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Effect of Fibers on the Properties of Self-Compacting Concrete

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Abstract: **Self-compacting concrete (SCC) is known to be brittle and can easily crack under low levels of tensile force just like the ordinary concrete. This behavior of brittleness can be overcome by using randomly oriented short discrete fibers. This study investigates the influence of different sizes and dosages of polypropylene fibers, steel fibers and basalt fibers on the fresh properties (Slump flow,T_{500} time, V-funnel flow time, L-box passing ability which are used to measure the workability) and the hardened properties (compressive strength test, splitting tensile strength test) of Self-compacting concrete. Overall, the addition of fibers generally decreases the workability of the fiber reinforced self-compacting concrete (FRSCC) and doesn't significantly increase the compressive strength because of that fibers may affect the Interfacial Transition Zone (ITZ) between the aggregate and the paste, steel and Polypropylene fibers can produce voids inside the paste form while the basalt fiber will absorb the mixing water and hence reduce the compressive strength.**

Keywords: **self-compacting concrete, fibers, fresh properties, hardened properties, compressive strength.**

1. INTRODUCTION

Self-compacting concrete (SCC) is a relatively new type of concrete with high flowability and cohesiveness compared to conventional concrete. It's a concrete which has the ability to flow by its own weight and achieve good compaction without external vibration. In addition, SCC has good resistance to segregation and bleeding because of its cohesive properties [1] and also has many economical and technical benefits. SCC was conceptualized in 1986 by Prof. Okamura at Ouchi University in Japan [1].

The relatively high cost of material used in such concrete continues to hinder its widespread use in various segments of the construction industry, including commercial construction. However, the productivity economics take over in achieving favorable performance benefits and works out to be economical in pre-cast industry. Despite the high expenses of self-compacting concrete compared to the regular concrete, it is probably more profitable in use by reducing the expenses of vibrating and by quicker casting. The working environment is better, the surfaces are improved and we get more homogenous concrete which gives better durability. A considerable amount of research work has been devoted over the last decade to make self-compacting concrete more robust [2]. Another way to enhance the robustness and the mechanicals properties of self-compacting concrete is the use of fibers. The modification of behavior in fresh, hardening and hardened states achieve by incorporating fiber in cement-based materials are well known [3]. In fact, fibers improve the characteristics in the hardening and hardened properties since they can bridge cracks, transmit stress across cracks and counterattack cracks growth. The mixing of fibers in the fresh concrete increases tensile strength and this can be achieved without need of iron fixers prior to casting. The use of fibers in regular concrete is more uncertain due to the fact that when the concrete is vibrated, the fibers will cluster around the vibrator and won't be spread evenly. The disadvantage with fibers is that when used in the concrete, the amount of fibers that can't be used is limited because a t a certain content of fibers, the self-compaction becomes impossible to achieve. When the critical fiber content is surpassed, a stiff structure of the granular skeleton makes self-compaction impossible.

The present work deals with 27concrete mixtures incorporating different sizes and dosage of: steel fibers, Polypropylene fibers and basalts fibers in order to study the influence of the types, sizes and dosage of the fibers on fresh and hardened properties of SCC. Workability and mechanicals properties depend on various parameters (Maximum aggregate size, fiber volume, fiber type, fiber geometry).

2. RESEARCH SIGNIFICANCE

Ensure the quality of projects and at the same time speed up the pace of construction, solve the shortage of skilled labor, eliminate the construction noises are some important aspects of the modern construction which hasn't been contented with ordinary concrete. For local engineering structure such as tunnels and underground structures with dense and congested reinforcement, vibrations cannot be implemented, making the construction very difficult to achieve when the ordinary concrete is used. One of the solution to overcome such failures is the use of self-compacting concrete or self-consolidating concrete (SCC). However, either SCC or the ordinary concrete both have their own shortcomings since they are brittles and can crack under low tensile forces. This behavior of brittleness can be overcome by using randomly oriented short discrete fibers, fibers can be used in addition to, or as a substitute of rebar to increase the tensile strength of the concrete (SCC). The author believes that the optimization of fresh and mechanical properties of the resulting fiber reinforced self-compacting concrete (FRSCC) is essential to ensure better mechanical and durables characteristics of concrete in the hardened state.

3. MATERIALS USED

3.1. Cementitious materials:

3.1.1. Cement:

Ordinary Portland cement in compliance with the standard in vigor in china: “ordinary used Portland cement “GB 175 was used in this investigation.

3.1.2. Fly ash:

The F-type grade 2 of fly ash in compliance with the standard in vigor in china: “fly ash used in cement and concrete “GB/T 1596-2005 with apparent density of 2.3 g/cm^3 (143.58 lb/ft^3) was used in this investigation. The properties of cement and Fly ash are given in the Table 1.

