A STUDY ON HYBRID FIBRE REINFORCED SELF COMPACTING CONCRETE

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ABSTRACT

Self-Compacting Concrete (SCC) is generally defined as the concrete which does not need compaction. Due to this feature, SCC is ideally suited for concreting structures, which have heavily congested reinforcement or difficult access conditions. The aim of this investigation is to study the performance of M30 grade SCC containing hybrid fibres (steel fibre and polypropylene fibre) along with the mineral admixtures such as Fly ash (F), Silica fume (S), Limestone Powder (LP) and Marble Powder (MP). Four mixes with different mix proportion are casted for this research such as control mix containing 40% Fly ash (CM), mix containing all the four mineral admixtures in equal proportion (10SFLPMP), control mix with hybrid fibre (CM-HF), mix containing hybrid fibre along with the equal percentage of four mineral admixture (10SFLPMP -HF). Two types of fibres such as steel and polypropylene are used in 0.75% and 0.25% respectively. In the present investigation, studies were carried out on the fresh and mechanical properties of SCC for all the mixes. The fresh property tests such as Slump flow test, V-Funnel test, U-Box test and J-Ring tests were conducted on SCC to check the compactability like filling ability, passing ability and segregation resistance. The durability tests such as Acid resistance test, Water absorption test and Rapid Chloride Penetration test were conducted for all the mixes. The hardened properties such as compressive strength, split tensile strength, flexural strength, ultrasonic pulse velocity test and modulus of elasticity were determined by conducting suitable tests on SCC. The impact strength of SCC slabs are found by conducting drop down impact test. From the fresh property test results obtained maximum workability is achieved for the mix 10SFLPMP. Adding fibres to the mix affects the workability. From the experimental test results compressive strength, split tensile strength and flexural strength of the mix (10SFLPMP -HF) is found to be 28.37%, 56.61% and 67.59% higher than the control mix. The hardened properties such as ultrasonic pulse velocity and modulus of elasticity was found higher for the mix containing fibres and admixtures. From the durability tests performed it can be concluded that the mix 10 SFLPMP-HF satisfies durable properties. From the impact test conducted the energy absorption of the mix 10 SFLPMP-HF is 37.50% higher than the CM. Based on the results obtained the optimum mix is found to be 10 SFLPMP-HF.

Key Words: Self Compacting Concrete (SCC), mineral admixtures, steel fibre, polypropylene fibre, fresh properties, mechanical properties, durability properties and impact behaviour.

1. INTRODUCTION

Self-Compacting Concrete (SCC) is an advancement in the area of construction which settles under its own weight without causing bleeding or segregation. It is highly flowable and encapsulate the congested reinforcement without external vibration. It is amicable in nature which facilitates expeditious construction. Using high cement content increases the cost of the project, so the use of mineral admixtures such as Fly ash, Silica fume, Limestone Powder and Marble Powderas a partial replacement of cement will decrease the cost of cement and the slump increases. The use of mineral admixtures improved the performance of SCC in fresh state and avoided the use of viscosity modifying agent [1]. The usage of Fly ash increases the setting time of mortars, which can be eliminated by mixing with LP [2]. The addition of Fly ash and Silica fume leads to enchanced reduction in water absorption and also increases the 28 day cube strength [3]. Fibre Reinforced Self Compacting Concrete (FRSCC) combines the benefits of SCC and the properties of fibres. One of the greatest disadvantage of using cementitious material is its vulnerability to cracking, so fibres are used which acts as crack arrester. Adding two or more fibres to the concrete mix enhances the strength of the concrete and it is known as Hybrid Fibre Reinforced Self Compacting Concrete (HFRSCC). The fracture properties of concrete gets increased upon the addition of fibres[4]. The average compressive strength, split tensile strength and modulus of elasticity is higher when hybrid (steel and polypropylene) fibres are used [5].

