

Research Article

Comparison of the Effects of Different Fibers on the Properties of Self-compacting Concrete

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Abstract: There have been made many improvements in the recipe of Self-Compacting Concrete (SCC) during last few years, the earlier efforts mainly focused on the improvement of rheology, mechanical properties and cost effectiveness. During this decade various types of fibers impregnation have been investigated on the enhancement of ductility and tensile strength. The principal aim of this research study was to investigate the role of different types of fiber impregnation such as steel, Polyvinyl Alcohol (PVA) and chopped basalt fibers on the fresh and hardened properties of SCC containing fly ash and/or silica fume as partial replacement of cement. In general, all types of fiber impregnation caused an increase in water demand to achieve the required workability and a small reduction (10 to 15%) in compressive strength. However, the contributing effects of fibers were observed in the improvement of flexural and tensile strength as well as enhanced ductility, PVA and basalt fibers showed better performance than the steel fibers in this respect.

Keywords: Chopped basalt fiber, fly ash, polyvinyl alcohol fiber, self-compacting concrete

INTRODUCTION

Self-compacting concrete has the ability to flow in every interstices in the complex form work and consolidate within that without any external compacting. To achieve the desired properties of concrete without involving any compaction effort such as vibration is a great challenge to concrete experts and producers. In order to attain this behavior, the fresh concrete must show both high fluidity and good cohesiveness at the time of casting, transporting, placement and setting (Domone, 2007; El-Dieb and Reda Taha, 2012). It is recognized that concrete is relatively a brittle material particularly during last few years efforts to substantially increase the compressive strength made it more brittle, which has faced many problems when subjected to cyclic or dynamic nature of loads at early periods of service life. Reinforcement of such concrete using randomly distributed short fiber materials may enhance the toughness of cementations matrices by stopping or manipulating the initiation, propagation, or coalescence of cracks (Corinaldesi and Moriconi, 2011; Ferrara *et al.*, 2012; Zerbino *et al.*, 2012).

Research findings within the last decade clearly established that ductility of certain structural family could be greatly enhanced by using fibers. Fibers are added not to enhance the tensile strength itself, but mainly to manage and control the cracking, prevent coalescence of cracks and also to change the failure behavior of concrete by bridging of fibers over the

cracks. Quite simply, ductility will get fiber strengthened cementations composites because fibers will bridge the crack surfaces and delay the start of the extension of localized crack (Fantilli *et al.*, 2011; Ding *et al.*, 2012).

Utilization of fibers into SCC mixes remains to be presented by many experts. Based on many parameters such as maximum aggregate size, fiber volume, fiber type, fiber geometry and fiber aspect ratio, fiber inclusion to concrete reduces down on the workability of concrete. Decrease in workability in FRC is really a dilatory for on-site such research. However, the mixture of hybrid FRC and SCC together can offer a means of creating a Hybrid Fiber strengthened Self-Compacting Concrete (HFR-SCC) with superior qualities not only for hardened condition but additionally fresh condition (Pons *et al.*, 2007; Aydin, 2007).

Steel fibers have a very substantially bigger strength and greater Young's modulus of elasticity compared to another types of fibers. This may lead to an enhanced flexural rigidity and contains great potential for cracking control, despite the fact that the volumetric density is high. It's also worth monitoring that steel is conductive in electric and magnetic fields and for that reason, the steel fibers content must be reduced with a certain level (Rao and Ravindra, 2010; Grünewald and Walraven, 2001).

The influence of hybrid fibers on the properties of High Volume Fly ash of Self-Compacting Concrete

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(HVF-SCC) are investigated by many expert, the Fiber Reinforced Self-Compacting Concrete (FR-SCC) can be produced by using high-volume of fly ash having reduction in compressive and tensile strength at early period of concrete life. By utilizing different type, shape and strength of fibers, SCC might be personalized for further possible application. As of this point, however, it is important to search for the result of fibers on workability characteristics of SCC. The characteristic factors of SCC, such it is filling ability and deformability, might be measured by a few techniques (Sahmaran *et al.*, 2005; Boulekbache *et al.*, 2010).

Adding fibers might include a slight effect on the workability of SCC. It can also be proven that the primary impacting on the factor of flow ability and workability may be the geometry of lengthy fibers instead of their strength. The flow ability rate decreases with inclusion of fibers, although no significant alternation in the ultimate flow ability might be found for fiber contents in SCC (Akçay and Tasdemir, 2012).

