Experimental Investigation on Fresh and Hardened Properties of Hybrid Fibre-Reinforced Self-Compacting Concrete

Ashly Joseph and S. Sreerath

Abstract Self-Compacting Concrete (SCC) is a concrete mix having high flowability and resistance to segregation. It fills the framework and consolidates under its own weight without external vibration. SCC has a brittle nature, therefore to improve its tensile properties as well as the behavior under the impact, impregnation of different kinds of fibres can be adopted [1]. Reinforced SCC with polypropylene fibre has shown promisable result in both fresh and hardened state, addition of Hooked end steel fibres along with polypropylene fibre could enhance flexural residual strength, producing a hybrid fibre-reinforced SCC, which is well suited for structural use. Three volume ratios of steel fibres (0.5, 1.0, 1.5%) were mixed with three amounts (0.3, 0.6, 0.9%) of polypropylene fibres. Studies are carried out on the fresh and hardened properties of SCC for all the mixes. The fresh property tests such as Slump flow test, V-Funnel test, U-Box test and L-box test was conducted on the developed SCC to check the compatibility, filling ability, passing ability and segregation resistance. The hardened properties such as compressive strength, split tensile strength, flexural strength was determined by conducting suitable tests as per the European guidelines of SCC (EFNARC) and compared with that of standard specimen. From the experimental test results compressive strength of concretes did not change considerably, but the addition of fibres had noteworthy effects on splitting tensile and flexural strengths. As expected, the increase in fibre content led to an increase in these strengths. Fresh properties of SCC were found to decrease with an increase in fibre content.

Keywords Self -Compacting concrete · Polypropylene fibre · Hooked end steel fibre

A. Joseph (✉) · S. Sreerath
Department of Civil Engineering, Federal Institute of Science and Technology, Angamaly, Kochi 683577, India
e-mail: ashlyjoseph35@gmail.com

S. Sreerath
e-mail: iamsreerath@gmail.com

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1 Introduction

Self-compacting concrete (SCC) can be considered as a concrete which has little resistance to flow so that it can be placed compacted under its own weight with little or no vibration effort, even it possesses enough viscosity to be handled with segregation or bleeding. SCC was developed in Japan in the late 1980 as a solution to attain durable concrete structure independent of the quality of construction work. The concept of using fibres as a reinforcement in the concrete mixture is not a new study. The use of fibres has been carried out from ancient times. There are different types of fibre reinforced concrete that are categorized based on the fibre that is employed. If steel fibre is used we get steel fibre reinforced concrete. Similarly, nylon reinforced concrete, glass fibre reinforced concrete, carbon fibre reinforced concrete etc. are some of the types. A composite can be stated as a hybrid when two or more type of fibres is used in a combined matrix to produce a composite that will reflect the benefit of each of the individual fibre used. This will finally furnish a synergetic response to the whole structure. Such a composite of concrete is termed as the Hybrid Fibre Reinforced Concrete (HFC) [2]. The mechanical properties of concrete are enhanced appreciably using fibres. This will reduce the chances of brittleness and hence small crack formation, as small cracks are the main factors behind propagation and larger cracks formation. Fibre debonding or chances of pull out are less as this cause requires large energy absorption. This is the reason that gives fracture resistance and toughness to HFC during dynamic as well as cyclic loads.

2 Experimental Program

2.1 Materials

The cement used for this study is Ordinary Portland cement (OPC-53 grade) conforming to IS: 12269-1987 Additionally, fly ash class F is designated in ASTM C 618 was used as mineral admixture [3]. The shape of the steel fibre and polypropylene fibres are provided in Figs. 1 and 2 [4]. Also, Table 2 presents the properties

Fig. 1 Hooked end steel fibre

Fig. 2 Polypropylene fibres

of hooked-end steel and polypropylene fibres that were used in concrete mixtures. A polycarboxylate-based superplasticizer conforming to ASTM C494 Type-F and with a specific gravity of 1.09 was used to increase the workability of concrete. In addition, the viscosity modifying agent (VMA) with a specific gravity of 1.0 was used to prevent from bleeding and segregation of aggregates from cement paste. Fine and coarse aggregates with SSD condition and maximum size of 12 mm were used in all mixtures. The sand and gravel had a specific gravity of 2.64 and 2.68 respectively. The sand had a fineness modulus of 2.71.

