	1.5%	2%
Mix 1% (SP 1%)	18	17.6	20.6	19.3	26.6	30.5	26.5	27.5
Mix 2% (SP 2%)	32.3	31. 7	30.1	31.7	40.7	42.3	41.3	42.8

more significant in compare to Mix 1% mixtures. No mixtures with fibers are in the recommended limits by EFNARC (2005) especially *L* box tests results revealed most of mixtures have not passing ability through the rebar for heavily reinforced sections. It is obvious that by increasing the volume ratio of fibers, the workability of SCC is decreased.

3.2 Compressive strength

Table 6 shows the results obtained from the compressive strength at 7 and 28 days for Mix 1% and Mix 2% with different volume ratios of steel fibers. The results revealed that the compressive strength increase by increasing the steel fibers volume ratios. The increase percentage of compressive strength for 1%, 1.5% and 2% for Mix 1% mixtures are 15%, 0% and 3%respectively for 28 days specimens. The increase percentage for Mix 2% mixtures are 4%, 1% and 5% respectively.

3.3 Flexural strength

Fig. 15 shows a beam specimen after flexural test. Most of the flexural cracks are in vertical direction between two concentrated loads in the tension zone. The first crack, maximum applied load maximum deflection and flexural strength of beams are shown in Table 7. The results reveal that maximum loads and flexural strengths increased by increasing the volume ratio of fibers in all specimens. The increment of fiber volume fractions of 1%, 1.5% and 2% for Mix 1% specimens causes the flexural strength increase by 29%, 48% and 68% respectively. Furthermore, the

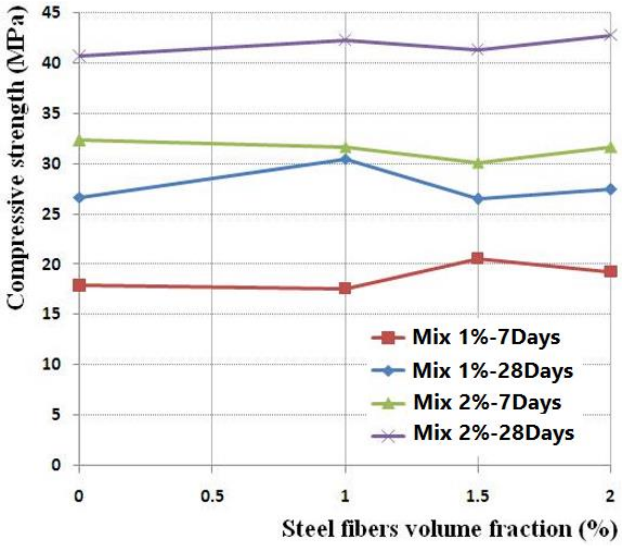


Fig. 14 Compressive strength results

(a) (b)

Fig. 15 beam specimen after test (a) general cracks view (b) major flexural crack

Table 7 Maximum load and flexural strength of beams

Specimen	First Crack Load (kN)	Maximum Load (kN)	Maximum Deflection (mm)	Flexural strength (MPa)	Percentage of increase of flexural strength
Mix 1%-0.0%F	5.2	33.2	79.8	6.2	0
Mix 1%-1.0%F	8.3	42.7	97.9	8.0	29%
Mix 1%-1.5%F	14.2	48.9	61.5	9.2	48%
Mix 1%-2.0%F	13.3	55.5	77.5	10.4	68%
Mix 2%-0.0%F	9.3	41.7	98.7	7.8	0
Mix 2%-1.0%F	11.8	51.0	92.2	9.6	23%
Mix 2%-1.5%F	12.8	55.1	82.7	10.3	32%
Mix 2%-2.0%F	18.9	60.6	36.4	11.4	46%

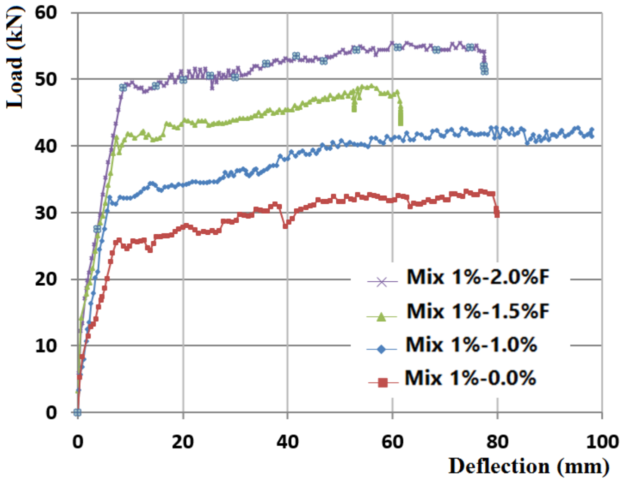


Fig. 16 Load-deflection curves from beams tests performed from Mix 1% with different ratio of steel fibers

