Influence of Polyvinyl Alcohol Fibres on Fresh and Hardened Properties of Self-Compacting Concrete

Subhan Ahmad[1], Arshad Umar[2], Amjad Masood[2]
[1]Department of Civil Engineering, Indian Institute of Technology, Roorkee. India
[2]Department of Civil Engineering, Aligarh Muslim University, Aligarh, India
Email: subhanahmadd@gmail.com

Received 06 July 2017, received in revised form 19 July 2017, accepted 25 July 2017

Abstract: **Polyvinyl alcohol (PVA) fibres were added to study their effect on workability and mechanical properties of SCC. Mixtures of self-compacting concrete with and without PVA fibres were prepared with a water-binder ratio of 0.35. It was observed that the addition of PVA fibres reduced the workability properties and improved the mechanical properties of SCC. Addition of fibres slightly increased the compressive strength and modulus of elasticity of SCC. Splitting tensile strength and modulus of rupture of SCC was found to be significantly increased after the addition of fibres.**
Keywords: Self-compacting concrete, mechanical properties, workability properties, polyvinyl alcohol fibre.

1. INTRODUCTION

Self-compacting concrete (SCC) is a relatively new building material which is able to flow under its own weight, totally filling the formwork, however maintaining homogeneity even in the existence of congested reinforcement, and then consolidating without compaction. Time required for construction is shorter and production of SCC is without noise and vibrations. Also, SCC yields a good surface finish and gives better freedom in design. Filling ability, passing ability and segregation resistance are the important properties of SCC which are attained by increasing the amount of fines (i.e. particles <0.125 mm), reducing water-powder ratio and using a superplasticizer [1,2]. With increase in content of fines, paste volume in SCC is increased, thus resulting in high shrinkage and creep. To reduce the paste content sometimes a stabilizer (viscosity modifying admixture) is used to improve the segregation resistance of SCC [3]. Fibre-reinforced self-compacting concrete (FRSCC) is a recent composite building material that merges the advantages of the SCC technology with the benefits of the fibre addition to a brittle material (concrete). It is a ductile material that in its fresh state runs into the interior of formwork, filling it in a natural way, passing through the obstacles, and consolidating under the action of its own weight. FRSCC can diminish two opposing weaknesses: cracking resistance in plain concrete and poor workability in fibre-reinforced concrete (FRC).

Small flexural and tensile strengths of plain concrete can be enhanced by adding fibres that blocks the transmission of micro-cracks, thus delaying the onset of tension cracks and enhancing the tensile strength of the material [4]. Many researches have been done on SCC reinforced with polypropylene and steel fibres [5-12]. Some researchers have also used glass fibres in SCC [13-16]. PVA fibres are used in fibre-reinforced engineered cementitious composites [17-19]; nevertheless the data available on their use in SCC is very limited. The main purpose of present study is to investigate the influence of PVA fibres on fresh and hardened properties of SCC.

Mazaheripour et al., 2011 [6] mixed polypropylene fibres to assess their effect on fresh and mechanical properties of lightweight SCC. They found that adding polypropylene fibres in lightweight SCC reduced slump flow and filling height in U-box test and increased V-funnel time. These fibres slightly increased compressive strength and elastic modulus but had substantial effect on flexural and splitting tensile strengths of lightweight SCC. Corinaldesi and Moriconi, 2004 [9] studied the effect of steel fibres on mechanical properties of SCC in thin precast elements. Increase in flexural strength was found to lower than compressive strength. 6 months drying shrinkage was reduced from 800 μm/m to 450 μm/m. Ding et al., 2008 [11] investigated fibre cocktail reinforced self-compacting high performance concrete (SCHPC) for fresh properties. Investigations indicated that 1 kg/m3 of micro polypropylene fibres and 10 kg/m3 of micro steel fibres did not have objectionable effect on SCC workability. Sahmaran, Yurtseven and Yaman, 2005 [7] examined the effect of hooked end type and straight type steel fibres on fresh and hardened properties of SCC. SCC reinforced with hooked end type steel fibres had higher workability than the SCC reinforced with straight steel fibres. SCC mix reinforced with only hooked end type steel fibres yielded the maximum 28 and 56 days compressive strength values, but SCC reinforced with equal amounts of straight type and hooked end type steel fibres had highest splitting tensile strength value. Mastali, Dalvand and Sattarifard, 2016 [18] established that flexural and compressive strengths and resistance to impact of SCC were enhanced after the addition of recycled glass fibres.