Investigation of the tensile, flexural and compressive strength behavior of mortar specimens could be found by inclusion the steel fibers in SCC. It was observed that the tensile or/and flexural strength of steel fiber reinforced mortar was at least two to three times higher than that of plain mortar, while the corresponding strains and deflections were at least 10 times higher than that of plain mortar specimens. The contribution of steel fibers can be observed significantly after matrix cracking in concrete, in which they arrest the propagating cracks (Dawood and Ramli, 2011).

Some of the (CRM) are supposed to enhance the properties of SCC by avoiding the bleeding at fresh stage and increasing the strength at the long term of hardened stage, in addition of that CRM can reduce the total cost of mixing by replacing of ordinary Portland cement or fine aggregate (Fathi *et al.*, 2013).

Evaluation of the fiber dispersion in the composite Polyvinyl Alcohol-Engineered Cementations Composite (PVA-ECC) is extremely challenging because of the low contrast of PVA fibers with the cement-based matrix, the researchers studied the Strength and fracture energy characteristics of self-consolidating concrete incorporating polyvinyl alcohol, they have been reported that in general the PVA fiber will decrease the flow ability and passing ability of SCC while it increase the V-funnel time with the increasing the PVA fiber volume (Hossain *et al.*, 2013).

Felekoğlu *et al.* (2009) Studied the effect and performance of self-compacting concrete using fly ash and two polymer micro-fibers (polypropylene and polyvinyl alcohol), the volume of fibers have been added to the mix was 1.0% to examine the workability properties as well as the mechanical properties of the mixture by adjusting the water to cement ratio and applied sample of concrete beam to the three point flexural loading test, they conclude that the high strength fiber with high strength matrix will achieve the best performance of flexural strength and

toughness, also they found out that from the load-deflection curve the Polypropylene fiber (PP) elongate and slip from the matrix easily while the Polyvinyl Alcohol (PVA) performed similar in the matrix because of its relatively rough surface.

Naik and Singh (1997) evaluated the compressive strength and bleeding of concretes mix containing two type of fly ash; class C fly ash and class F fly ash. They found out that concrete containing class C fly ash showed higher early age (1 to 14 days) and less bleeding than that of concretes containing class F fly ashes.

Basalt Rock materials don't have any toxic reaction with air or water, are non-combustible and explosion proof. When in touch with other chemicals they produce no chemical responses that could damage health or even the atmosphere. Its good hardness and thermal qualities might have various applications as construction materials. Basalt is really a major alternative towards the asbestos, which poses health risks by harmful respiratory system. Basalt base composites can replace steel (1 kg of basalt stands for equals 9.6 kg of steel) as lightweight concrete could be receive from basalt fiber (Sim *et al.*, 2005; Singha, 2012; Liu *et al.*, 2006).

The main objective of this research study was to compare the effect of three different types of fibers (steel, PVA and basalt) on the properties of self-compacting concrete containing various kind of cement replacement material (fly ash and silica fume). There were 12 trial mixes divided into three groups of SCC were prepared. Fresh concrete properties were conducted using slump flow, slump T₅₀ and V-funnel tests, whereas the hardened properties included the determination of compressive, splitting tensile and flexural strengths with the total porosity and Ultrasonic Pulse Velocity (UPV).

MATERIALS AND METHODS

Material selection: ASTM, type-1 Ordinary Portland Cement (OPC) was utilized within the experiment, its chemical composition is provided in Table 1. Fly ash utilized in this research was class-F based on the EN 450:1995 standard and originally obtained from the Manjung energy station, Lumut, Perak, Malaysia, it is chemical characteristics is provided in Table 1. Silica fume was acquired from Elkem material in dry densified form with Grade 920E with LOI less than 4%

Table 1: Chemical composition of binder used in this study
Percentage (%)

Chemical composition	OPC ¹	Fly ash ¹	Silica fume ²
SiO ₂	20.3	56.39	96.360
Al ₂ O ₃	4.2	17.57	0.210
Fe ₂ O ₃	3.0	9.07	0.770
CaO	62.0	11.47	0.240
MgO	2.8	0.98	0.520
SO ₃	3.5	0.55	0.550
K ₂ O	0.9	1.98	0.102
Na ₂ O	0.2	1.91	0.120