Addition ofsteel fibre improves the flexural strength as well as the deflection capacity. Cracking behaviour is gradual and it is more ductile when polypropylene fibres are used [6]. The formation of micro cracks can be reduced when fibres are used. Inclusion of hybrid fibre reduces the generation of first crack and increases the failure load [7]

2. SIGNIFICANCE OF THIS STUDY

The main aim of this work is to study the properties of SCC and FRSCC experimentally both in fresh and hardened state. Therefore the following mixes are casted for the experimental design. They are Control mix containing 40% Fly ash (CM), Mix containing all the four mineral admixtures in equal proportion (10SFLPMP), Control mix with hybrid fibre (CM-HF), Mix containing hybrid fibre along with the equal percentage of four mineral admixture (10SFLPMP-HF). The mechanical properties included in this study are compressive strength, split tensile strength, flexural strength, ultrasonic pulse velocity test and modulus of elasticity. These properties are tested at 7, 14 and 28 days. The durability tests such as Acid resistance test, Water absorption test, Water Permeability test and Rapid Chloride Penetration test were conducted for all the mixes. The energy absorption of SCC slabs are tested by conducting Impact test. The results of the tested specimens are compared with the Control mix.

3. EXPERIMENTAL STUDY

3.1 Materials Used

Ordinary Portland Cement

Ordinary Portland Cement (OPC) 53 grade confirming to IS 12269:1993 is used in this research work. It has a specific gravity of 3.12 and fineness value is 319 m^2/kg. Fly ash and Silica fume are the pozzolanic materials used in this research. Fly ash has a specific gravity 2.38 and fineness value is 306 m^2/kg. Silica fume has specific gravity of 2.59 and fineness value 1133 m^2/kg.

LP and MP are the filler materials used in this investigation. LP has specific gravity of 2.55 and fineness value 547 m^2/kg and MP has specific gravity of 2.6 and fineness value is 789 m^2/kg. Coarse aggregate and Fine aggregate conforming to IS 383-1970 is used. CA of nominal size 12.5mm and retained in 10 mm sieve is used and locally available river sand passing through 4.75mm sieve is used in this investigation. The properties of aggregate is shown in Table 1.

Table 1 Properties of Aggregates

Properties	Fine Aggregate	Coarse Aggregate
Specific gravity	2.72	2.68
Water absorption	0.5	0.5
Fineness modulus	2.73	-
Zone	II	II

Super plasticizer

A modified polycarboxylic ether super plasticizer (Master Glenium 8233) is used in this investigation. The chemical admixture is light brown colour liquid with Specific gravity 1.09 with chloride content less than 0.2%. It complies with IS 9103 – 1999.

Steel fibre and Polypropylene fibre

Hooked end steel fibres obtained from Stewols India Pvt. Ltd having length 35mm and diameter 0.45mm and aspect ratio 77.77 is used. Polypropylene fibre having length 12mm diameter 7.5 µm and aspect ratio 1600 is used.

Figure 1 Steel and Polypropylene Fibre

4. MIX PROPORTION OF MATERIALS

The mix composition is arrived by trial and error method which should satisfy EFNARC specification. In this investigation 4 mixes are prepared with varying percentages of fillers and fibres. As per EFNARC specification total powder content should be 400-600kg/m^3,coarse aggregate content is 28-35% by total volume. In this research Coarse aggregate content is 790kg/m3, fine aggregate content is 1000kg/m3 and W/B ratio is kept as 0.35 for all the mix. The fresh properties of each mix is checked for passing ability, Filling ability and Segregation resistance by using fresh property tests of SCC. Silica fume mixes require higher dosage of Super plasticizer [8]. Dosage of Superplasticizer is determined from Marsh Cone test. For the mix containing FA dosage of superplasticizer is 2.35% and for SF mix dosage is 2.75%. The % of fillers and the dosage of Super plasticizer for every mix is given in Table 2.

Table 2 Mix Proportions

Materials	**CM**	**CM-HF**	**10SFLPMP**	**10SFLPMP-HF**
Cement (kg/m^3)	312	312	312	312
Coarse aggregate (kg/m^3)	790	790	790	790
Fine aggregate (kg/m^3)	900	900	900	900
F (kg/m^3)	208	208	52	52
S (kg/m^3)	-	-	52	52
LP (kg/m^3)	-	-	52	52
MP (kg/m^3)	-	-	52	52
Super plasticizer (%)	2.35	2.35	2.75	2.75
Water (kg/m^3)	182	182	182	182
Steel fibre (%)	-	0.75	-	0.75
Polypropylene fibre (%)	-	0.25	-	0.25