2. MATERIALS USED

2.1 Cement

Ordinary Portland cement confirming to IS: 8112, 1989 [20] was used in the study. Chemical composition and physical properties of the cement used are given in Table 1 and 2 respectively.

2.2 Admixtures

2.2.1 Mineral admixture: Class F fly ash obtained from "Qasimpur thermal power station, Aligarh" Uttar Pradesh was used in the study.

2.2.2 Chemical admixtures: A superplasticizer (polycarboxylic ether based) complying with ASTM C 494 type F [21] with 1.10 density and pH approximately 5.0 was used. A stabiliser (VMA) meeting ASTM C 494 type S [21], specific performance admixtures requirements was also used in the study.

Table 1 Chemical properties of cement used

S.No	Chemical Composition	Value Obtained (%)
1.	Silicon dioxide (SiO_2)	19.50
2.	Aluminum oxide (Al_2O_3)	9.57
3.	Ferric oxide (Fe_2O_3)	3.36
4.	Calcium oxide (CaO)	60.00
5.	Magnesium oxide (MgO)	1.63
6.	Sulphur trioxide (SO_3)	2.53
7.	Sodium oxide (Na_2O)	0.82
8.	Potassium oxide (K_2O)	1.21
9.	Loss on ignition	1.23

Table 2 Physical properties of cement used

S.No	Test	Values obtained	Requirement of IS: 8112-1989
1.	Normal consistency (%)	28	–
2.	Initial setting time (min)	55	30 (minimum)
3.	Final setting time (min)	175	600 (maximum)
4.	Compressive strength (MPa) 3 days 7 days 28 days	24.1 33.9 44.8	23 33 43
5.	Soundness (mm)	2.5	10 (maximum)
6.	Fineness (retained on 90µm sieve)	8	10 mm
7.	Specific gravity	3.15	–

2.3 Aggregates: Sand passing from 4.75 mm sieve and confirming to Indian Standard Specification IS: 383, 1970 [22] was used. Coarse aggregate of 12.5 mm maximum size was used. The results of physical properties of fine and coarse aggregates are given in Table 3.

Table 3 Physical properties of aggregates

S.No	Characteristic	Fine Aggregate	Coarse Aggregate
1.	Specific Gravity	2.46	2.66
2.	Fineness Modulus	2.65	6.88
3.	Water Absorption	0.85%	0.3%
4.	Loose Bulk Density (kg/m3)	1580	1470
5.	Compacted Bulk Density (kg/m3)	1760	1660

2.4 Polyvinyl Alcohol Fibres: The PVA fibres used in the study were 12 mm long with specific gravity 1.3 and tensile strength 1500 Mpa.

3. MIX PROPORTIONS:

Self-compacting concrete has roughly same amount of fine and coarse aggregates [23] therefore, fine and coarse aggregate content were fixed to 725 kg/m^3 and 775 kg/m^3 respectively. Self-compactibility was achieved at a water-binder ratio of 0.35 and a superplasticizer dose of 0.8%. Small amount (0.3%) of VMA was also added to avoid segregation of the mix. Details of the mix proportion for SCC and SCC-P are given in Table 4.