¹: OPC and fly ash, the data provides by Shafiq *et al.* (2007); ²: Silica fume, the data provides by Nuruddin *et al.* (2010); ³: Test result obtained from XRF, s University Teknologi PETRONAS, Malaysia

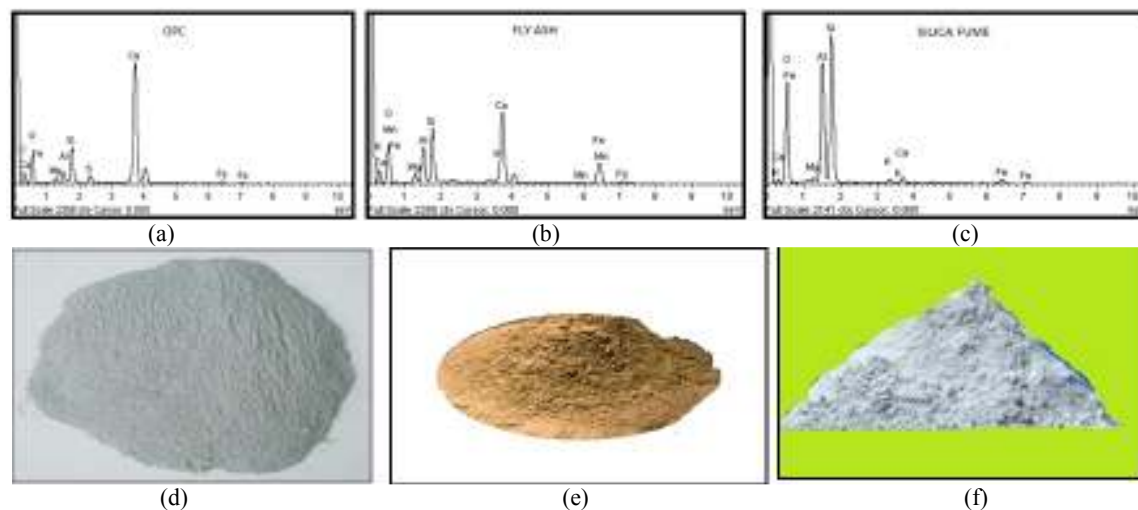


Fig. 1: XRD and photo of OPC, fly ash and silica fume respectively



Fig. 2: Photo of steel, PVA and basalt fibers respectively

Table 2: Grading of the coarse and fine aggregate

BS sieve size (mm)	Passing (%)	
	Coarse aggregate 10-5 mm	Fine aggregate >3.35 mm
10.00	91.2	
5.00	85.4	
3.35	68.4	56.7
2.36	46.9	50.2
2.00	33.2	39.3
1.18	18.7	23.5
0.60	7.9	11.6
0.30	-	7.3
0.21	-	4.8
0.15	-	1.2
Pan	0.0	0.0

Table 3: Characteristic of fibers

Physical properties	Steel fiber	PVA fiber	Basalt fiber
Length (mm)	20.00	30.00	25.00
Diameter (mm)	0.20	0.70	0.18
Density (g/cm ³)	>2300	2400	4100-4840
Tensile strength (MPa)	7.85	1.30	2.65
Elastic modulus (MPa)	210	25-40	100.11
Aspect ratio	100	42.86	138.89

and particular area (BET) of 15-35 m/g as needs according to the ASTM C1240, the chemical composition of silica fume is proven in Table 1. Figure 1 show the photo and XRD results of the binder utilized in the experiment.

Similarly the fine aggregate utilized in the experiment were clean natural sand with specific gravity of 2.61 and fineness modulus of 2.76, the

maximum size of it is 3.35 mm. As the coarse aggregate was utilized as (10-5) mm crushed granite stone according to the BS: 812-103.2-1989 with specific gravity of 2.66 in SSD. The two types of aggregates were sieved as highlighted in Table 2. HRWR super plasticizer from SIKA-KIMIA Malaysia was utilized for enhancing the workability of concrete. It's an impressive liquid based super plasticizer for producing free flowing concrete that complied with the BS: 5075. The fibers used in experiment were steel, PVA and a chopped basalt fiber, their own characteristics was shown in Table 3 while their photos appear in Fig. 2.