5. SAMPLE PREPARATION AND CURING CONDITION

To determine Split tensile strength and Elastic modulus cylindrical specimen of size Ø 150mm X 300mm are used. Specimen size of 150mm X 150mm X 150mm is used to determine Cube Compressive strength, water absorption test and water permeability test. Flexural strength is determined by using the specimen of size 500mm X 100mm X 100mm. Separate specimens were used for each test and 3 specimens for calculated for each test and their mean is taken. The specimens are demoulded and cured in a water tank and tested at the age of 7, 14 and 28 days. To conduct acid resistance test and sulphate attck test cubes of size 100mm x 100mm x 100mm is used.

6. FRESH CONCRETE PROPERTIES

SCC should fulfil three requirements i.e filling ability, passing ability and segregation resistance. The following tests are conducted to check these properties. They are Slump flow – to access filling ability, it measures flow spread and flow time T_{500} , V-Funnel test – to measure filling ability and segregation resistance , J-Ring test – to measure filling ability and passing ability and U-Box test. The tests are conducted as per EFNARC guidelines [8].

7. MECHANICAL PROPERTIES

Compressive strength, Splitting tensile strength, flexural strength, Elastic modulus and Ultrasonic Pulse velocity test are determined as per stipulations mentioned in IS 516-1959 , IS 5816-1999 and IS 9221- 1979 respectively.

8. DURABILITY PROPERTIES

The durability properties are examined by conducting tests such as Acid resistance test, , Water absorption test, Water Permeability test and Rapid Chloride Penetration Test.

10. IMPACT BEHAVIOUR

The impact strength of SCC slabs are found by conducting drop down impact test. The test is performed for all the mixes. Slab size used is 1000mm x 1000mm x 25mm. Cover provided is 6mm. 6mm rods at 150 c/c is used as reinforcement. The impact test slab specimen and set up for the test is shown in Fig 2, 3 and 4 respectively.

Figure 2 Reinforcement used in slab

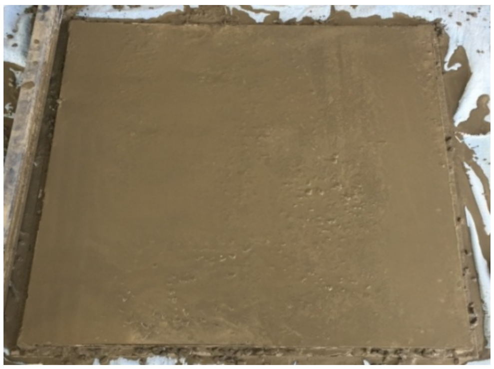

Figure 3 Casting of slab

Figure 4 Test set up to conduct Impact test

11. EXPERIMENTAL RESULTS

11.1 Fresh concrete properties of SCC

The results of various fresh property tests on SCC such as Slump flow, T_{50} test, V-Funnel test, J-Ring test and U-Box test of various mixes are given in Table.3

Table 3 Fresh Properties of SCC

Mix ID	Slump flow (mm)	T_{50} (sec)	J ring mm	U box mm	V-Funnel sec	V-Funnel at T_5 Sec
CM	690	4.6	6.0	20	12.0	11.33
10SFLPMP	720	3.9	5.5	16	9.0	9.0
CM-HF	675	4.9	7.1	19	9.14	10.0
10SFLPMP-HF	710	4.0	6	16	8.26	8.30

For all the slump flow ranges from 675-720mm. The slump flow time to reach the diameter of 500mm was less than 5s. The Slump flow increases with the addition of mineral admixtures. Steel fibres with hooked end cause jamming of concrete particles and this affects the flow rate. V-Funnel time varies from 8.26 – 12s. Addition of 10% Limestone powder decreases the V-Funnel flow time. The increase o MP dosage in SCC increases the V-Funnel flow time [10]. V-Funnel at T5 sec test is done to check the segregation resistance, the values were found to be within the limit. From the U-Box test conducted the variation in height of concrete in two compartments is in the range 16-20mm. Adding fibres in higher dosage reduces the workability of the concrete [11]. From the fresh property test results all the mixes were in limits of EFNARC [12].