Table 4 Mix proportion of different mixes

Material	SCC	SCC-P
Cement (kg/m$_3$)	530	530
Fly ash (kg/m$_3$)	70	70
Fine aggregate	725	725
Coarse aggregate (kg/m$_3$)	775	775
Water (kg/m$_3$)	210	210
Super-plasticizer (%)	0.8	0.8
VMA (%)	0.3	0.3
PVA fibres (kg/m$_3$)	0	2

4. PREPARATION AND CASTING OF TEST SPECIMENS:

5.1 Fresh Properties of SCC: To evaluate the workability of SCC following tests were performed.

a) Slump flow test with T_{500} time as per BS EN 12350-Part 8:2010 [24].

b) L-box test as per BS EN 12350-Part10: 2010 [25].
c) V-funnel flow tests; T0 and T5 as per BS EN 12350-Part 9: 2010 [26, 27].

5.1.1 Slump Flow Test with T500 Time: Slump flow test was performed according to BS EN 12350-Part 8:2010 [28]. This test is done to evaluate the flowability of SCC in the absence of obstacles. Flowability of SCC is evaluated by measuring the horizontal flow diameter in two perpendicular directions and taking average of the two. Viscosity of fresh concrete is also assessed using this test by determining the time needed by SCC to fill a circle of 500 mm diameter (T500).

5.1.2 L-box Test: L-box test was carried out according to BS EN 12350-Part10: 2010 [29]. L-box is used to evaluate passing ability of fresh SCC by calculating the ratio, H2/H1. Vertical column of the L-box is completely filled with fresh SCC and gate is raised to allow the SCC to flow into the horizontal section of L-box. Height of fresh concrete at the start (H1) and end (H2) of the horizontal section is measured. Passing ability of SCC is found to be satisfactory if the ratio, H2/H1 is between 0.8 and 1.0.

5.1.3 V-funnel Test: V-funnel test was done according to BS EN 12350-Part 9: 2010 [30]. This test is performed to evaluate the fluidity and segregation resistance of SCC. V-funnel is completely filled with SCC and the shutter located at the bottom of the funnel is opened. Time taken to empty the V-funnel is T0. Time taken to empty the funnel when shutter at the bottom of V-funnel is opened after 5 minutes is referred to as T5.

5.2 Hardened Properties of SCC: Compressive strength, flexural strength and modulus of elasticity tests were done as per IS: 516, 1959 [27] while IS: 5816, 1999 [28] was used for splitting tensile strength.

6. RESULTS AND DISCUSSIONS

6.1. Fresh Properties: The workability (fresh) properties of SCC mixtures are given in Table 5. All the properties are within the limits recommended by EFNARC, 2005 [23].

Table 4 Mix proportion of different mixes

Mix	Slump flow (mm	T_{500} (s)	L-box ratio H_2/H_1	V-funnel time (s)	
				T_0	T_5
SCC	720	3	0.91	7.5	9.8
SCC-P	700	3.5	0.90	8	11
Acceptance criteria (EFNARC, 2005)	600-800	2-5	0.8-1.0	6-12	+3

6.1.1 Slump Flow and T500 Flow Time: SCC has a slump flow of 720 mm but slump flow was decreased by 20 mm when PVA fibres were added in SCC. T500 flow time was found to be 3 s for SCC and 3.5 s for SCC-P.

6.1.2 L-box Ratio: Blocking ratio was found to be 0.91 for SCC. Addition of PVA fibres reduced the blocking ratio by 0.01.
6.1.3 V-funnel Time: Increase in V-funnel time after the addition of PVA fibres in SCC was found to be 0.5 s. Difference between T0 and T5 for both the mixes were within the limit prescribed by EFNARC, 2005 [23] i.e. 3 s.

6.2 Hardened properties: Results of the properties of hardened concretes are given in Table 6. Relationships of splitting tensile strength and modulus of elasticity with compressive strength are also given in Table 6 (a) and 6 (b).