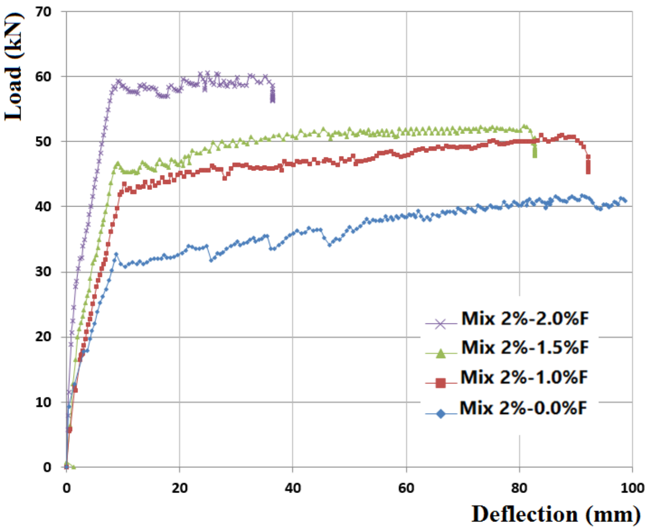


Fig. 17 Load-deflection curves from beams tests performed from Mix 2% with different ratio of steel fibers

addition of fiber volume fractions of 1%, 1.5% and 2% for Mix 2% specimens causes the flexural strength increase by 23%, 32% and 46% respectively. Figs. 16 and 17 show load deflection diagrams for Mix 1% and Mix 2% beams with different volume ratio of fibers respectively. The diagrams clearly show the flexural capacity increase by increasing the fiber volume fractions. As expected, the randomly distributed steel fibers are able to prevent growing of micro cracks by their bridging action across the micro cracks. Fig. 18 reveals all load deflection diagrams together. As it can depicted from diagrams, addition of supper plasticizer 1% to 2% for two-mix design causes the maximum deflection to increase for all specimens except for 2% steel fiber volume friction. Fig. 19 shows the diagrams of flexural strength increment for Mix 1% and Mix 2% beams with different steel fibers volume fractions. The diagrams revealed that the increment of flexural strength for Mix 1% beams is higher than Mix 2% beams.

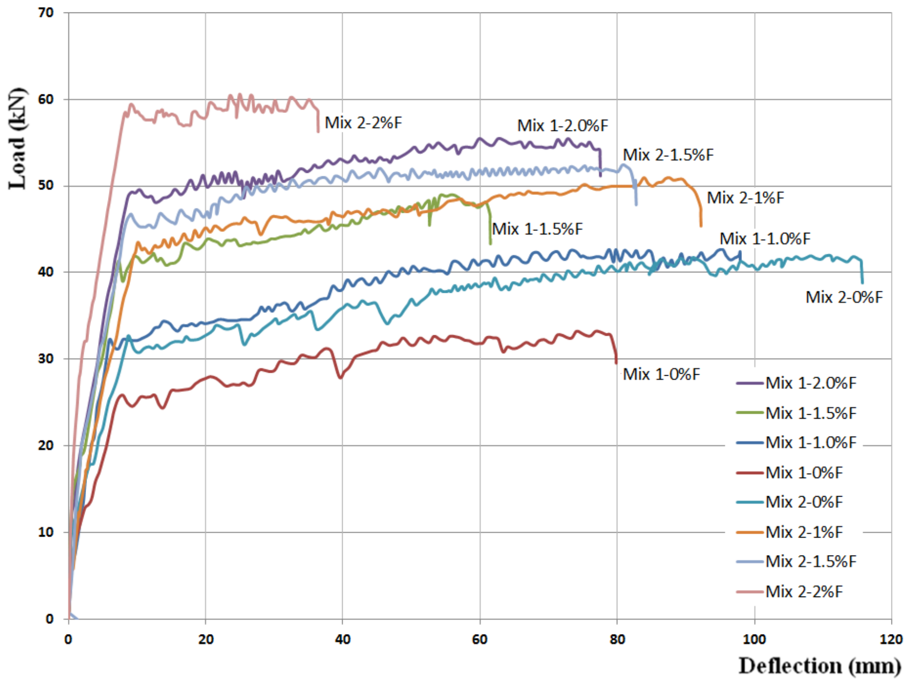


Fig. 18 Load-deflection curves for Mix 1% and Mix 2% beams with different ratio of fibers