11.2 Hardened properties of SCC

Compressive Strength

The compressive strength of CM, CM-HF, 10SFLPMP and 10SFLPMP-HF mixes achieved at different ages are given in Fig. 5

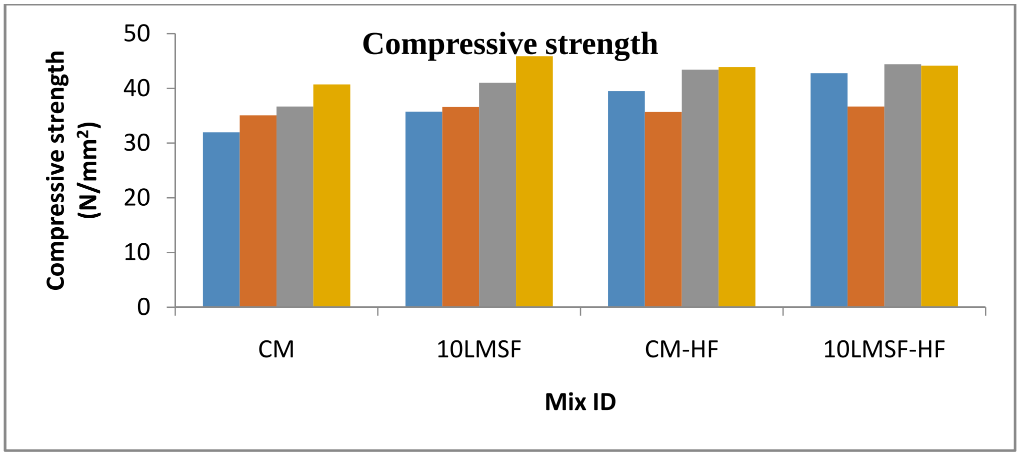

Figure 5 Comparison of Compressive Strength test results

At 28 days maximum compressive strength was achieved for mix containing fillers in equal proportion and hybrid fibres. Compressive Strength for 10SFLPMP-HF mix is found to be higher when it is compared to other mixes and is 28.37% higher than control mix. The enhancement in the strength is due to the addition 1% fibre content. Steel fibre causes crack closing force and contributes to the development of compressive strength. From 56 and 90 days strength it is clear that by adding Flyash improves the long term strength.

Split Tensile Strength

Split tensile strength of CM, CM-HF, 10SFLPMP and 10SFLPMP-HF mixes achieved at different ages are given in Fig. 6.

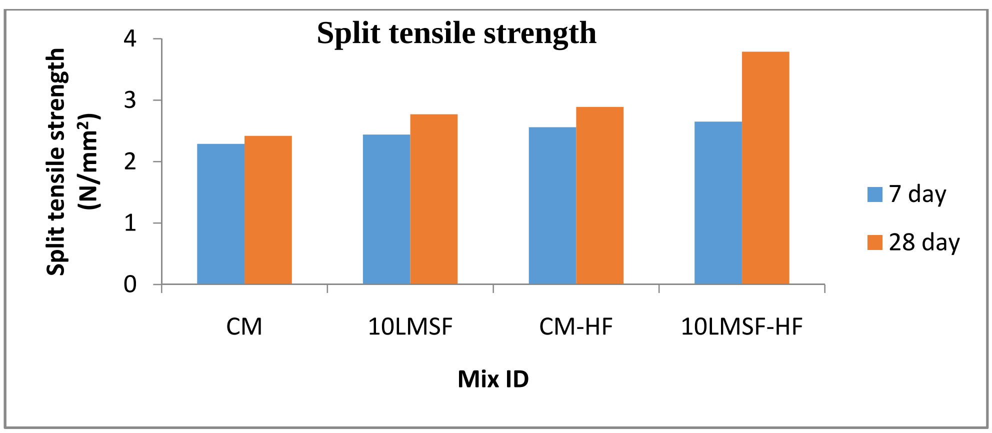

Figure 6 Comparison of Split Tensile test results

The increase in split tensile strength for the mix CM-HF, 10SFLPMP and 10SFLPMP-HF was respectively when compared to control mix. Maximum slitting tensile strength was for 10SFLPMP-HF when it is compared to other mixes and is 56.61% higher than Control mix.

