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

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ABSTRACT

Glass and polyvinyl alcohol (PVA) fibres were added to study their effect on workability and mechanical properties of self-compacting concrete (SCC). Four mixes; SCC, SCC with glass fibres (SCC-G), SCC with PVA fibres (SCC-P) and SCC with glass and PVA fibres (SCC-GP) were prepared with a water-binder ratio of 0.35. It was observed that the addition of glass and 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 were found to be significantly increased after the addition of fibres. Glass fibres were found to be more effective in increasing the mechanical properties of SCC.

KEYWORDS: Self-compacting concrete, Mechanical properties, Workability properties, Glass fibre, Polyvinyl alcohol fibre.

INTRODUCTION

Self-compacting concrete does not need external vibration for its compaction, resulting in better durability, reduced time required for placing, improved aesthetics and being friendly to the environment (Okamura and Ouchi, 2003). The increased flowability of SCC may cause segregation and bleeding during its transportation and placement, which can be overcome by using viscosity modifying admixtures (VMAs) (Umar and Tamimi, 2011; Ahmad and Umar, 2017; Dhinaveshvaram et al., 2013).

Extensive research has been conducted on SCC reinforced with steel and polypropylene fibres (Mazaheripour et al., 2011; Gencel et al., 2011; Sahmaran et al., 2005; Aslani and Nejadi, 2013; Corinaldesi and Moriconi, 2005; Yehia et al., 2016; Ding et al., 2008; Aslani and Samali, 2014). Some researchers have also used glass fibres in SCC (Ahmad et al., 2017; Babu et al., 2008; Mastali et al., 2016; Prasad et al., 2009). PVA fibres are used in fibre-reinforced engineered cementitious composites (Xu et al., 2010; Noushini et al., 2014), but the data available on their use in SCC is very limited.

Mazaheripour et al. (2011) added polypropylene fibres to study their effect on workability and mechanical properties of lightweight SCC. Adding polypropylene fibres to lightweight SCC increased V-funnel time and reduced slump flow and filling height in U-box test. Polypropylene fibres marginally increased compressive strength and elastic modulus, but had significant effect on flexural and splitting tensile strengths of lightweight SCC. Corinaldesi and Moriconi (2004) investigated the mechanical properties of SCC with steel fibres in thin precast elements. Increase in

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compressive strength was found to be higher than in flexural strength. Drying shrinkage after 6 months was found to be reduced from 800 µm/m to 450 µm/m. Ding et al. (2008) studied the fresh properties of fibre cocktail-reinforced self-compacting high-performance concrete (SCHPC). Investigation showed that 10 kg/m^3 of micro-steel fibres and 1 kg/m^3 of micro-polypropylene fibres did not have negative effect on the workability of SCC mixture. Sahmaran et al. (2005) investigated the effect of straight type and hooked end type steel fibres on workability and hardened properties of SCC. SCC reinforced with straight type steel fibres had lower workability than SCC reinforced with hooked end type fibres. SCC mix with only hooked end type steel fibres had maximum 28- and 56-day compressive strength values, but SCC containing equal amounts of straight type and hooked end type steel fibres yielded highest splitting tensile strength value. Mastali et al. (2016) concluded that compressive and flexural strengths and impact resistance of SCC were improved after the addition of recycled glass fibres.

MATERIALS AND METHODS

Cement

Ordinary Portland cement of Grade 43 confirming to IS: 8112, 1989 was used in this study. Physical properties and chemical composition of OPC-43 used are given in Table 1 and Table 2, respectively.

Table 1. Physical properties of cement

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	-

Table 2. Chemical composition of OPC-43 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

Admixtures

Mineral Admixture

Class F fly ash was used in the study which was obtained from "Qasimpur thermal power station, Aligarh", Uttar Pradesh. Physical and chemical properties of fly ash are given in Table 3 and Table 4, respectively.