Table 1. Cementitious materials properties

Chemicals and physicals properties			
Cement		Fly ash	
Type:	Portland Cement/ Silicate Cement	SiO2, % 52	52
Strength Grade (Mpa)	42.5R	Al2O3, %	23
Apparent density(kg/m^3)	3000	Fe2O3, %	11
Color	Grey	CaO, %	5 2
Fineness	>90um	SO3, %	0.8
Bending Strength	6.0	Na2O, %	1.0
Compressive Strength	72.5	K2O, %	2.0
Content of Sulfur Trioxide	8.5-10.5	Blaine fineness, kg /m^2	420
Magnesia Content	1.5-2.0	Apparent density, kg/m^3	2000

1 Mpa = 0.1450377 ksi; 1 kg/m^3 = 0.000036127292 lb/in^3; 1 kg /m^2 = 0.0014 lb/in^2

3.2. Aggregates:

Aggregate typically constitute 70-80% of concrete, aggregate types and sizes play an essential role in modifying concrete properties; the influence of type and grading of aggregate on the mechanical properties of concrete is important.

3.2.1. Coarse aggregate:

According to domestic and international standards and engineering experiences such as: the technical specification for the application of self-compacting concrete CECDS 203: 2006, The design and the construction guide of self-compacting concrete 02-2004 which specifications provides the maximum size of coarse aggregate to not be more than 20 mm (in.), Crushed granite aggregate available from local site with an apparent density of 2.6 g/cm^3 (162.31 lb/ft^3) was used.

3.2.2. Fine aggregate:

Locally available river sand with an apparent density of 2.599 g/cm^3 (162.25 lb/ft^3) and a fineness modulus of 2.5 was used. The gradation of aggregate in accordance with the JGJT 283-2012 Technical specification for the application of self-compacting concrete is given the Table 2.

Table 2. Gradation of aggregates

Fine aggregates		Coarse aggregates	
Sieve sizes	% passing	Sieve sizes	% passing
0.15 - 0.3 mm	-	< 4.75 mm	-
0.3 - 0.6 mm	61.78	4.75 - 9.5 mm	62.65
0.6 - 1.25 mm	72.10	9.5 – 16 mm	64.28
1.25 - 2.36 mm	81.17	16 – 19 mm	74
2.36 - 4.75 mm	99.98	> 19mm	99.39

– = not measured items. 1 Millimeter (mm) = 0.03937 Inches (in.)

a. Polypropylene fibers b.Steel fibers c. Basalt fibers

Fig.1. Photographs of polypropylene, metallic and basalt fibers

3.3. Water and high range water reducer:

Clean tap water available at the test site was used. Admixture of polycarboxylic acid retarding water reducer was used to enhance the workability of concrete. It's an impressive liquid based superplasticizer for producing free flowing concrete that complied with the technical specification for the application of self-compacting concrete JGJ/T 283-2012.

3.4. Fibers:

The type of fibers used in this research were steel fibers, basalt and propylene fibers. Steel fibers are characterized by a high modulus and a high bond with the matrix, they are flexible, ribbon like and totally stainless. Thus they can be used with no restriction in the design of reinforced concrete. Basalt fibers are mainly used (as crushed rock) in construction, industrial and high way engineering. One can also melt basalt (1300-1700°C) and spin it into fine fibers. When used as (continuous) fibers, basalt can reinforce a new range of (plastic and concrete matrix) composites. It can also be used in combination with other reinforcements (e.g. basalt/carbon) [4-5, 6, and 7]. The polypropylene fibers have a low modulus and a weak bond with matrix in comparison with metallic fibers. There are slipping fibers, designed to be used as a replacement for steel fibers, they have similar geometry. They are straight, auto-fibrillating and although made of a single piece of fibers and are used in concrete to obtain a much better, much stable surface and more resistant piece of concrete. They reduce the danger of micro-cracks dramatically, this increase the life time of the piece of polypropylene. The characteristics of fibers used are shown in table 3. While their photos appear in Figure 1.

Table 3. Characteristics of fibers

Physical properties	Steel fibers	Basalt fibers	Polypropylene fibers
Length(mm)	6,12,18	6,12,18	6,12,18
Density(g/cm3)	7.8	2.63	0.91
Tensile strength(Mpa)	1150~1300	3000~4800	550
Elastic Modulus(Mpa)	200	93.1	4.2
Aspect ratio	100	9~13	25

– = not measured items. 1 Mpa = 0.1450377 ksi; 1g/cm^3 = 62.427961lb/ft^3

4. RESEARCH METHODOLOGY

The tests used to assess the properties of self-compacting concrete with fibers added in the fresh and hardened state were the Slump flow spread, slump flow time T_{500} time, segregation index, V-funnel flow time, L-box passing ability which are a measure of the workability for the fresh properties and the compressive strength test and the splitting tensile strength test for the mechanicals properties.