Flexural strength

Flexural strength of SCC mixes CM, CM-HF, 10SFLPMP and 10SFLPMP-HF was conducted at the age of 28 days as per IS 516-1959. The flexural strength of all the mixes are given in Fig 7.

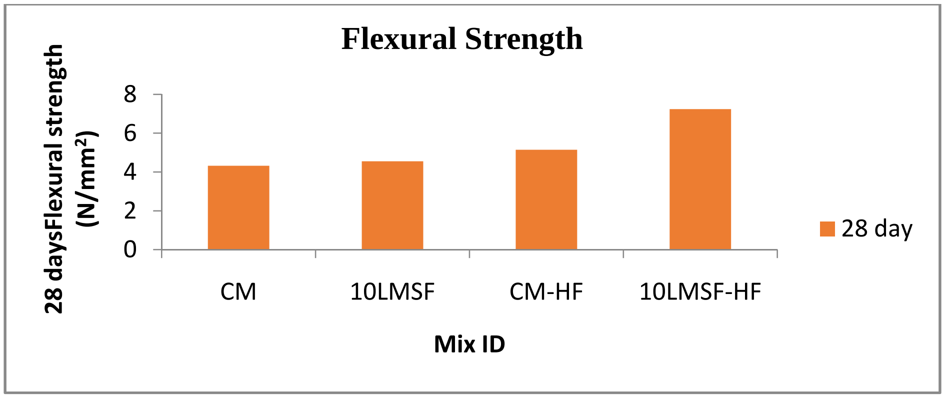

Figure 7 Comparison of Flexural Strength test results

It was observed that maximum flexural strength was obtained for the mix containing all the mineral admixtures in equal proportion and fibres. The percentage increase was found to be 67.59% higher than the Control mix. The flexural strength increases due to the superior performance of steel fibres with hooked end embedded in the cement matrix. The random distribution of steel fibre in the mix controls the crack and increases the load carrying capacity of the beam.

Modulus of Elasticity

Table 4 represents the modulus of elasticity of CM, CM-HF, 10SFLPMP and 10SFLPMP-HF mixes

The average modulus of elasticity 10SFLPMP-HF mix is higher than CM, CM-HF and 10SFLPMP. It clearly shows that adding fibres increases the modulus of elasticity.

Ultrasonic Pulse Velocity

The Ultrasonic pulse velocity test results of all the mixes are given in Table 5. It can be concluded from the result that due to addition of steel fibre pulse velocity decreased slightly due to the presence of voids when compared to the control mix and the mix without fibres.

attained at 28 days. The stress strain behavior of all the mixes is shown in Fig 6, 7, 8 and 9.

Table 4 Modulus of Elasticity of SCC mixes

Mix ID	**Modulus of Elasticity N/mm^2**
CM	26042.82
10SFLPMP	33649.53
CM-HF	30444.12
10SFLPMP-HF	36455.13

Table 5 UPV test results

Mix ID	**CM**	**10SFLPMP**	**CM-HF**	**10SFLPMP-HF**
Velocity (Km/s)	4.276	4.581	3.824	4.442
Dynamic modulus of elasticity (Gpa)	44.53	51.82	34.76	47.66

Since the fibres are randomly oriented, the waves gets deflected to other direction it takes more time to reach the other direction. The maximum velocity of 4.8km/s was observed for the mix 10SFLPMP which consists of all the four admixtures in equal proportion. All the samples fall under the category “good” and “excellent” as per the IS code.

11.3 DURABILITY TEST RESULTS

Acid Resistance Test

Table 6 and 7 shows the variation of weight and compressive strength for all the mixes immersed in HCl and H_2SO_4 for 30 days respectively.Specimens immersed in H_2SO_4 shows more weight loss and compressive strength loss than the specimens immersed in HCl

Table 6 Weight loss and compressive strength loss for all mixes immersed in HCl

Mix ID	% weight loss after defined age	% compressive strength loss after defined age
CM	4.67	12.44
10SFLPMP	5.34	8.72
CM-HF	4.57	9.15
10SFLPMP-HF	5.38	9.08

Table 7 Weight loss and compressive strength loss for all mixes immersed in H_2SO_4