2.2 Mixing Design and Testing Procedures

For self-compacting concrete, there is no specific method for mix design. Mix design is done as per IS 10262:2019 and EFNARC 2005. The composition of the mixes is presented in Table 1. In the present paper the hybrid mixes were prepared with the use of steel and polypropylene fibres. Three volume ratios of steel fibres 0.5, 1.0 and 1.5%, were tested. The examined steel fibres were 35 mm long with a sector of the circle cross-section and hooked end shape (Table 2). The considered polypropylene fibres of lengths 12 mm (Table 2) were added in the amounts of 0.3, 0.6 and 0.9%, by volume of concrete [5]. The different combinations of steel and polypropylene fibres can be found in Table 3, where the rheological parameters of hybrid fibre-reinforced self-compacting concrete (HFR-SCC) including slump-flow and L-box tests are also summarized. The mechanical properties of the HFR-SCC mixes were tested in compressive, split tensile and flexural strength at the age of 28 days. All the test was conducted as per the European guidelines of SCC (EFNARC). The compressive tests have been carried out in 2000 kN hydraulic compression testing machine on cubes with dimensions of 150 × 150 × 150 mm. For every mix, 6 specimens have been tested with a constant loading rate. The flexural tensile parameters were tested in two-point bending tests on three beams for each mix with dimensions of 100 × 100 × 500 mm. The split tensile strength test was tested in 1000 kN universal testing machine on cylinders with dimensions of 150 × 300 mm.

Table 1 Composition of HFR-SCC mix

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Fly ash (kg/m^3)	Steel fibres (%) by volume	Polypropylene fibres (%) by volume	Superplasticizer (kg/m^3)	Viscosity modifying agent (kg/m^3)
508	438	564	395	353	0.5, 1.0, 1.5	0.3, 0.6, 0.9	7.48	1.6

Table 2 Properties of fibres

Designation	SF	PP
Length [mm]	35	12 mm
Tensile strength [MPa]	1100 MPa	400
Effective diameter	0.65 mm	0.022 mm
Aspect ratio (length/effective diameter)	53.85	545
Fibre shape	Hooked end steel fibre	Straight
Acid/Alkali resistance	–	Excellent

Table 3 Properties of fresh HFR-SCC mix

Mix	Slump flow (mm)	T_{500} slump flow (s)	V-funnel flow time (s)	L-box (PA)	U-box (mm)
SCC control mix	755	3	6	0.86	1
0.5SF	750	3	6.44	0.85	2
0.5SF+0.3PP	740	3.3	7.51	0.84	4
0.5SF+0.6PP	670	3.8	8.46	0.82	4
0.5SF+0.9PP	610	4.1	9.86	0.8	4.1
1SF	740	4.3	6.77	0.85	5
1SF+0.3PP	733	4.6	7.84	0.84	5.2
1SF+0.6PP	660	4.8	8.91	0.83	5.2
1SF+0.9PP	600	5.1	9.98	0.82	5.3
1.5SF	715	5	7	0.9	6
1.5SF+0.3PP	710	5.2	7.94	0.92	6.4
1.5SF+0.6PP	650	5.6	9.24	0.93	6.5
1.5SF+0.9PP	555	6	10.1	0.98	6.6

3 Test Results and Discussion

3.1 Properties of Mixes in the Fresh State

In general, fresh parameters decrease with an increase in the amount of fibres, which is a well-set knowledge [6]. The mixes prepared with the use of only steel fibres satisfied the requirements for the SCC in the fresh state. All the hybrid mixes conformed to the demanded range of slump flow test (650–800 mm), except for those containing 0.9% of the PP fibres. The passing ability of all hybrid mixes were investigated in L-box tests and U-box test, where 0.9% of PP fibres was applied, gives higher value than control specimen. Considering the summary amount of fibres it can be concluded that for the $V_f > 2\%$ the hybrid mixes did not satisfy the requirements for the SCC.

This trend was observed without regard for superplasticizer amount. In all hybrid mixes the increase in porosity in comparison to plain SCC was observed.

3.2 Compressive Strength

As expected, the application of hybrid fibres did not have any significant influence on the compressive strength of the SCC matrix (Fig. 3), which can be attributed to the fact that the fibres influence mostly the post-cracking behaviour of the matrix [7]. An increase in the compressive strength was noted when the steel fibres were added up to 1.5%. Increase in compressive strength is due to the effective role of steel fibres as agents preventing propagation of cracks, reducing their development, providing higher contact surface area and denser matrix. A slight increase in the compressive strength was noted for the mix containing 0.3% of PP fibres and all other specimens containing polypropylene fibres showed lower compressive strength than of control mix at the age of 28 days and the value of f_c varied in the range of 0.5–16%. The compressive strength reduction can be generally explained by the fact that the fibres are some perturbation which causes higher amount of voids in the matrix. The highest observed decrease of f_c in case of application of the PP fibres can be also attributed to the instability of the mix in the fresh state [8].