Table 4. Shows the proportions of self-consolidating concrete mixture. A total of 27 concrete mixtures has been developed in the laboratory with varying dosages of three kinds of fiber: Steel fibers, Polypropylene fibers and basalt fibers on the basis of a control SCC mixture (with 0% fiber noted NF). For each type of fiber, nine mixtures have been developed. The first 3 mixtures for each type of fiber contain a quantity of fiber of 0.1%, 0.2% and 0.3% by volume of total mixture respectively and a length of 6 mm (0.24 in.) of fiber for each mixture. The second 3 mixtures and the last 3 mixtures are alike to the first 3 mixtures but with the lengths of 12 (0.47 in.) and 18 mm (0.71 in.) of fibers respectively.

Table 4. Proportions of reference plain mixture

Unit : kg/m^3 (1 kg/m^3 = 0.000036127292 lb/in^3)					
cement	Fly ash	gravel	sand	water	HRWR
413	140	725	733	193	11

4.1. Concrete mixing procedure:

Coarse and fine aggregates were added into the mixer and homogenized for 30 secs. Cement and fly ash were then added and mixing continued for 10 secs. A total of 60% of water were then distributed all over the mix and the mixing continued for 30 secs. The remaining 40% of water was mixed with the high range water reducer, then mixed for 60 secs. After a stopping period of 30 secs, mixing continued, and fibers were added by hand gradually over the concrete mix within the next 60 secs to ensure that clumping, clustering and conglomerating effect were minimized. Then continued for additional 120 secs and then stopped. The total mixing time was 310 secs and then, immediately after mixing and preparation, slump flow test, v-funnel test and l-box test were conducted according to the European guidelines For Self-compacting Concrete.

4.2. Test on fresh properties:

Slump flow test is used to evaluate the horizontal free flow (flowability) of SCC in the absence of obstructions. The test method is very similar to the test method for determining the slump of concrete. The difference is that, instead of the loss in height, the diameter of the spread concrete is measured in two perpendicular directions and recorded as slump flow. The higher the slump flow, the larger is concrete's ability to fill formworks. During the slump flow test, the time required for the concrete to reach a diameter of 500 mm (19.69 in.) is also measured and recorded as T_{500}. This parameter is an indication of the viscosity of concrete and indicates the stability of the concrete. A lower time points to a greater fluidity or smaller workability loss. A standard slump cone was used (Figure 2) for the test and the concrete was poured into the cone without consolidation.

The V-funnel test is used to determine the filling ability and viscosity of concrete. For this test, a V-funnel shape and a container are needed. The V shape funnel (Figure 2) is filled with concrete and after a delay of (10 or 12 secs) from filling the funnel, the bottom outlet gate of the funnel is open and the time it takes for the concrete to flow through the apparatus from the opening of the gate to the time it's possible to see vertically through the funnel into the container is measured. Good flowable and stable concrete would take a short time to flow out.

The L-Box test (Figure 2) is used to assess the passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking. There are two variations, the two bars test and the three bars test [8]. The three bars test which simulates more congested reinforcement is the one used for the test in this study. After have closed the gate between the vertical and the horizontal section, concrete was poured from the container into the filling hopper of the L-Box. It has been allow to stand for 60 to 70 s. After the movement had ceased, the vertical distance and the end of the horizontal section of the L-Box, between the top of the concrete and the top of the horizontal section of the box at three positions equally spaced across the width of the box were measured. These three measurements were used to calculate the mean depth of concrete as H2, the same procedure were used to calculate the depth of concrete immediately behind the gate as H1. The product of the division of the two depth was recorded as the passing ability.

a. Slump flow cone b. V – Funnel c. L-box

Fig.2. Tests on Fresh properties

4.3. Test on hardened properties:

Specimens for the testing of hardened properties were prepared by direct pouring of concrete into cube shaped molds without compaction. For each concrete mixture, 3 specimens were cast in cube shaped molds of 100 mm (3.94 in.) side. The cube shaped molds were used for the compressive strength test and the splitting test. After casting, the concrete specimens were kept into the laboratory at room temperature during 24h. After demolding, they were placed in a saturated limewater bath until the time of testing. Curing was done in accordance with GB50081-2002 Standard. It is well recognized that adequate curing of concrete is very important not only to achieve desired compressive strength but also to make durable concrete. The splitting tensile strength tests and the compressive strength tests were carried out in accordance with GB50081-2002 Standard Test Method for mechanical properties of ordinary concrete at 7 and 28 days.

a. Compressive strength test b. Splitting tensile strength test c. Specimens after test

Fig.3. Compressive strength test and splitting test

5. RESULTS AND DISCUSSIONS

Table 5. Shows the results of experimental tests of fresh stage such as slump flow, slump T_{500}, V-Funnel and L-box. The trend of the result prove that the addition of fibers in general reduce the workability of self-compacting concrete.