Trial mix procedures: The experimental work was started by developing the FR-SCC mix with total binder as 350 kg/m³ of OPC with two types of aggregate content and three type of fibers which are steel, PVA and chopped basalt fiber, the trend of primary result of slump and V-funnel test showed the possibility to add the fibers to SCC as 1.0% only by weight of binder, then the binder content has been extend to 450 kg/m³ and the other CRM type was replaced the cement such as fly ash and silica fume. The new SCC mix have been created and tested by the slump and V-funnel test which showed little increase than the previous mixture but still no more fiber content can add to the mix, after that the aggregate type have been kept to small size only such as 5-10 mm and the total binder amount (OPC and CRM types) has been increased to 600 kg/mm³. The result after the

Table 4: FR-SCC design mix

Groups	OPC (%)	Fly ash (%)	Silica fume (%)	No of mix	Fiber % (steel-PVA-basalt)
One	100	0	0	4	2.0
Two	70	30	0	4	2.0
Three	90	0	10	4	2.0

Table 5: Mixing details

Groups	Code mix	CRM (kg/m ³)			Fibers (kg/m ³)			Water (kg/m ³)
		OPC	Fly ash	Silica fume	Steel fiber	PVA fiber	Basalt fiber	
One	SCC ₁	600	0	0	0	0	0	200
	SF-SCC ₁	600	0	0	12	0	0	200
	PV-SCC ₁	600	0	0	0	12	0	200
	BF-SCC ₁	600	0	0	0	0	12	200
Two	SCC ₂	420	180	0	0	0	0	196
	SF-SCC ₂	420	180	0	12	0	0	196
	PV-SCC ₂	420	180	0	0	12	0	196
	BF-SCC ₂	420	180	0	0	0	12	196
Three	SCC ₃	540	0	60	0	0	0	192
	SF-SC ₃	540	0	60	12	0	0	192
	PV-SCC ₃	540	0	60	0	12	0	192
	BF-SCC ₃	540	0	60	0	0	12	192

For all concrete mixtures, coarse aggregate = 750 kg/m³, fine aggregate = 900 kg/m³ and super plasticizer = 12 kg/m³

modification prove and attain self-compatibility of this mix with the fiber content, eventually the FR-SCC mix was fixed and the other study have been started to highlight the effect of the different fibers and CRM type on the concrete mixture through the hardened properties.

Mix proportion: There are twelve mix of FR-SCC were created formed three groups which are 100% OPC in group one and 30% of fly as in group two and 10% of silica fume as in the last group. Each group contains 4-mix according to the type of fiber which is replaced as 2.0% by weight of cement in all groups. The group one was kept as the control to compare it with the other groups to highlight the effect of different fibers and CRM in the SCC mix. Mix proportioning is tabulated in Table 4 and 5 which show the design and arrangement of the mixing of the experimental task.

RESULTS AND DISCUSSION

Fresh properties: Table 6 shows the result of experimental test of fresh stage such as slump flow, slump T₅₀ and V-funnel. The orientation of the result proved that the addition of fibers in general reduced the workability of SCC as in movement and time of slump. From the Table 6, the slump flow result of FR-SCC mixes was within the EFNARC standard (EFNARC, 2002), the highest slump flow value was 760 mm of sample SCC₃ which contain 10% silica fume without fiber while the lower slump flow was 550 mm of sample BF-SCC₁ which include 100% cement with 2.0% basalt fiber. In group one the steel, PVA and basalt fibers reduced the slump flow by 2.94, 8.82 and 19.12%, respectively. The reduction in group two was 2.86, 11.43 and 17.14%, respectively per the steel, PVA and basalt fibers. The results of group three

Table 6: Fresh test result

Groups	Code mix	Slump flow (mm)	Slump T ₅₀ second	V-funnel second
One	SCC ₁	680	5	10
	SF-SCC ₁	660	5	11
	PV-SCC ₁	620	4	13
	BF-SCC ₁	550	5	17
Two	SCC ₂	700	3	9
	SF-SCC ₂	680	2	12
	PV-SCC ₂	620	2	14
	BF-SCC ₂	580	2	18
Three	SCC ₃	760	5	10
	SF-SC ₃	740	4	12
	PV-SCC ₃	700	3	12
	BF-SCC ₃	680	5	19

regarding the slump flow test were 2.63, 7.89 and 10.52%, respectively. The comparison between fly ash and silica fume through FR-SCC mixes show that the silica fume enhance the slump flow by 11.76% than that of 2.94% of fly ash at the comparison of 3-control mixes of SCC₁, SCC₂ and SCC₃.