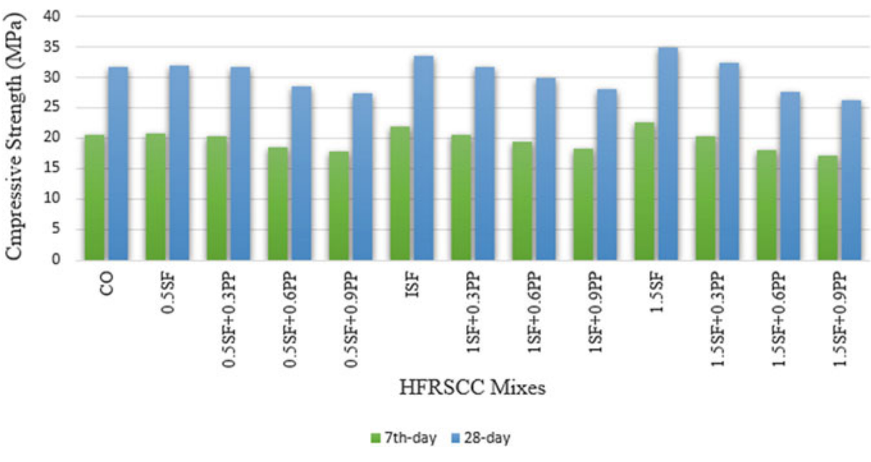

Fig. 3 Graphical representation for compressive strength of HFRSCC mixes

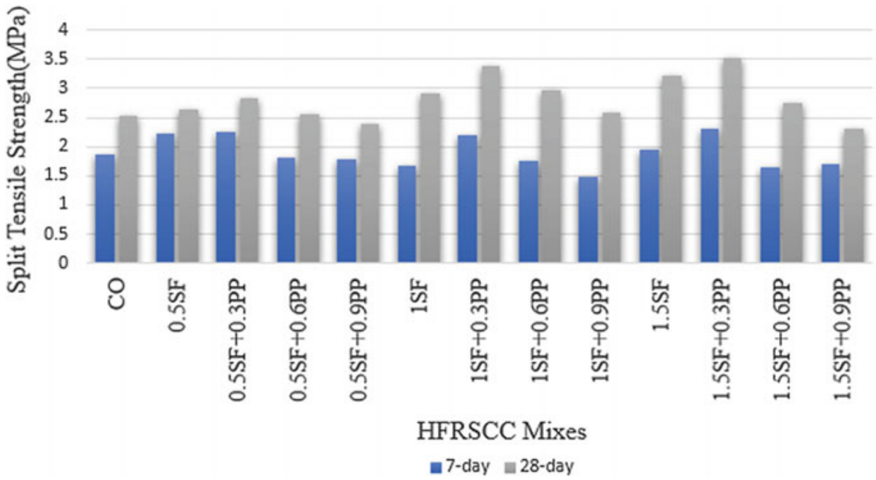

Fig. 4 Graphical representation for split tensile strength of HFRSCC mixes

3.3 Split Tensile Strength

The results show that while the compressive strength of concretes did not change considerably, the addition of fibres had noteworthy effects on splitting tensile strength. As expected, the increase in fibre content led to an increase in the strength. The addition of 0.5, 1.0, and 1.5% of steel fibres into concrete led to an increase of splitting tensile strength at the age of 28 days by 0.4, 15 and 27% compared to control mix. However, the hybrid mix 1.5SF+0.3PP specimen shows higher splitting tensile strength than the control specimen and percentage in increase were 39%. As a matter of fact, due to the longer length, more suitable shape, greater modulus of elasticity and higher tensile stress of steel fibres than polypropylene fibres, steel fibres adequately bridge between the internal micro cracks of concrete and improve the splitting tensile strength. Exceptionally, for the hybrid mixes containing 0.6% of polypropylene fibre shows a relative increase in split tensile strength when compared with control specimen. Lower splitting tensile strength was found in hybrid mixes containing 0.9% polypropylene fibre. The reduction in the splitting tensile strength may be because of their different characteristics such as length, shape, modulus of elasticity and tensile stress. The comparison between the splitting tensile strength of the control specimen and specimens containing fibres is presented in Fig. 4 [9].