Table 6 (a) Compressive strength and modulus of elasticity of different mixes

Mix	Compressive strength (MPa)			Modulus of elasticity (Mpa) E	
	3 days	7 days	28 days	Value	Relationship
SCC	26.33	33.66	44.44	24050	$3913\sqrt{f_c'}$
SCC-P	28.26	35.64	46.88	24750	$3920\sqrt{f_c'}$

Table 6 (b) Splitting tensile and flexural strengths of different mixes

Mix	Splitting tensile strength (MPa) f_x		Flexural strength (MPa)
	Value	Relationship	
SCC	4.30	$0.72\sqrt{f_c'}$	4.60
SCC-P	4.75	$0.77\sqrt{f_c'}$	4.90

6.2.1 Compressive Strength: Compressive strength of SCC was found to be increased by 7.33%, 5.9% and 5.5% after 3, 7 and 28 days respectively when PVA fibres were added. Aslani and Nejadi, 2013 [8]; Babu et al., 2008 [14]; and Prasad, Kumar and Oshima, 2009 [16] also reported a slight increase in compressive strength of SCC after the addition of fibres.

6.2.2 Splitting Tensile Strength: Splitting tensile strength of SCC after the addition of PVA fibres was increased by 10.5%. Mazaheripour et al., 2011 [6]; Aslani and Nejadi, 2013 [8] and Prasad, Kumar and Oshima, 2009 [16] also found that addition of fibres increased the splitting tensile strength of SCC. The relationship between the splitting tensile strength (fct) and cylindrical compressive strength (fc') obtained experimentally for SCC mixtures are compared with the relationships obtained by other researchers, ACI-318, 2008 [30] and AASHTO, 2006 [31] in Fig. 1. Ratios of splitting tensile strength and cylindrical compressive strength (fct /√ fc') for SCC with PVA fibres are in good agreement with the tensile strength models given for SCC by Prasad, Kumar and Oshima, 2009 [16] and Dinakar, Babu and Santhanam, 2008[29].

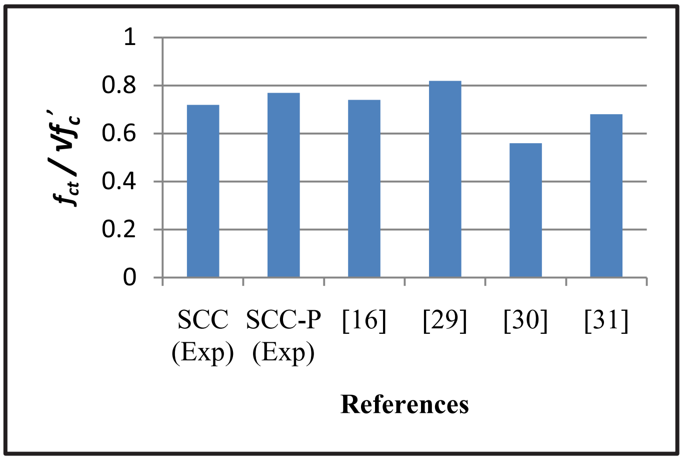

Fig.1 fct/$\sqrt{f_c'}$ ratios obtained experimentally, other researchers and committees

6.2.3 Flexural strength: Addition of PVA fibres in SCC increased flexural strength by 6.55%. Increase in modulus of rupture after the addition of fibres is also observed by other researchers [13-16].

6.2.4 Modulus of Elasticity: When polyvinyl alcohol fibres were added in SCC a small increase of 2.8% in modulus of elasticity was found. Increase in modulus of elasticity after the addition of fibres in SCC is also observed by Aslani and Nejadi, 2013 [8]; Sherif et al., 2016 [10] and Prasad, Kumar and Oshima, 2009 [16]. Modulus of elasticity of concrete is related to its compressive strength [30, 32]; therefore its increase is attributed to the increased compressive strength. E /$\sqrt{f_c'}$ ratios calculated using experimental data, given by other researchers [29, 33] and ACI-318, 2008 [30] is shown in Fig.2. Experimental results are in good agreement with Dinakar, Babu and Santhanam, 2008[29]; Persson, 2001 [33] but have a smaller value than given in ACI-318, 2008 [30].