Table 5. Results of fresh and hardened concrete tests

		Slump Flow, cm	$T_{500,}$ secs	V-Funnel, secs	L-Box, %passing	Compressive Strength at 7 days, Mpa	Compressive Strength at 28 days, Mpa	Splitting Mpa
NF	0.0	730	2,06	5,53	0,89	198,022	298,011	30,042
Steel Fibers	0.1SF6	720	2,11	5,03	0,88	214,842	309,653	26,3
	0.2SF6	702	2,35	6,58	0,76	230,344	330,163	26,535
	0.3SF6	689	2,55	7,56	0,85	284,575	350,673	26,771
	0.1SF12	705	2,21	5,68	0,87	247,404	282,003	44,085
	0.2SF12	680	2,48	6,36	0,86	204,775	289,1435	42,695
	0.3SF12	648	2,69	9,42	0,84	162,146	296,284	41,3
	0.1SF18	700	2,38	6,06	0,86	233,55	293,109	47,601
	0.2SF18	668	2,64	7,16	0,84	81,881	293,109	41,779
	0.3SF18	595	2,86	10,45	0,82	197,965	259,117	38,731
Polypropylene Fibers	0.1POF6	685	2,67	7,12	0,87	212,018	251,64	26,737
	0.2POF6	626	3,05	10,3	0,85	160,373	174,999	33,005
	0.3POF6	574	3,42	14,25	0,81	108,728	131,728	22,06
	0.1POF12	650	3,12	9,14	0,84	236,099	247,427	34,952
	0.2POF12	573	3,59	12,51	0,82	207,505	214,913	30,781
	0.3POF12	498	3,95	15,36	0,8	166,272	261,999	26,61
	0.1POF18	605	3,57	11,2	0,83	185,381	244,683	34,854
	0.2POF18	540	4,03	14,87	0,8	203,908	243,767	33,704
	0.3POF18	455	4,52	17,63	0,77	183,645	228,361	29,9
Basalt Fibers	0.1BF6	660	3,02	9,89	0,85	245,023	302,105	24,957
	0.2BF6	602	4,15	13,45	0,78	221,9155	278,1555	25,21
	0.3BF6	554	5,06	18,21	0,72	198,808	254,206	25,463
	0.1BF12	593	3,85	12,56	0,82	204,445	257,21	27,07
	0.2BF12	530	4,78	15,76	0,72	204,745	257,51	32,48
	0.3BF12	461	5,64	19,32	0,69	204,645	257,41	30,68
	0.1BF18	525	4,7	15,23	0,78	152,519	193,706	31,097
	0.2BF18	445	5,89	19,78	0,7	152,6905	168,0965	36,507
	0.3BF18	395	6,7	23,41	0,64	152,862	142,487	34,707

Note: NF, SF, PO and BF represent the shortening of no fibers (mixtures where no fibers were added), Steel Fibers, Polypropylene fibers and Basalt fibers respectively while the numeric at the beginning represent fiber percentage by volume and letters at the end represent fiber sizes.

5.1. Results on fresh properties:

5.1.1. Slump flow and T_{500} mm.:

According to the European guidelines for self-compacting concrete, the minimum specified slump flow for self-consolidating concrete is 550 mm (21.65 in.). According to Table 5, the concrete mixtures where the steel fibers were added have a slump flow diameter > 550 mm (the minimum spread value is 595 mm (23.43 in.) and the maximum is 720 mm (28.35 in.)). On the basis of the Table 5, all the concrete mixtures with steel fibers satisfied the criteria of the European guidelines.

The mixtures where basalt fibers were added have a slump flow diameter ranging from 550-660 mm (21.65-25.98 in.)for those where 6 mm of basalt fibers were added and the fiber content ranged from 0.1% to 0.3% by volume of total mixture; For the others mixtures, the slump flow diameter is < 550 mm and hence don't achieve the self-consolidation criteria except for the one which had 12 mm of basalt fiber and a content of 0.1% by volume of total mixture.

The mixtures where the Polypropylene Fibers were added have a slump flow diameter ranging from 550-660 mm for those where 6 and 12 mm (0.24 and 0.47 in.) of Polypropylene Fibers were added and the fiber content ranged from 0.1 % to 0.3% by volume of total mixture. The mixtures where a content of 0.1% by volume of total mixture and 6 mm of

Polypropylene Fibers, a content of 0.3% by volume of total mixture and 12 mm of Polypropylene Fibers, a content of 0.2% and 0.3% by volume of total mixture and 18 mm (0.71 in.) of Polypropylene Fibers where added had a slump flow diameter of 685,498,540 and 455 mm respectively (26.97, 19.61, 21.26, 17.91 in.).