3.4 Flexural Strength

The results of the flexural tests generally reaffirmed the role of the long fibres in attracting the macro-cracks and short fibres in arresting the micro-cracks. The results

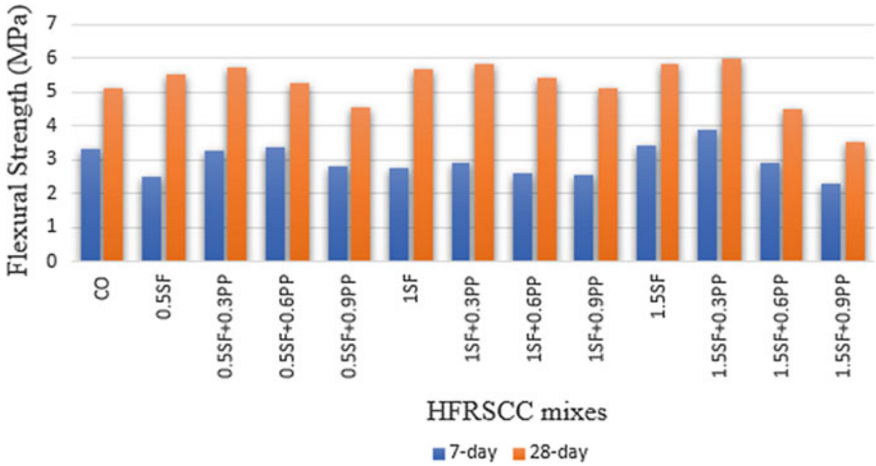

Fig. 5 Graphical representation for flexural strength of HFRSCC mixes

showed that the flexural parameters of HFR-SCC were pronouncedly enhanced due to hybrid fibre addition. By adding 0.5, 1.0 and 1.5% of steel fibres into SCC, the flexural strength increased by 7, 10 and 14% at the age of 28 days [10]. The hybrid mix 1.5SF+0.3PP specimen shows higher flexural strength than the control specimen and percentage in increase were 17%. The specimens containing 0.9% polypropylene fibres showed lower flexural strength. For the hybrid mixes containing 0.6% of polypropylene fibre shows a relative increase in flexural strength when compared with control specimen. On the contrary, the reduction in the flexural strength may be because of their different characteristics such as length, shape, modulus of elasticity and tensile stress. The increase of the total amount of fibres for 2% even to 3% can be ineffective in enhancing the flexural parameters of hybrid fibre reinforced mixes. The comparison between the splitting tensile strength of the control specimen and specimens containing fibres is presented in Fig. 5.

4 Summary and Conclusions

The following main conclusions can be drawn from the laboratory investigations:

- Analyzing the results of the hybrid mixes in the fresh state, Fresh properties of SCC were found to decrease with an increase in fibre content, considering the summary amount of the fibres, it can be concluded that for the fibres volume ratio higher that 2% the mixes did not satisfy requirement for the SCC. The mixes containing 0.9% PP fibres should be analyzed as conventional concrete.

- The steel fibres decreased the slump flow in SCC due to the presence of fibres which prevent cement paste from flowing. Polypropylene fibres (0.6 and 0.9%) drop the slump flow of hybrid fibre-reinforced mixtures considerably
- In comparison with steel fibres, polypropylene fibres showed greater effects on increasing the viscosity and V-funnel time flow. Addition of steel fibres with polypropylene fibres makes the V-funnel flow time to increase up to 66%. All the V-funnel flow times were within the allowable range (6–12 s) for SCCs
- The compressive strength of SCC slightly increased with the addition of steel fibres at the 28 days. The reason is attributed to the effective role of steel fibres as agents preventing propagation of cracks, reducing their development, and providing higher contact surface area
- Hybrid mix containing 0.6 and 0.9% of polypropylene gives a reduction in compressive strength compared to the control sample up to 38%. The reason is attributed to polypropylene fibres increased the porosity and rate of trapped air in the concrete but for the hybrid mix containing 0.3% polypropylene fibre shows a slight influence on compressive strength of the SCC matrix.
- The hybrid mixes 1.5SF+0.3PP specimen shows higher splitting tensile strength than the control specimen and percentage in increase was 39%. Hybrid mix containing 0.9%, polypropylene decreased the splitting tensile strength gradually and even became lower than the control sample in some hybrid fibre-reinforced specimens.
- Flexural parameters of HFR-SCC were pronouncedly enhanced due to hybrid fibre addition. Steel fibres play the most important role in enhancement of the flexural parameters of hybrid fibre-reinforced SCC mixes. The hybrid mix 1.5SF+0.3PP shows higher flexural strength than the control specimen and percentage in increase 17%.
- Among all the hybrid combination, 1.5SF+0.3PP mix performed better in all respects compared to other hybrid combination.

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