Table 3. Physical properties of fly ash

Constituents	Percent by weight
Colour	Grey (blackish)
Specific gravity	2.14

Table 4. Chemical properties of fly ash

Constituents	Percent by weight
Loss on ignition	4.15
Silica (SiO_2)	58.57
Iron oxide (Fe_2O_3)	3.46
Alumina (Al_2O_3)	28.18
Calcium oxide (CaO)	2.22
Magnesium oxide (MgO)	0.33
Total sulphur (SO_2)	0.07
Insoluble residue	-
Alkalies (a) Sodium oxide (Na_2O) (b) Potassium oxide (K_2O)	 0.58 1.26

Chemical Admixtures

A polycarboxylic ether-based super-plasticizer complying with ASTM C 494 type F with a density of 1.10 and pH of approximately 5.0 was used in the study. A viscosity modifying admixture meeting ASTM C 494 type S specific performance admixture requirements was also used in the study.

Aggregates

Sand confirming to Indian Standard Specification IS: 383, 1970 and passing from 4.75 mm sieve was used in the study. The maximum size of coarse aggregate used in the study was 12.5 mm. The results of physical properties of fine and coarse aggregates are given in Table 5.

Table 5. 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/m^3)	1580	1470
5.	Compacted bulk density (kg/m^3)	1760	1660

Fibres

Glass Fibres

Alkali resistant glass fibres (Cem-FIL AR) were used in the experimental work, since ordinary glass fibre cannot be used in Portland cement concretes because of chemical attack by the alkaline cement paste (Mehta, 2006). The properties of glass fibres used in the experimental work are given in Table 6. Standard specifications for Alkali Resistant (AR) glass fibre for fibre-reinforced concrete and cement are given in ASTM C1666/C1666M.

Table 6. Properties of glass fibres

S. No.	Property	Value	ASTM C1666/C1666M – 08 specification
1.	Specific gravity	2.68	2.68 ± 0.3
2.	Modulus of elasticity (GPa)	72	_
3.	Tensile strength (MPa)	1600	1000-1700
4.	Diameter (micron)	14	8–30
5.	Zirconia content (%)	38	16 (min)
6.	Length (mm)	12	_

Polyvinyl Alcohol Fibres

PVA fibres are suitable for a variety of applications, because they are superior in crack arresting, have high elastic modulus, excellent tensile and molecular bond strength and are highly resistant to alkali, fatigue and abrasion (Noushini et al., 2014). The properties of PVA fibres are given in Table 7.

Table 7. Properties of PVA fibres

Specific gravity	1.3
Tensile strength (MPa)	1500
Modulus of elasticity (GPa)	41.7
Length (mm)	12

Casting and Curing

Numerous trial mixes were prepared by altering the water-binder ratio and dosage of super-plasticizer. Since self-compacting concrete has nearly equal amounts of fine and coarse aggregates, fine and coarse aggregate contents were fixed to 725 kg/m^3 and 775 kg/m^3, respectively. Self-compactibility was attained at a water-binder ratio of 0.35 and a super-plasticizer dosage of 0.8%. 0.3% of viscosity modifying admixture was also added to avoid segregation of the mix. The mixing proportions finally decided through numerous trial mixes are given in Table 8. 2 kg/m^3 of glass and PVA fibres were added to SCC. Four mixes; self-compacting concrete without fibres (SCC), SCC with glass fibres (SCC-G), SCC with PVA fibres (SCC-P) and SCC with glass and PVA fibres (SCC-GP) were prepared.

Mixing was carried out in a mixer with tilting drum and two rotating blades. Casting, curing and storage of concrete specimens were carried out as per Indian Standards, except that there was no compaction during casting.

EXPERIMENTAL PROGRAM

Fresh Properties of SCC

To assess the workability properties of SCC, the following tests were performed, which are shown in Fig.1.

1. Slump flow test with T_{500} time.
2. L-box test.
3. V-funnel flow tests; T_0 and T_5.

Slump Flow Test with T_{500} Time

Slump flow test was conducted as per BS EN 12350-Part 8:2010. This test is used to assess the flowability of SCC in the absence of obstacles. Flowability of SCC is assessed by measuring the horizontal flow diameter in two perpendicular directions and taking the average of the two. Viscosity of the mix is also evaluated using this test by determining the time needed for SCC to reach 500 mm flow (T_{500}).