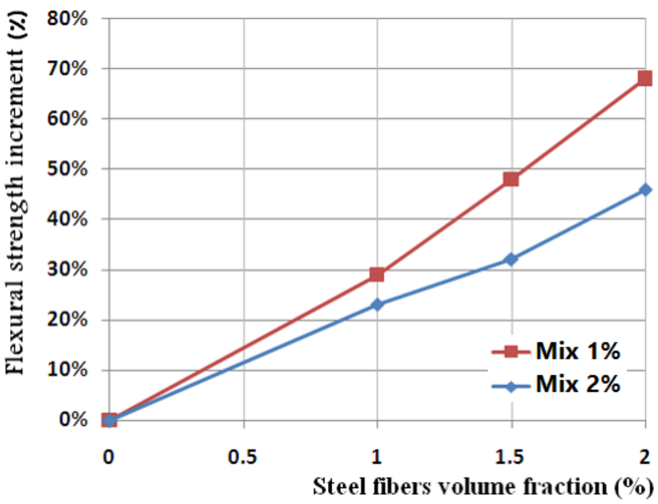


Fig. 19 Flexural strength increment of Mix 1% and Mix 2% beams with different fibers volume fraction

3.4 Flexural analysis of steel fiber reinforced of SCC beams

Fig. 20 shows the stress-strain distribution at cross section of steel fiber reinforced of SCC beams (CNR-DT 204/2006). The actual stress distribution of steel fibers is estimated by a simplified method based on Model Code (2010). In the suggested method, the stress distribution of steel fibers is represented by a rectangular stress block over whole tensional zone of the cross section of the beam. In this paper, the rigid plastic model is utilized to define the post cracking behavior of steel fibers in tension. The ultimate residual strength, F_{Ftu} is determined according to approach described in section 2.3 of RILEM TC 162-TDF using following expression

$$F_{Ftu}=f_{R3}/3 \tag{1}$$

The residual flexural tensile strength f_{Ri}, is determined by performing three point bending tests on 150×150×550 mm notched beams according to RILEM TC 162-TDF. Based on the equilibrium condition of force and moments the ultimate moment of steel fiber reinforced SCC beams is determined as follows

$$M_n = A_s f_y (d - \lambda x/2) + F_{Ftu} by (h - y/2 - \lambda x/2) \tag{2}$$

Table 8 shows a comparison of measured and predicted ultimate flexural strength of beams with different steel fiber volume frictions. The predicted ultimate flexural strength of beams are calculated based on Model Code (2010) Eq. (2). The residual flexural tensile, f_{R3} was assumed 1.37, 2.16 and 2.94 MPa for the 1%, 1.5% and 2% steel fiber volume fractions for Mix 1% and Mix 2% specimens based on the load-CMOD (crack mouth opening displacement) of experimental

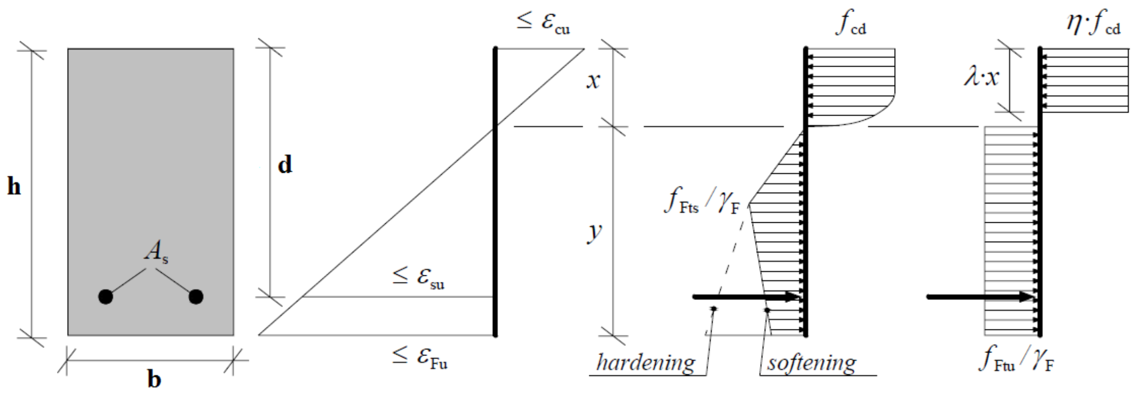


Fig. 20 stress-strain relationship (a) cross section (b) strain distribution (c) actual stress and force distribution (d) simplified stress and force distribution