The slump T₅₀ results show the self-compatibility behavior of the FR-SCC mixes whereas the values were located between the 2 to 5 sec according to the EFNARC. It has been observed through the slump T₅₀ results that the fibers increased the discharging time of 500 mm diameter of mixes, the PVA fibers mixes record time more than the steel and basalt fibers because their surface area is small than that of the rest.

The V-funnel results of FR-SCC mixes show the loss in the viscosity due to the fibers, the basalt fibers have maximum V-funnel time of the mixes and their values are out of the 6-12 sec of EFNARC because at time of mixing the basalt will absorb the mixing water causing reduction and problem in viscosity, so it is recommended that the mixes of SCC with the basalt fiber should contain more extra super plasticizer to avoid the short in viscosity.

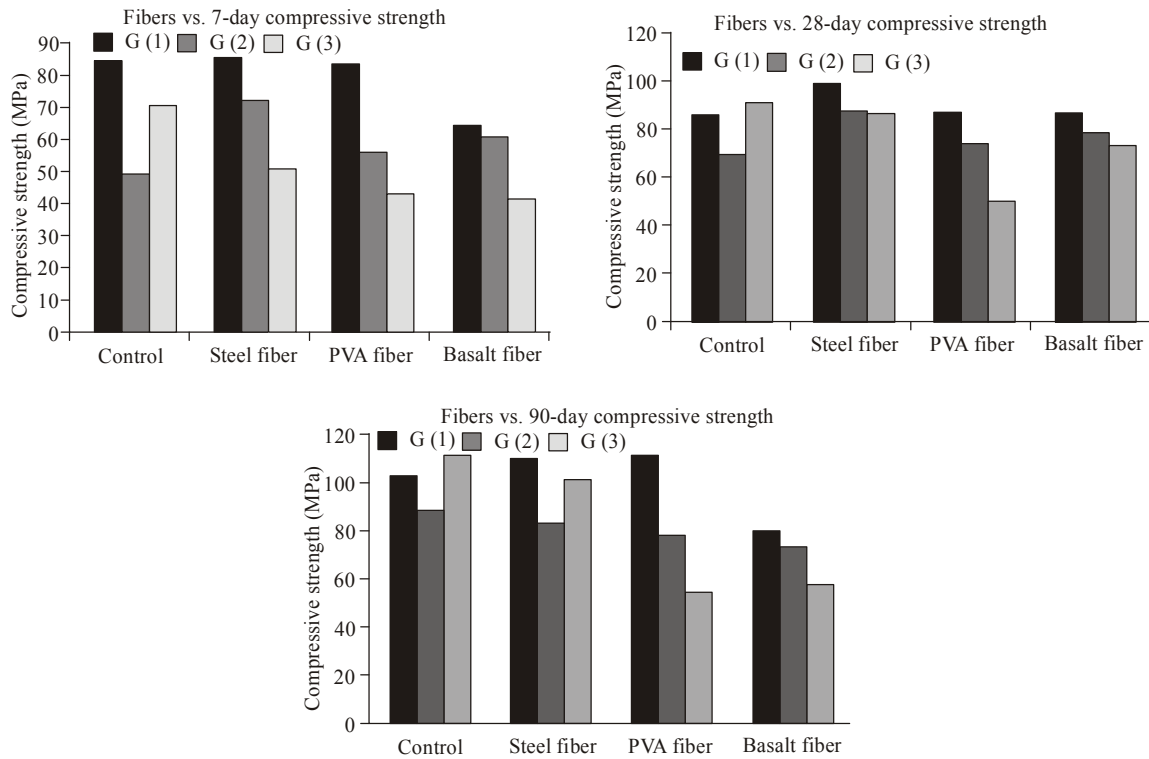


Fig. 3: Effect of fibers on the compressive strength

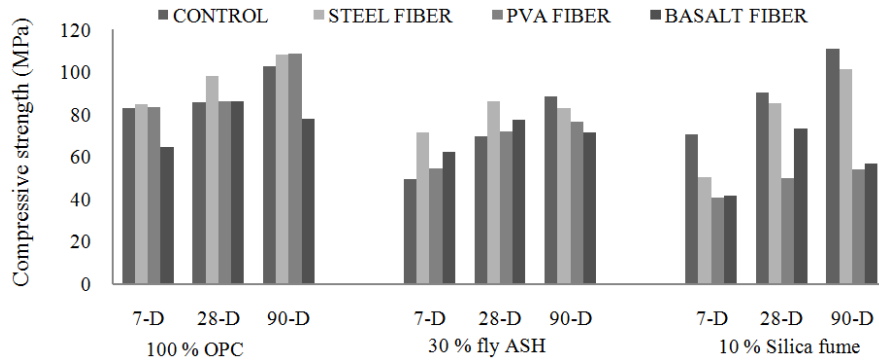


Fig. 4: Effect of binder on the compressive strength

Compressive strength: The compressive strength was conducted on 7, 28 and 90 days on the cube sample of size 100 mm³ according to the BS1881-part 116: 1983, three molds were cast for each one and the average was calculated. The cube sample was remolded after 24-h 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 Universal Testing Machine (UTM) having a capacity