A value of slump flow spread located between 550-660 mm (21.65-25.98 in.) is suitable for the pouring of concrete structures from up to down with no or very few reinforcements, where the pouring point can be free to move, where the equipment use for the placement of concrete is small and do not need a high level of flow (such as pipe piles and other deep foundation) [9]. A value of slump flow spread ranging between 660-750 mm (25.98-29.53 in.) is an indication of a good slump flow thus a good deformability; those mixtures have enough deformability under their own weight and have a moderate viscosity, attributes necessary to avoid segregation and in particular when it comes to cast common structures with a normal reinforcement such as walls, columns, beams and so on [9]. The results of slump flow test are plotted in Figure 4. Adding different lengths and dosage of steel fibers, basalt fibers and Polypropylene fibers increases the resistance to flow and reduces the flowability due to increasing the interlocking and friction between fibers and aggregate.

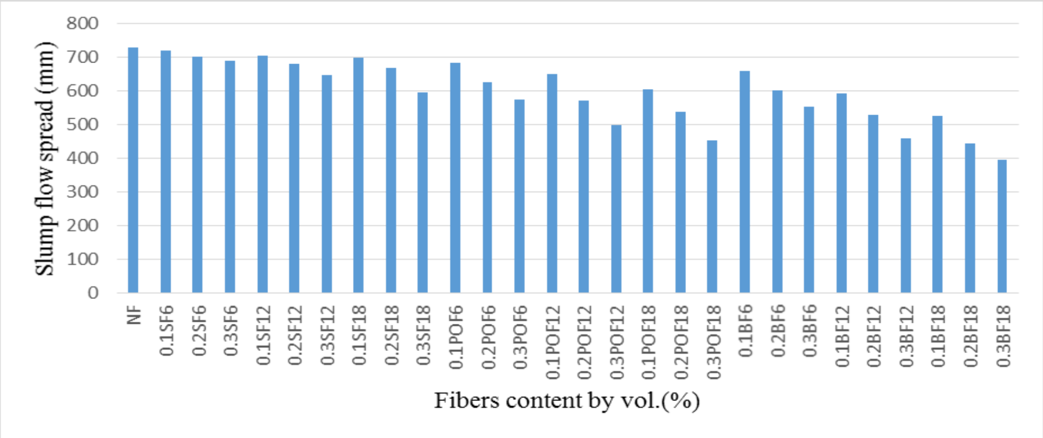

Fig.4. Effect of steel fibers, basalt fibers and Polypropylene fibers on slump flow test of SCC

The values of T_{500} mm which is the time taken to the nearest 0.1 secs for the concrete flow to reach the 500 mm (19.69 in.) circle at any point during the slump flow test was also measured and recorded as T_{500} (sec) (Slump Flow Time), it indicates the speed of flow and hence the viscosity of the self-compacting concrete. Table 5 and Figure 5. Show the results of T_{500} mm. The values were ranging between (2.11-2.86), (3.02-6.7), (2.67-4.52) secs for mixtures with steel fibers, basalt fibers and Polypropylene Fibers respectively. According to the European guidelines for self-compacting concrete, SCC can be classified as VS1 for $T_{500} \leq 2$ secs or VS2 for $T_{500} > 2$ secs. The VS1 mixtures even in the case of a reinforced bar, have a good filling performance. They are able to self-leveling and their surface is smooth after pouring, but they also face more bleeding and segregation possibilities. With the VS1 mixtures, there is no upper limit, but with the increase of the flow time, the concrete is more likely to have a contact deformation. The negative impact is likely to lead to the formation of void on the molding surface and other defects or the pause and the delay in the pouring will be very sensitive.