Table 8. Mix proportions of different mixes

Material	Mix			
	SCC	SCC-G	SCC-P	SCC-GP
Cement (kg/m^3)	530	530	530	530
Fly ash (kg/m^3)	70	70	70	70
Fine aggregate (kg/m^3)	725	725	725	725
Coarse aggregate (kg/m^3)	775	775	775	775
Water (kg/m^3)	210	210	210	210
Super-plasticizer (%)	0.8	0.8	0.8	0.8
VMA (%)	0.3	0.3	0.3	0.3
Glass fibres (kg/m^3)	0	2	0	2
PVA fibres (kg/m^3)	0	0	2	2
Room temperature	31	30	29	29
Concrete temperature	27.5	27.5	29	29

(a) Slump flow test

(b) L-box test

(c) V-funnel test

Figure (1): Tests conducted on fresh SCC

L-box Test

L-box test was conducted as per BS EN 12350-Part10: 2010. This test is used to assess passing ability of SCC by calculating the blocking ratio (H_2/H_1). Vertical column of the L-box is filled with SCC and the gate is lifted to allow SCC to flow into the horizontal part of the L-box. Height of concrete at the beginning (H_1) and end (H_2) of the horizontal section is measured. Passing ability of SCC is satisfactory if the blocking ratio (H_2/H_1) is between 0.8 and 1.0.

V-funnel Test

V-funnel test was performed as per BS EN 12350-Part 9: 2010. This test is performed to measure the fluidity and segregation resistance of SCC. V-funnel is filled completely with SCC and the shutter at the bottom of the funnel is opened. Time taken to empty the V-funnel is T_0. Time taken to empty the funnel when the shutter at the bottom of the V-funnel is opened after 5 minutes is referred to as T_5.

Hardened Concrete Properties

Compressive strength, modulus of rupture and modulus of elasticity tests were performed in accordance to IS: 516, 1959; whereas IS: 5816, 1999 was used for splitting tensile strength.

RESULTS AND DISCUSSION

Fresh Properties

The results of workability properties of SCC mixtures are given in Table 9. All the properties are within the limits recommended by EFNARC, 2005.

Slump Flow and T_{500} Flow Time

SCC has an excellent slump flow of 720 mm, but slump flow was decreased when the fibres were added to SCC. Glass and PVA fibres reduced slump spread by 20 mm and T_{500} flow time was found to be minimum for SCC (3 s) and maximum for SCC-GP (4.5 s). Addition of glass and PVA fibres increased T_{500} time by 1 s and 0.5 s, respectively. Slump flow and T_{500} flow time for different mixes are shown in Fig. 2.

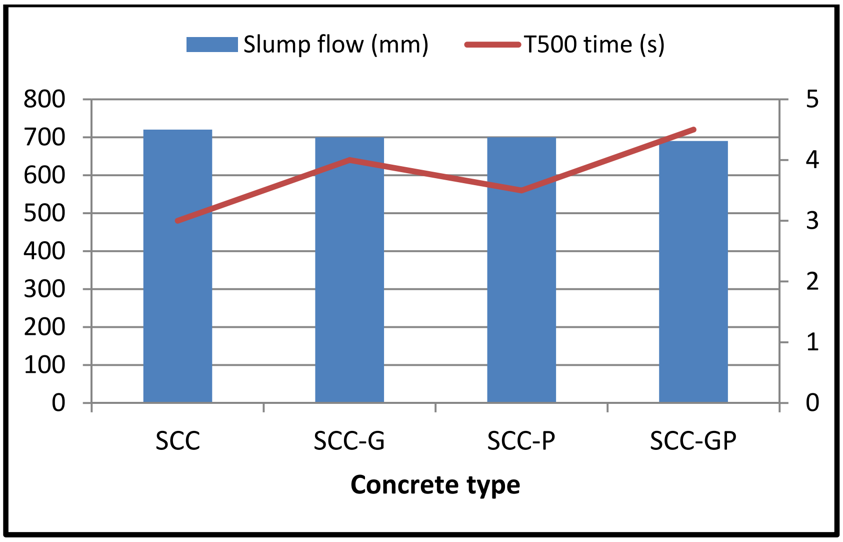

Figure (2): Slump flow and T_{500} time of SCC mixtures

L-box Ratio

Blocking ratio was found to be maximum for SCC (0.91) and minimum for SCC-GP (0.87). Addition of glass and PVA fibres reduced the blocking ratio by 0.03 and 0.01, respectively.