of 1000 KN. Figure 3 show the effect of fibers on the compressive strength of FR-SCC mixes while Fig. 4 demonstrate the effect of binder content on the compressive strength, the 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. Steel and PVA fiber can produce voids inside the paste form while the basalt fiber will absorb the mixing water and hence reduce the compressive strength. From Fig. 4 which proved the effect of binder type on the compressive strength the fly ash having weak result at the early age and high at the long term and compare with the silica fume, the result show that the fly ash is perform better than the silica fume.

Splitting tensile strength: The splitting tensile strength test was performing on the cylinder of size 100*200 mm according to the ASTM: C496M-04 after 28-day of curing in water tank. The tensile strength is among the fundamental and important qualities of the concrete, the

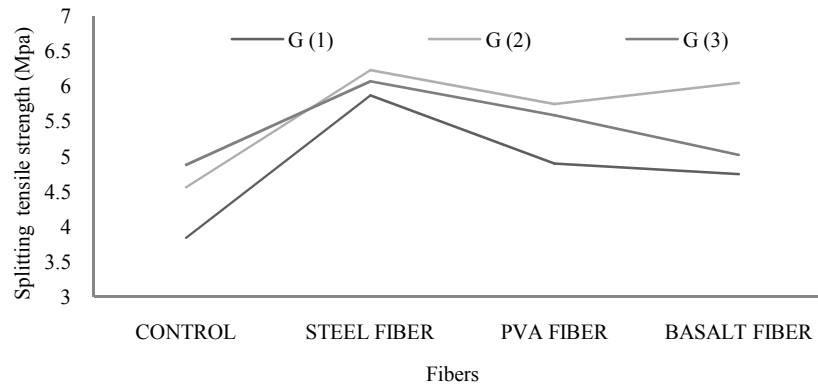


Fig. 5: Fiber vs. 28-day splitting tensile strength

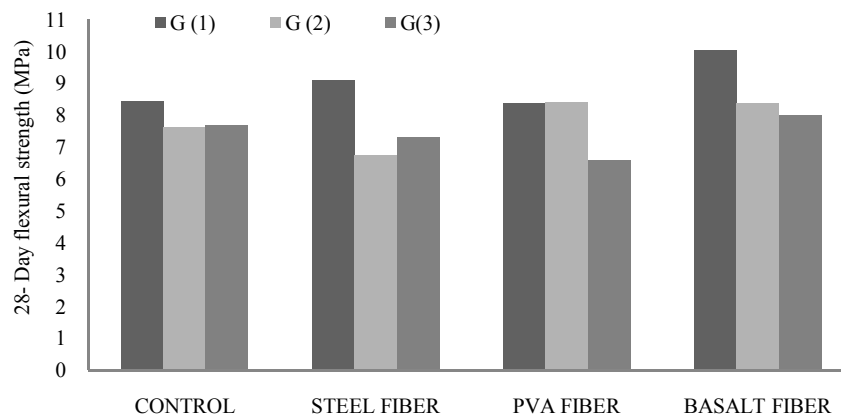


Fig. 6: Effect of fiber on the flexural strength

Groups	Code mix	Incremental (%)
One	SCC ₁	0
	SF-SCC ₁	+8.00
	PV-SCC ₁	-0.47
	BF-SCC ₁	+19.10
Two	SCC ₂	0
	SF-SCC ₂	-11.65
	PV-SCC ₂	+10.21
	BF-SCC ₂	+9.82
Three	SCC ₃	0
	SF-SCC ₃	-4.69
	PV-SCC ₃	-14.19
	BF-SCC ₃	+4.17

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 cracking is a kind of tension failure.