Table 8 Measured and predicted flexural strength of beams

Specimen	Measured moment (kN-m)	Prediction moment (kN-m)	Ratio $M_{u\text{- Prediction}} / M_{u\text{-measured}}$
Mix 1%-0.0%F	12.4	15.2	1.2
Mix 1%-1.0%F	16	17.6	1.1
Mix 1%-1.5%F	18.3	18.5	1.01
Mix 1%-2.0%F	20.8	19.8	0.95
Mix 2%-0.0%F	15.6	15.6	0
Mix 2%-1.0%F	19.1	18	0.94
Mix 2%-1.5%F	20.7	19.3	0.93
Mix 2%-2.0%F	22.7	20.7	0.91

test results of Ning *et al*. (2015). In the lack of actual experimental test results, the prediction ultimate flexural strength of beams are presented in Table 9 just show a general estimation and in practical proposed the residual flexural tensile must be determined by performing three point bending tests on notched beams, according to the RILEM TC162-TDF (2003).

3.5 Cracking patterns

Fig. 21 shows the cracking pattern of Mix 1% and Mix 2% beams with different fiber volume fraction. Table 8 summarizes the number of cracks, the length of the cracked zone, average spacing of between cracks and spacing reduction. In all specimens, the major cracks are located in the middle zone of beams and in the vertical direction which present flexural cracks. Because it is due to usage of minor axis of the beam in plan of loading. For most of the beams, the average spacing of between cracks decrease by increasing the fiber volume fraction. It can be explained by bridge action of steel fibers through the crack opening and the ability of fibers to transfer stress to the concrete through a crack (Fritih *et al*. 2013). Fig. 22 shows the failure mode of all specimens which are in flexural mode as it can be expected.

3.6 Flexural toughness

The flexural toughness test method evaluates the flexural performance of toughness parameters derived from fiber-reinforced concrete in terms of areas under the load-deflection curve obtained

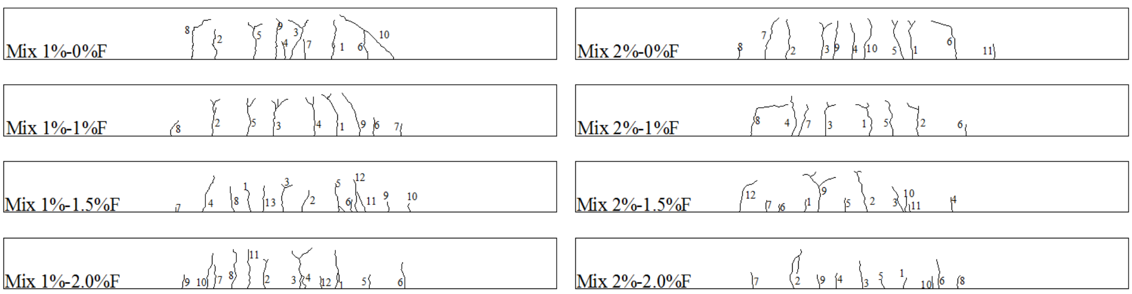


Fig. 21 Cracking pattern of Mix 1% and Mix 2% beams with different fibers volume fraction

Table 9 Effects of steel fibers on cracking pattern at failure level of beams

Specimen	Number of Crack	Length of Cracked zone (cm)	Average crack spacing (cm)	Spacing reduction (%)
Mix 1%-0.0%F	10	80.3	8.9	0
Mix 1%-1.0%F	9	91.1	11.4	0
Mix 1%-1.5%F	13	93	7.8	12
Mix 1%-2.0%F	12	88.5	8.	10
Mix 2%-0.0%F	11	102	10	0
Mix 2%-1.0%F	8	86	12	0
Mix 2%-1.5%F	11	85	8.5	15
Mix 2%-2.0%F	10	81.4	9	10