V-funnel Time

V-funnel time increased slightly as the fibres were added to SCC. Increase in V-funnel time for glass and PVA fibres was 0.5 s. V-funnel time increased by 1 s when both fibres were added to SCC. Differences between T_0 and T_5 for all the mixes were within the limit prescribed by EFNARC, 2005; i.e., 3 sec.

Table 9. Fresh properties of different mixes of SCC

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-G	700	4.0	0.88	8	10
SCC-P	700	3.5	0.90	8	11
SCC-GP	690	4.5	0.87	8.5	11
Acceptance criteria (EFNARC, 2005)	600-800	2-5	0.8-1.0	6-12	+3

Hardened Properties

Results of hardened properties of CC and SCC mixtures are given in Table 10. Relationships between splitting tensile strength and compressive strength ($f_{ct} = K_1\sqrt{f_c'}$) and modulus of elasticity and compressive strength ($E = K_2\sqrt{f_c'}$) are also given in Table 10. Tests performed for evaluating hardened properties of concrete specimens are shown in Fig. 3.

(a) Compressive strength test

(b) Splitting tensile strength test

(c) Flexural strength test

(d) Modulus of elasticity test

Figure (3): Tests on hardened concrete

Table 10. Hardened properties of different mixes

Mix	Compressive strength (MPa)			Splitting tensile strength (MPa) f_{ct}		Flexural strength (MPa)	Modulus of elasticity (MPa) E	
	3 d	7 d	28 d	Value	Relationship		Value	Relationship
SCC	26.33 (0.3)	33.66 (0.2)	44.44 (0.3)	4.30 (0.2)	$0.72\sqrt{f_c'}$	4.60 (0.1)	24050 (65)	$3913\sqrt{f_c'}$
SCC-G	29.35 (0.4)	37.30 (0.5)	48.93 (0.3)	5.20 (0.4)	$0.83\sqrt{f_c'}$	5.30 (0.2)	25300 (40)	$3925\sqrt{f_c'}$
SCC-P	28.26 (0.3)	35.64 (0.6)	46.88 (0.7)	4.75 (0.3)	$0.77\sqrt{f_c'}$	4.90 (0.1)	24750 (30)	$3920\sqrt{f_c'}$
SCC-GP	31.25 (0.4)	38.67 (0.5)	50.88 (0.7)	5.60 (0.4)	$0.85\sqrt{f_c'}$	5.85 (0.1)	25950 (50)	$3945\sqrt{f_c'}$

* Numbers in parentheses represent the standard deviation.

Compressive Strength

When glass fibres were added to SCC, compressive strength was increased by 11.47%, 10.82% and 10.1% after 3, 7 and 28 days, respectively. Compressive strength of SCC was increased by 7.33%, 5.9% and 5.5% after 3, 7 and 28 days, respectively when PVA fibres were added. Also, 3-, 7- and 28-day compressive strengths increased by 18%, 14.9% and 14.5%, respectively when both fibres were added to SCC. As micro- cracks develop in the matrix, the fibre in the vicinity of such micro- cracks tries to arrest these cracks and prevent further propagation. Prasad et al. (2009), Aslani and Nejadi (2013) and Babu et al. (2008) also reported an increase in compressive strength of SCC after the addition of fibres. The results of compressive strength are shown in Fig. 4.