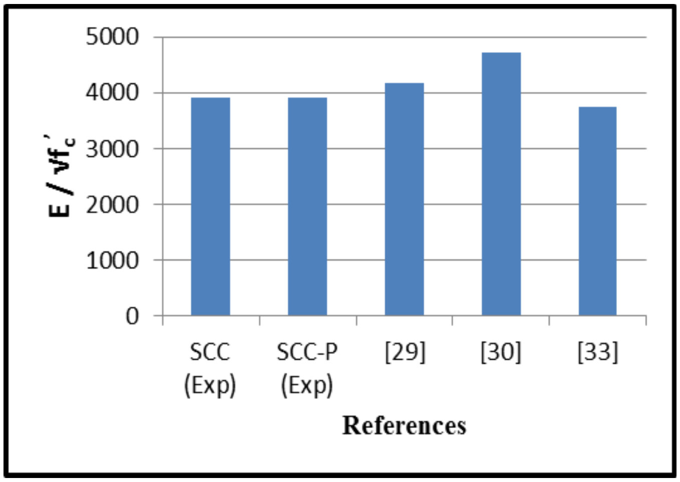

Fig.2 E /$\sqrt{f_c'}$ ratio of different researchers and ACI-318

7. CONCLUSIONS:

Following conclusions can be drawn on the basis of experimental study presented in this paper.

a) Workability properties of SCC were reduced by the addition of PVA fibres due to their close contact with the cement paste.

b) Use of PVA fibres slightly increased the compressive strength of SCC. Addition of PVA fibres has no effect on the rate of gain of compressive strength of SCC.

c) Modulus of rupture and splitting tensile strength of SCC increased significantly after the addition of PVA fibres.

d) Addition of PVA fibres had no significant effect on modulus of elasticity of SCC.

REFERENCES

[1] Okamura, Hajime, and Masahiro Ouchi. 2003, "Self-compacting concrete." Journal of advanced concrete technology 1, no. 1: pp.5-15.

[2] Iqbal, Shahid, et al. "Mechanical properties of steel fibre reinforced high strength lightweight self-compacting concrete (SHLSCC)." Construction and Building Materials 98 (2015): 325-333.

[3] Ahmad, Subhan, and Arshad Umar. "Characterization of Self-Compacting Concrete." Procedia Engineering 173 (2017): 814-821.

[4] Mehta, P. K., and P. J. M. Monteiro. 2006, "Microstructure and properties of hardened concrete." Concrete: Microstructure, properties and materials: pp.41-80.

[5] Madandoust, R., M. M. Ranjbar, and A. A. Moshiri. 2014, "The Effects of Steel and Pet Fibers on the Properties of Fresh and Hardened Self-Compacting Concrete." Asian Journal of Civil Engineering (BHRC) 15.5: pp.671-682.

[6] Mazaheripour, H., et al. 2011, "The effect of polypropylene fibres on the properties of fresh and hardened lightweight self-compacting concrete." Construction and Building Materials 25.1: pp.351-358.

[7] Sahmaran, Mustafa, Alperen Yurtseven, and I. Ozgur Yaman. 2005, "Workability of hybrid fibre reinforced self-compacting concrete." Building and Environment 40.12: pp.1672-1677.

[8] Aslani, Farhad, and Shami Nejadi. 2013, "Self-compacting concrete incorporating steel and polypropylene fibers: Compressive and tensile strengths, moduli of elasticity and rupture, compressive stress–strain curve, and energy dissipated under compression." Composites Part B: Engineering 53: pp.121-133.

[9] Corinaldesi, V., and G. Moriconi. 2004, "Durable fibre reinforced self-compacting concrete." Cement and concrete research 34.2: pp.249-254.

[10] Yehia, Sherif, et al. 2016, "Mechanical and durability evaluation of fiber-reinforced self-compacting concrete." Construction and Building Materials 121: pp.120-133.

[11] Ding, Yi-ning, et al. 2008, "The investigation on the workability of fibre cocktail reinforced self-compacting high performance concrete." Construction and Building Materials 22.7: pp.1462-1470.