Mix ID	% weight loss after defined age	% compressive strength loss after defined age
CM	5.59	16.46
10SFLPMP	6.02	14.12
CM-HF	6.15	15.92
10SFLPMP-HF	6.77	14.08

Water Absorption Test

The water absorption percentage of the specimens is shown in Table 8. Mix containing mineral admixtures in equal proportion and hybrid fibre combination decreased the water absorption

Table 8 Water absorption %

Mix ID	Absorption %
CM	3.21
10SFLPMP	2.25
CM-HF	2.79
10SFLPMP-HF	2.19

Rapid Chloride Penetration Test

The results of Rapid Chloride Penetration are shown in Table 10 . All the mixes exhibited low permeability

Table 10 RCPT results

Mix ID	Charge passed (Coulombs)	Chloride Permeability
CM	726	very low
10SFLPMP	196	very low
CM-HF	685	very low
10SFLPMP-HF	165	very low

11.4 IMPACT BEHAVIOUR

The Table 11 shows the energy absorption of SCC slabs for all the mixes. The crack pattern for all the SCC slabs is shown in Fig 8,9,10 and 11. The impact response is dependent on drop weight impact machine [12]

Table 11 Impact Energy absorbed

Mix ID	Impact Energy absorbed (J)
CM	894.67
10SFLPMP	1183.34
CM-HF	1006.50
10SFLPMP-HF	1230.17

Figure 10 Crack pattern of CM-HF

Figure 8 Crack pattern of CM

Figure 11 Crack pattern of 10SFLPMP-HF

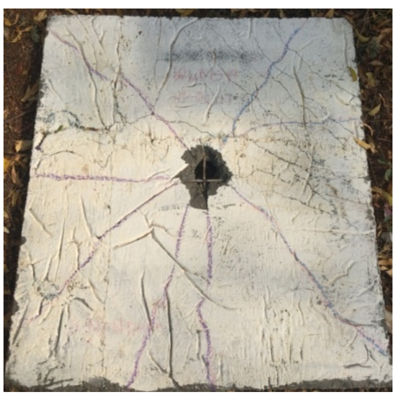

Figure 9 Crack pattern of 10SFLPMP

12 SUMMARY OF RESULTS

- The developed SCC mix with and without the addition of hybrid fibres (steel and polypropylene) satisfy the rheological properties.
- From the fresh property results it can be concluded that adding fibres affects the workability of fresh concrete.
- The fresh concrete properties such as slump flow (675-720mm), T50 (3.9-4.6s), V-Funnel time (8.26-12s), J-Ring (5.5-7mm) and U-Box (16-20mm) values satisfy EFNARC limits.
- A hybrid volume fraction of 1% with (75-25) steel-polypropylene combine appreciably improve the compressive strength, split tensile strength and flexural strength for the respective specimens.
- Compressive Strength for 10SFLPMP-HF mix is found to be higher when it is compared to other mixes and is 28.37% higher than control mix.

- Split Tensile Strength for 10SFLPMP-HF mix is found to be higher when it is compared to other mixes and is 56.61% higher than Control mix.
- Flexural Strength for 10SFLPMP-HF mix is found to be higher when it is compared to other mixes and 67.59% is higher than Control mix.
- Ultrasonic Pulse Velocity values showed that the mix containing fibres possess good quality grading and the value of dynamic modulus of elasticity is found to be higher for 10MPSFLP-HF.
- From the durability tests performed it can be concluded that the mix 10 SFLPMP-HF satisfies durable properties.
- From the impact test conducted the energy absorption of the mix 10 SFLPMP-HF is 37.50% higher than the CM.
- It was found that 1% HFRSCC with (0.75%-0.25%) steel-polypropylene fibre combination performed better than normal Self Compacting Concrete.

13. CONCLUSION

SCC mix containing Steel-Polypropylene fibres along with the filler materials in equal proportion recorded higher strength values and high energy absorption value. It is because mineral admixtures improves workability and Fly ash contributes to long term strength. Steel fibre improve split tensile strength and flexural strength and polypropylene fibre acts as crack arrester and improves the bond with cement matrix. The results clearly demonstrate that the mix containgfibres and the mineral admixtures in equal proportion (10SFLPMP-HF) has superior performance.

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