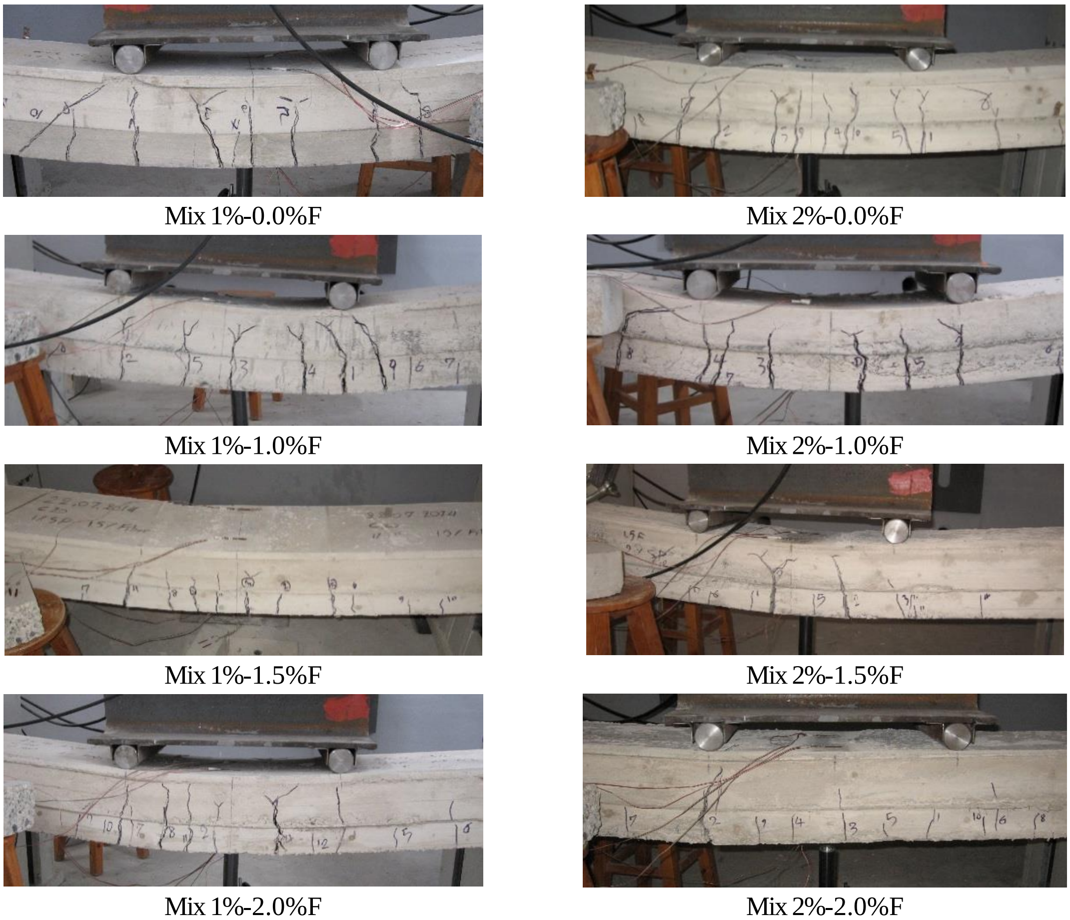


Fig. 22 Failure mode of Mix 1% and Mix 2% beams with different fibers volume fraction