[12] Aslani, F., and B. Samali. 2014, "Flexural toughness characteristics of self-compacting concrete incorporating steel and polypropylene fibres." Australian Journal of Structural Engineering 15.3: pp. 269-286.

[13] Ahmad, Subhan, Arshad Umar, and Amjad Masood. "Properties of Normal Concrete, Self-compacting Concrete and Glass Fibre-reinforced Self-compacting Concrete: An Experimental Study." Procedia Engineering 173 (2017): 807-813.

[14] Babu, T. Suresh, MV Seshagiri Rao, and D. Rama Seshu. 2008, "Mechanical properties and stress-strain behavior of self-compacting concrete with and without glass fibres." Asian journal of civil Engineering (Building and Housing) 9.5: pp.457-472.

[15] Mastali, M., A. Dalvand, and A. R. Sattarifard. 2016, "The impact resistance and mechanical properties of reinforced self-compacting

concrete with recycled glass fibre reinforced polymers." Journal of Cleaner Production 124: pp.312-324.

[16] Prasad, M. L. V., P. Rathish Kumar, and Toshiyuki Oshima. 2009, "Development of analytical stress–strain model for glass fibre reinforced self-compacting concrete." Int J Mech Solids 4.1: pp.25-37.

[17] Toutanji, H., et al. 2010, "Properties of poly (vinyl alcohol) fibre reinforced high-performance organic aggregate cementitious material: converting brittle to plastic." Construction and Building Materials 24.1: pp.1-10.

[18] Xu, Bo, Houssam A. Toutanji, and John Gilbert. 2010, "Impact resistance of poly (vinyl alcohol) fiber reinforced high-performance organic aggregate cementitious material." Cement and Concrete Research 40.2: pp.347-351.

[19] Noushini, A., K. Vessalas, and B. Samali. 2014, "Rheological properties and compressive strength behaviour of polyvinyl alcohol fibre-reinforced concrete." Australian Journal of Structural Engineering 15.1: pp.77-88.

[20] IS: 8112-1989. Specifications for 43-Grade Portland cement. New Delhi, India: Bureau of Indian Standards.

[21] Admixture, Water-Reducing. "ASTM C 494/C 494M." Type B 3.

[22] IS: 383-1970. Specifications for coarse and fine aggregates from natural sources for concrete.New Delhi, India: Bureau of Indian standards

[23] EFNARC. 2005, Specification and guidelines for self-compacting concrete.

[24] BS EN 12350-8:2010. Testing fresh self-compacting concrete. Slump flow test

[25] BS EN 12350-10: 2010. Testing fresh self-compacting concrete. L-box test

[26] BS EN 12350-9:2010. Testing fresh self-compacting concrete. V-funnel test.

[27] IS: 516-1959. Indian standard code of practice- Methods of test for strength of concrete. New Delhi, India: Bureau of Indian Standards.

[28] IS 5816: 1999. Indian Standard code of practice-Method of test for splitting tensile strength of concrete. New Delhi, India: Bureau of Indian Standards.

[29] Dinakar P, Babu KG, Santhanam M. 2008, “Mechanical properties of high-volume fly ash self-compacting concrete mixtures”. Struct Concr;9(2): pp.109–16.

[30] ACI Committee. 2008, "American Concrete Institute, and International Organization for Standardization." Building code requirements for structural concrete (ACI 318-08) and commentary. American Concrete Institute.

[31] Kim, Young Hoon. 2008, "Characterization of self-consolidating concrete for the design of precast, pretensioned bridge superstructure elements." PhD diss., Texas A&M University.

[32] CEB – FIP – 90. Model code for prediction of elastic modulus.

[33] Persson, Bertil. 2001, "A comparison between mechanical properties of self-compacting concrete and the corresponding properties of normal concrete." Cement and concrete Research 31.2: pp.193-198.

◆ ◆ ◆