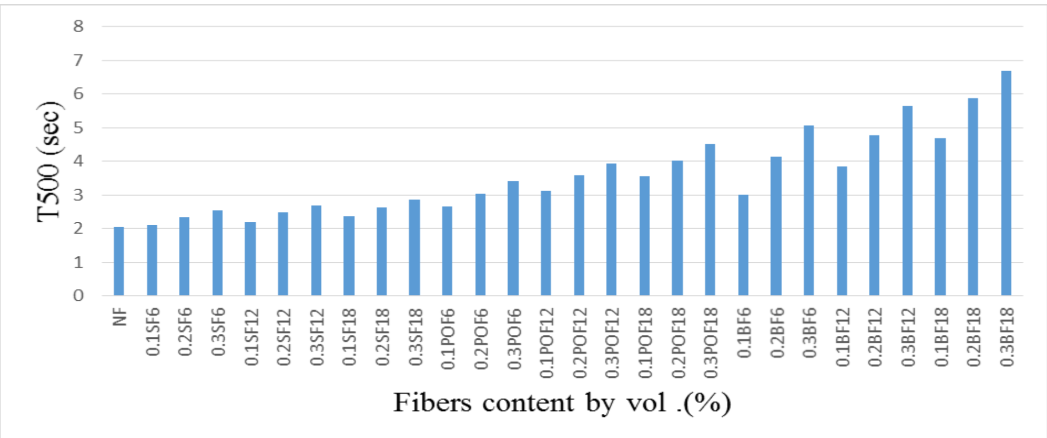

Fig.5. Effect of steel fibers, basalt fibers and Polypropylene fibers on T_{500} time test of SCC

5.1.2. L-box passing ability:

The L-Box with 3 bars was used in this study to assess the passing ability of the mixtures and ensure that the concrete will have a good passing ability even in presence of congested reinforcement. The Blocking Ratios results (BR=H2/H1) of the tests are summarized in Table.5 and plotted in Figure.6. According to the European criteria for L-box passing ability and on the basis of table 5, mixtures with steel fibers and Polypropylene Fibers have a good passing ability (>0.8) and can be used for structures with a rebar spacing of 60–80 mm (2.36-3.15 in.)[10]. For the mixtures with basalt fibers, only those with 6 and 12 mm of basalt fiber and a content of 0.1% by volume of total mixture have a good passing ability. The results show that the BR increased with the increasing of steel fiber and Polypropylene Fibers content, decrease with the increase of basalt fibers content. The higher the steel fiber and Polypropylene Fibers content, the higher the BR was and in reverse, the higher the basalt fibers, the lower the BR was.

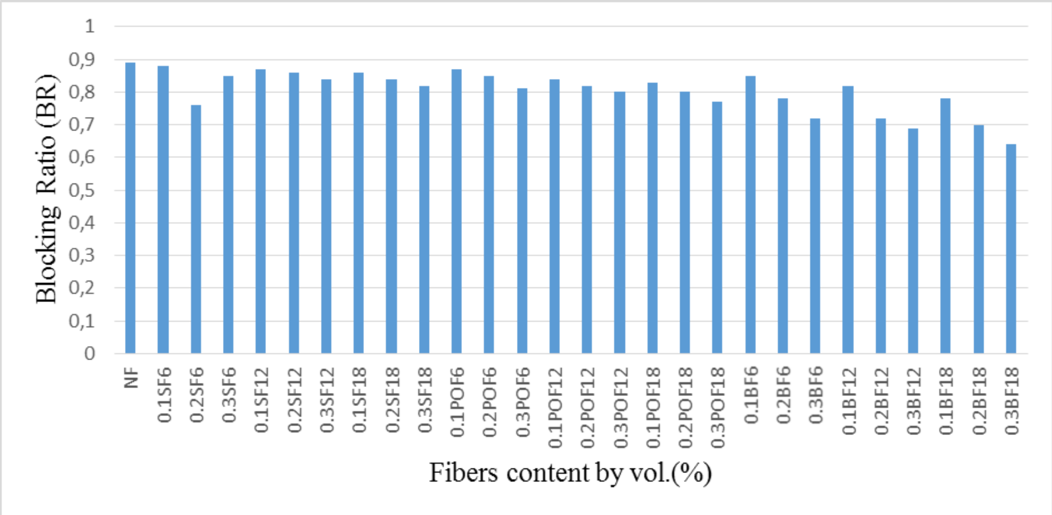

Fig.6. Effect of steel fibers, basalt fibers and Polypropylene fibers on L-box test

5.1.3. V-Funnel Flow Time:

The V-funnel is use to assess the viscosity and the filling ability of self-consolidating concrete [11]. The Results shown the lost in viscosity due to fibers. The basalt fibers have the maximum V-funnel time of the mixtures (23.41 secs) and their values range from 9.89 to 23.41 secs. SCC is classified into two categories: VF1 (≤ 8 sec) and VF2 (9-25) sec [12].The results fall in VF1 and VF2 categories, referring to that the mixtures have moderate to relatively high viscosity, indicating reduced filling ability and at the same time ameliorated segregation resistance. V-Funnel flow time increased by incorporating fibers in mixtures as illustrated in Figure 7 Similar behavior was observed in the T_{500} test. Besides, the higher the fiber content, the higher the flow-time. This can be ascribed to, the increasing in fiber content leads to increase the friction between the fibers and aggregates and the friction of the fibers with each other which could extend the required time to empty the V-funnel [13].