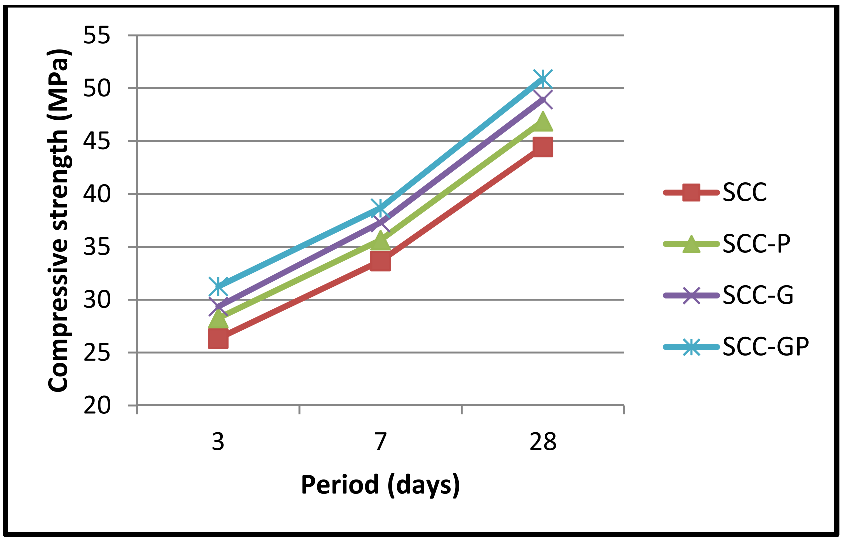

Figure (4): Compressive strength of different mixes

Splitting Tensile Strength

Splitting tensile strength of SCC after the addition of glass and PVA fibres was increased by 20.9% and 10.5%, respectively. When both fibres were added to

SCC, splitting tensile strength was found to be increased by 30%. Prasad et al. (2009), Aslani and Nejadi (2013), Babu et al. (2008) and Mazaheripour et al. (2011) also found an increase in splitting tensile strength of SCC after the addition of fibres. Tensile strength of concrete is improved by introducing fibres because of the obstruction of propagation of micro-cracks. The relationship between splitting tensile strength (f_{ct}) and cylindrical compressive strength (f_c') for SCC mixtures is compared with the results obtained by other researchers (ACI-318, 2008; AASHTO, 2006) in Fig. 5. Ratios of splitting tensile strength and cylindrical compressive strength ($f_{ct}/\sqrt{f_c'}$) for fibre-reinforced SCC are in good agreement with the tensile strength models given for SCC by Prasad et al. (2009), Dinakar et al. (2008) and Kim (2008).

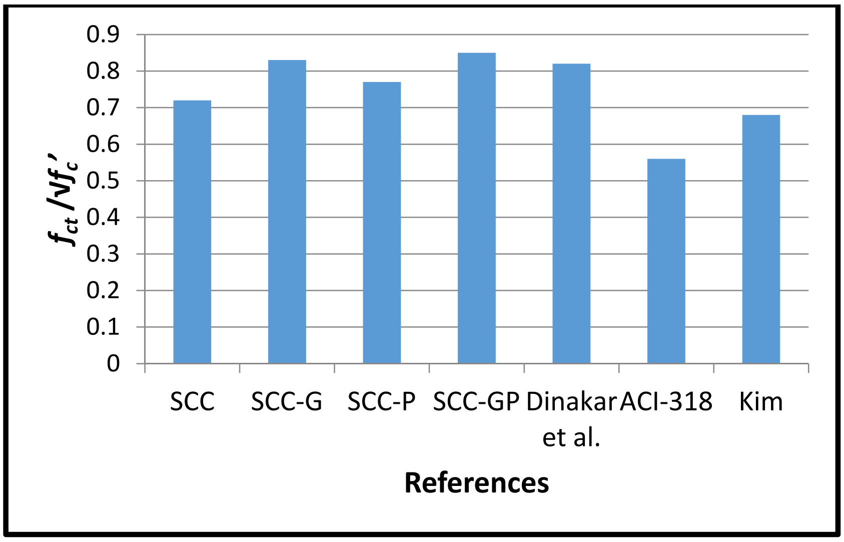

Figure (5): $f_{ct}/\sqrt{f_c'}$ **ratios obtained experimentally by other researchers and committees**