Figure 5 demonstrate how much the fibers effect the splitting tensile strength per each group, in group one the steel fiber increase the strength while the PVA and basalt fibers record values less than that of control. The other groups show same way of group one but their values are more. The basalt fiber in group two of 30% of fly ash shows losses in strength lower than the PVA.

The fly ash group owns highest result comparing with other groups.

Flexural strength: Figure 6 shows the result of flexural strength test which was conduct on the beam of size (100*100*500) mm³ according to the BS 1881: part 118:1983, the basalt fiber increase the result by 19.10% as the maximum value per mixes. The basalt fiber generally performs better than the steel and PVA fibers; Table 7 shows the negative and positive incremental in flexural strength results by fibers per groups.

Porosity characteristics: Porosity behavior is the a part of the durability aspects of concrete which show it is life time, one of the objectives related to this research is to investigate the effect of the fibers in the performance of the SCC-mix. By Mercury Intrusion technique (MIP) the porosity status could found per the FR-SCC mix. Table 8 and Fig. 7 demonstrated the result and shape of porosity test respectively. Porosity values increase with the increase of fibers content for all FR-SCC mixes while the silica fume and fly ash allow their fineness particles to fill the microscopic voids between the paste and aggregate comparing with the cement particles which did not show ability to fill the existing space.



Fig. 7: Mercury intrusion porosimetry machine



Fig. 8: Portable Ultrasonic Non-destructive Digital Indicating (PUNDIT)

Table 8: Porosity + UPV test result

Groups	Code mix	Porosity (%)	UPV m/sec
One	SCC ₁	4.41	5166
	SF-SCC ₁	6.64	5000
	PV-SCC ₁	4.14	4620
	BF-SCC ₁	8.72	4050
Two	SCC ₂	5.20	6800
	SF-SCC ₂	7.26	4500
	PV-SCC ₂	7.42	4958
	BF-SCC ₂	7.70	4336
Three	SCC ₃	6.77	5380
	SF-SCC ₃	7.27	4770
	PV-SCC ₃	7.85	4218
	BF-SCC ₃	7.26	3727

Ultrasonic pulse velocity: Ultrasound Pulse Velocity test (UPV) is actually a non-destructive test that is carried out by delivering high-frequency wave (over 20 kHz) through the media. By using the principal that the wave travels faster in denser media compared to the looser one, an engineer can determine the quality of concrete in the velocity from the wave this might apply to several kinds of concrete for example normal concrete, self-compacting concrete, etc.

Portable Ultrasonic Non-destructive Digital Indicating Test (PUNDIT) is utilized for this target. Two transducers, one as transmitter and the other one as

receiver are used to send and receive 55 kHz frequency as shown in Fig. 8. The velocity of the wave is measured by inserting two transducers, one on each side of FR-SCC sample. Next the thin grease layer is rubbed to the surface of transducer in order to ensure effective transfer of the wave between concrete and transducer. Table 8 and Fig. 8 show the results and figure of UPV experimental test.

The goal of the UPV test is it to investigate the effect of fibers on the relationship between the compressive strength and UPV. The test was done on PUNDIT instrument according to BS-1881: Part 203: 1986 while the methodology of the test was done by the direct method of UPV test. The small variation observed appear to become a sign from the uniformity of concrete matrix in most mixes of FR-SCC, generally the fibers let the concrete samples to be looser media than the mixes do not have fiber and that is why the velocity of FR-SCC show decreased.