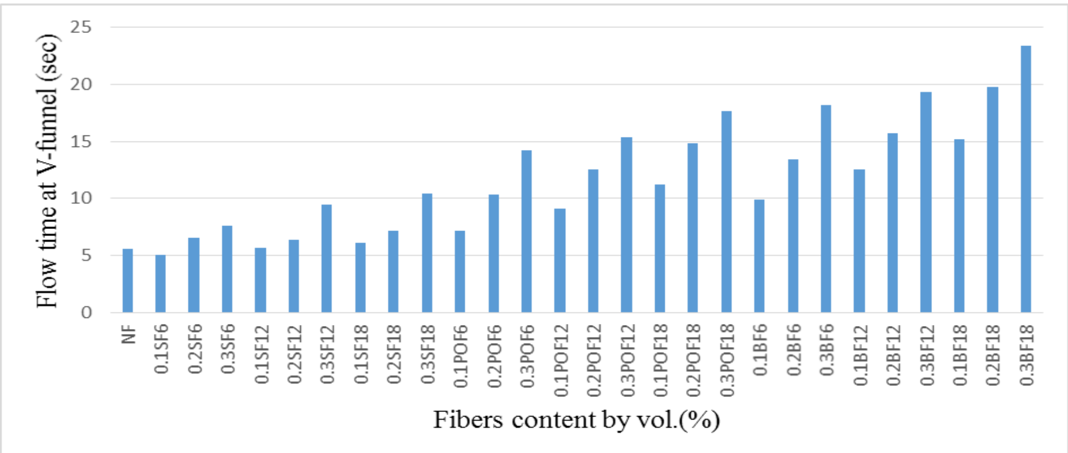

Fig.7. Effect of steel fibers, basalt fibers and Polypropylene fibers on V-funnel test of SCC

5.2. Results on hardened properties:

5.2.1. Compressive strength;

The compressive strength is one of the most important properties of hardened concrete. The compressive strength was conduct on 7 and 28 days on the cube sample of 100 mm (3.94 in.) side according to the BS1881-part 116: 1983, three molds were cast for each mixtures. The cube sample was remolded after 24h and kept in water tank for curing, the cube after remolded was free from any honeycomb with flat surface. The compressive test was done on the Machine shown in Fig.4, having a capacity of 1000 KN (8850745.77 lb). Figure.8 and 9 Show the effect of fibers on the compressive strength of FR-SCC mixes. On the basis of table 5, fibers in general did not increase the compressive strength because of that fibers may affect the Interfacial Transition Zone (ITZ) between the aggregate and the paste, but the compressive strength of mixtures with fibers is larger than the mixture where fibers haven't been added. Steel and Polypropylene fibers can produce voids inside the paste form while the basalt fiber will absorb the mixing water and hence reduce the compressive strength.

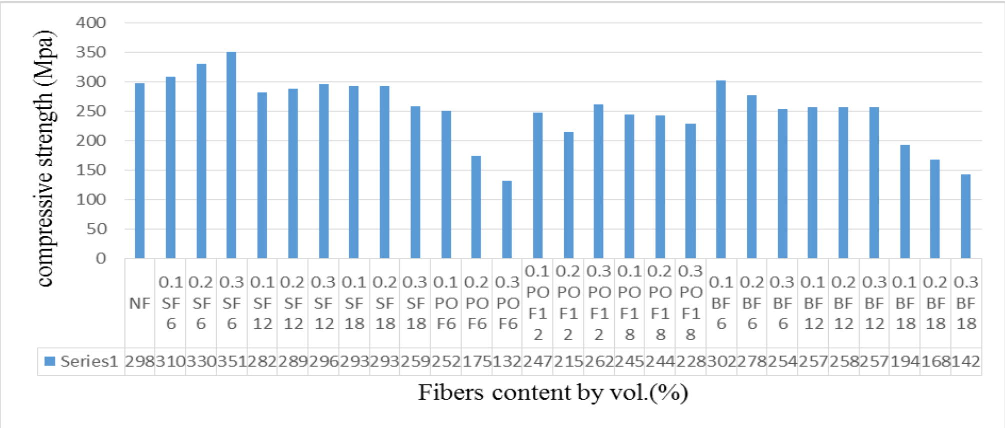

Fig.8. Effect of steel fibers, basalt fibers and Polypropylene fibers on the compressive test at 28 days of SCC

5.2.2. Splitting tensile strength:

Figure.9 demonstrates how much the fibers effect the splitting tensile strength per fibers, the mixtures where 6mm of steel fibers were added and the fiber content ranged from 0.1% to 0.3% by volume of total mixture have a tensile strength less than the mixture where no fibers were added, while mixtures with 12 and 18 mm of steel fibers at the same content increase the tensile strength. For the Polypropylene, there is an increase in the tensile strength for the mixtures with 6mm and a content of Polypropylene fibers of 0.2%, the mixtures with 12mm and 18 mm and a content of Polypropylene fibers of 0.1% by volume of total mixture and the mixture with 18 mm and a content of Polypropylene fibers of 0.3% by volume of total mixture. The others Polypropylene mixtures have a tensile strength less than the mixture where no fibers were added. The mixtures with 6 mm of basalt fibers and a content ranging from 0.1 to 0.3% by volume of total mixture have a tensile strength less than the mixture where no fibers were added while the rest all increase the tensile strength. The mixtures with steel fibers own highest result comparing with other mixtures.