Modulus of Rupture

Addition of glass and PVA fibres to SCC increased modulus of rupture by 15.22% and 6.55%, respectively. Modulus of rupture of SCC was found to be increased by 27.2% when both fibres were added to SCC. The tested prisms for SCC failed suddenly and split into two separate parts, while the prisms of SCC with fibres were cracked at failure without separation. Increase in modulus of rupture after the addition of fibres is also observed by other researchers (Ahmad et al., 2017; Babu et al., 2008; Mastali et al., 2016; Prasad et al., 2009).

Modulus of Elasticity

When glass and polyvinyl alcohol fibres were added to SCC, the increase of modulus of elasticity is found to be 5.2%, and 2.8%, respectively. Modulus of elasticity was increased by 8% when both fibres were added to SCC. Increase in modulus of elasticity after the addition of fibres to SCC was also observed by Prasad et al. (2009), Aslani and Nejadi (2013) and Yehia et al. (2016). Modulus of elasticity of concrete is related to its compressive strength (ACI, 2008; CEB-FIP, 1990); therefore, increase in modulus of elasticity may be attributed to the increased compressive strength. $E/\sqrt{f_c'}$ ratios calculated using experimental data, given by other researchers (Dinakar et al., 2008; Persson, 2001) and ACI-318 (2008) are shown in Fig. 6. Experimental results are in good agreement with Dinakar et al. (2008) and Persson (2001), but have a smaller value than given in ACI-318 (2008).

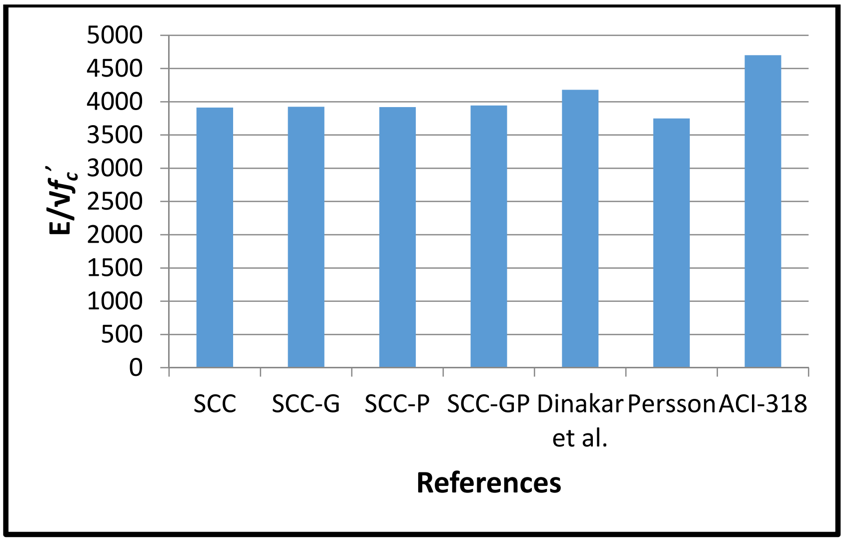

Figure (6): E / $\sqrt{f_c'}$ ratio of different researchers and ACI-318

CONCLUSIONS

On the basis of experimental study presented in this paper, following conclusions can be drawn:

1. Workability properties of SCC were reduced by the addition of fibres due to their intimate contact with the cement paste.
2. Use of glass and PVA fibres slightly increased compressive strength of SCC. Increase in compressive strength was found to be more when glass fibres were added to SCC. Addition of fibres has no effect on the rate of gain of compressive strength of SCC.
3. Modulus of rupture and splitting tensile strength of SCC increased significantly after the addition of glass and PVA fibres. Glass fibres were found to be more effective in increasing the modulus of rupture and splitting tensile strength of SCC. This may be attributed to the higher tensile strength of glass fibres.
4. Addition of fibres had no significant effect on modulus of elasticity of SCC.

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