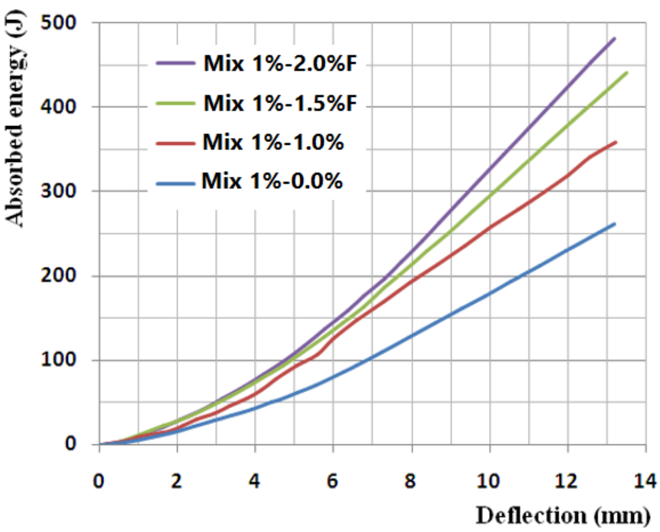


Fig. 23 Absorbed energy vs. deflection curves for Mix 1% beams

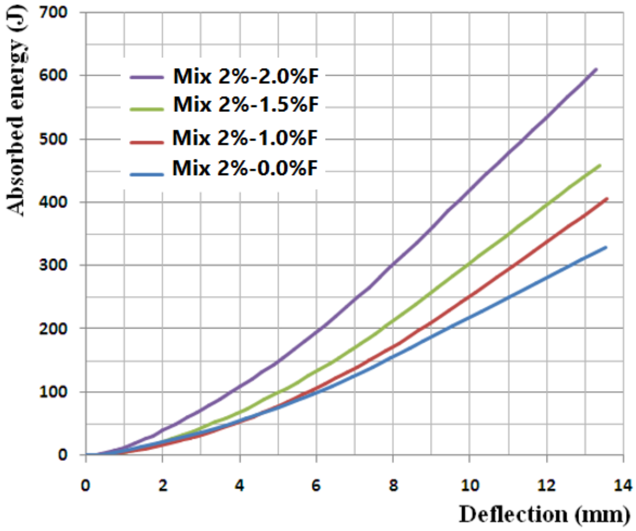


Fig. 24 Absorbed energy vs. deflection curves for Mix 2% beams

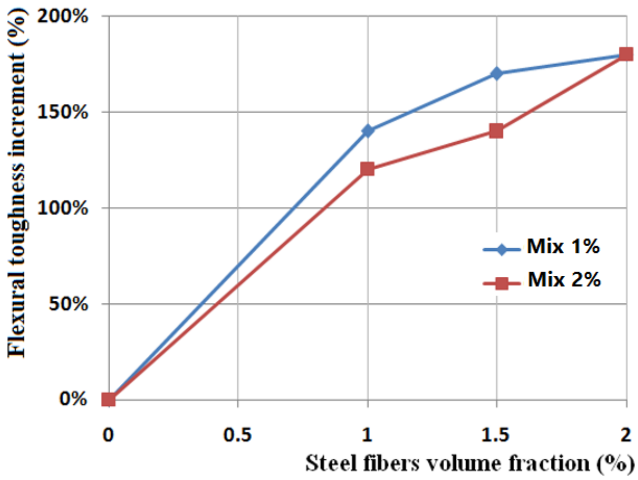


Fig. 25 Flexural toughness increment vs. different fibers volume fraction deflection

by testing a simply supported beam under third-point loading (ASTM C 1018 1997). For all beams specimens, the flexural toughness is equal to the absorbed energy corresponding to 13.3 mm mid span deflection which is equal to a deflection of 1/150 times the span. Figs. 23 and 24 show absorbed energy-deflection diagrams for Mix 1% and Mix 2% beams respectively. For the Mix 1% beams, the flexural toughness for different fiber volume frictions of 1%, 1.5% and 2% was 1.4, 1.7 and 1.8 times, respectively, higher than plain beam specimen. For the Mix 2% beams, the flexural toughness for different fiber volume frictions of 1%, 1.5% and 2% was 1.2, 1.4 and 1.8 times, respectively, higher than plain beam specimen. Fig. 25 shows flexural toughness increment with different steel fibers volume fractions. According to Fig. 25, it can be observed that for all beam specimens, flexural toughness of Mix 1% beams is higher than Mix 2% beams with same fiber volume fractions except 2% in which the increase of specimens are the same for both mixes.

4. Conclusions

An experimental investigation was conducted to assess the rheological and mechanical behavior of two different superplasticizer volume ratios of self-compacting concrete with different steel fibers volume ratios. The following results can be drawn from the current paper:

An increase in the steel fibers volume fraction decreases the flowability of self-compacting concrete. This impact is more significant for Mix 2% in compare to Mix 1% which reveals the role of superplacticizer in flowability of SCC. The results show that by increasing the steel volume ratio, the T50 times, *V*-Funnel time, T50J time increase and slump flow diameter decrease. Addition of steel fibers volume ratio, significantly reduces the passing ability of SCC through rebar especially for Mix 2%. Based on the achieved results, the compressive strength was slightly increased by addition of the steel fibers volume fractions for both Mix design. The results reveal that maximum loads and flexural strengths of beams increased by increasing the percentages of fibers in all specimens. The improvement of flexural strength for Mix 1% is higher than Mix 2% by utilization of steel fibers. Addition of steel fibers volume ratios increases flexural toughness and ductility of all beams specimens. The flexural toughness and ductility improvement directly depends on the steel fibers volume ratios. Enhancement of flexural toughness for Mix 1% beams is higher than Mix 2% beams. The fibers influence the failure pattern of beams by decreasing the average spacing between the cracks and decreasing the crack length with the increase in fiber volume frictions.

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