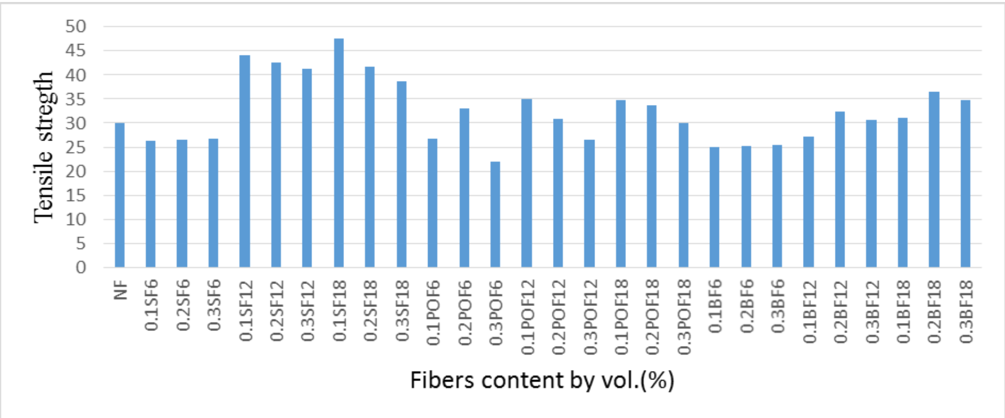

Fig.9. Effect of steel fibers, basalt fibers and Polypropylene fibers on the Splitting tensile test of SCC

6. CONCLUSIONS

This paper presents the fresh and mechanical properties of FRSCC mixtures developed by incorporating steel fibers, basalt fibers and Polypropylene fibers. The fresh properties of the concrete mixtures were evaluated using slump flow (spread), T500 time, L-box passing ability and V-funnel flow time tests according to standard specifications. In addition, some mechanicals properties (compressive and tensile strength) of concrete mixtures in hardened state were also evaluated. The conclusions can be drawn as following:

1. Overall (on the basis of Table 5), an increase in fiber volume (steel, basalt and Polypropylene fibers) decreases slump flow and L-box index passing ability with a consequent increase in V-funnel flow time and in the T_{500} time for the most concrete mixtures, as confirmed in other research studies. This result can be attributed to increased internal resistance to flow owing to the incorporation of fiber.

2. Mixtures where steel fibers where added show highest slump values for the flow ability than the other mixtures while having the lowest values for the T_{500} times than the other mixtures. The basalt fibers own the highest values for the discharging of 500 mm (19.69 in.) diameter (T_{500}). Mixtures with steel fibers and Polypropylene Fibers have a good passing ability (>0.8) and can be used for structures with a rebar spacing of 60–80 mm (2.36-3.15 in.).

3. The BR increased with the increasing of steel fiber and Polypropylene Fibers content, decrease with the increase of basalt fibers content. The higher the steel fiber and Polypropylene Fibers content, the higher the BR was and in reverse, the higher the basalt fibers, the lower the BR was.

4. V-Funnel flow time fall in VF1 and VF2 categories, referring to that the mixtures have moderate to relatively high viscosity, indicating reduced filling ability and at the same time ameliorated segregation resistance. V-Funnel flow time increased by incorporating fibers in mixtures. Similar behavior was observed in the T_{500} test. Besides, the higher the fiber content, the higher the flow-time. This can be ascribed to, the increasing in fiber content leads to increase the friction between the fibers and aggregates and the friction of the fibers with each other which could extend the required time to empty the V-funnel.

5. fibers in general did not increase the compressive strength because of that fibers may affect the Interfacial Transition Zone (ITZ) between the aggregate and the paste, but the compressive strength of mixtures with fibers is larger than the mixture where fibers haven't been added. Steel and Polypropylene fibers can produce voids inside the paste form while the basalt fiber will absorb the mixing water and hence reduce the compressive strength.

6. The concrete isn't usually likely to resist the direct tension due to its low tensile strength and brittle character. However, the resolution of tensile strength of concrete is essential to determine the stress where the concrete totally may crack. The mixtures with steel fibers own highest result comparing with other mixtures.

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