In order to compare the performance and effect of fibers on UPV results, the steel fiber decreased the velocity by 3.21, 33.82 and 11.34% per groups one, two and three respectively, while the PVA fiber reduced by 10.56, 27.09 and 21.60%, respectively the lost

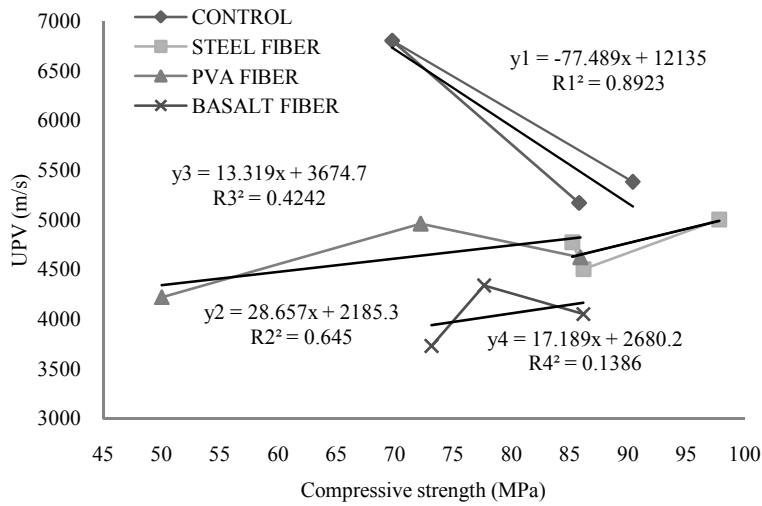


Fig. 9: UPV vs. compressive strength

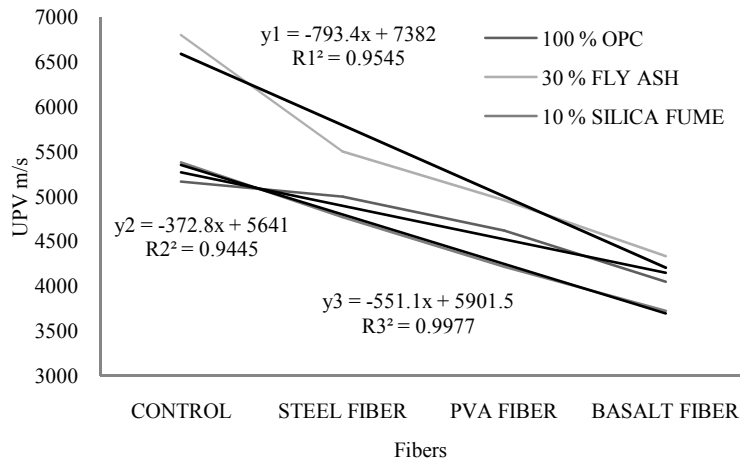


Fig. 10: UPV vs. binder

percentage of basalt fiber are 21.60, 36.24 and 30.72%, respectively. The trend of result show small variation except those mixes includes basalt fibers.

Relationship between compressive strength and UPV: Correlation of compressive strength and UPV are presented in Fig. 9, the strong relation was found for the control series based on the R-squared value (0.8923), the other series prove that the steel fiber did not affect the status of concrete media too much, the basalt series record lower value of R (0.1386) and that can be attributed to their possibility to absorb the water of mixing and then became as lumps inside the concrete, the PVA show 0.4242 for R-value and that due to its surface area.

In order to investigate and compare the effect of binder content on the UPV values, the Fig. 10 include three groups and prove that there are no different between it and that based on their R-values.

CONCLUSION

From the experimental work the conclusions can be drawn as following:

- The addition of fibers generally decreased the workability results of FR-SCC, the PVA fibers series show highest slump values both for the flow ability and discharging of 500 mm diameter than the other series. There were small variations of V-funnel time results for FR-SCC mixes while basalt fibers have maximum V-funnel time of the mixes and their values are out of the 6-12 sec of EFNARC.
- Fibers significantly decreased the compressive strength but with fly ash and silica fume at long term the FR-SCC gain the losses in strength, steel and PVA fiber can produce voids inside the paste form while the basalt fiber will absorb the mixing water and hence reduce the compressive strength.

- The splitting tensile strength behaves almost in the similar way without variation, steel fibers show lower strength losses than the other series, silica fume enhanced the splitting tensile strength in order to optimize the best binder content performance.
- Basalt fibers increase the flexural strength while the steel and PVA fibers show losses in the results per mixes.
- Porosity values increase with the increase of fibers content for all FR-SCC mixes while the silica fume and fly ash allow their fineness particles to fill the microscopic voids between the paste and aggregate comparing with the cement particles which did not show ability to fill the existing space.
- The Ultrasonic Pulse Velocity (UPV) results are verified and prove that the fibers moderate decreased the result, the correlation between the compressive strength and UPV prove that the basalt and PVA fiber series owns weak relationship than the steel fibers series.

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