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A Study of Effects of Steel Fibre on the Properties of High Performance Concrete

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ABSTRACT

In this investigation a series of compression tests were conducted on 150 mm, cube and 150mm x 300mm, cylindrical specimens using a modified test method that gave the complete split tensile strength and 100x100x500mm beam for flexural strength using silica fume with and without steel fiber of volume fractions 0, 1.0, 2 and 3% of 0.5mm Ø of aspect ratio of 80 on Portland Pozzolona cement using in M-60 grade concrete. As a result the incorporation of steel fibers, silica fume and cement has produced a strong composite with superior crack resistance, improved ductility and strength behavior prior to failure. Addition of fibers provided better performance for the cement-based composites, while silica fume in the composites may adjust the fiber dispersion and strength losses caused by fibers, and improve strength and the bond between fiber and matrix with dense calcium-silicate-hydrate gel. The results predicted by mathematically modeled expressions are in excellent agreement with experimental results. On the basis of regression analysis of large number of experimental results, the statistical model has been developed. The proposed model was found to have good accuracy in estimating interrelationship at 28 days age of curing. On examining the validity of the proposed model, there exists a good correlation between the predicted values and the experimental values as showed in figures. The variation in the compressive stress and split tensile stress with respect to changes in the fibre content can be observed. From the results obtained, it is clear that the compressive and split tensile strength of concrete is maximum when the fibre content is 3% of the concrete.

Keywords: FRC, HPC, Steel Fibers.

I. INTRODUCTION

Concrete is a composite material containing hydraulic cement, water, coarse aggregate and fine aggregate. The resulting material is a stone like structure which is formed by the chemical reaction of the cement and water. This stone like material is a brittle material which is strong in compression but very weak in tension. This weakness in the concrete makes it to crack under small loads, at the tensile end. These cracks gradually propagate to the compression end of the member and finally, the member breaks. The formation of cracks in the concrete may also occur due to the drying shrinkage. These cracks are basically micro cracks. These cracks increase in size and magnitude as the time elapses and the finally makes the concrete to fail. The formation of cracks is the main reason for the failure of the concrete. To increase the tensile strength of concrete many attempts have been made. One of the successful and most commonly used method is providing steel reinforcement. Steel bars, however, reinforce concrete against local tension only. Cracks in reinforced concrete members extend freely until encountering are bar. Thus need for multidirectional and closely spaced steel reinforcement arises. That cannot be practically possible. Fibre reinforcement gives the solution for this problem. So to increase the tensile strength of concrete a technique of introduction of fibres in concrete is being used. These fibres act as crack arrestors and prevent the propagation of the cracks. These fibres are uniformly distributed and randomly arranged. This concrete is named as fibre reinforced concrete. The main reasons for adding fibres to concrete matrix is to improve the post-cracking response of the concrete, i.e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material. The initial researches combined with the large volume of follow up research have led to the development of a wide variety of material formulations that fit the definition of Fibre Reinforced Concrete.

High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementitious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer. The term 'high performance' is somewhat pretentious because the essential feature of this concrete is that it's ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence High performance concrete is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhance the strength, durability and workability qualities to a very high extent.

MATERIALS AND METHODS

Sample : In order to study the interaction of Steel fibres (hooked end) with concrete under compression, flexure, split tension and impact, 24 cubes, 24 beams and 24 cylinders were casted respectively. The experimental program was divided into four groups. Each group consists of 6 cubes, 6 cylinders and 6 beams, of 15x15x15cm, 15(dia) x30cm and 15x15x50cm respectively.

- The first group is the control (Plain) concrete with 0% fibre (PCC)
- The second group consisted of 1% of Steel fibres (hooked end), with aspect ratio 80, by volume.
- The third group consisted of 2% of Steel fibres (hooked end), with aspect ratio 80, by volume.
- The fourth group consisted of 3% of Steel fibres (hooked end), with aspect ratio 80, by volume.

Methodology: High performance concrete was designed as per the procedure laid down in ACI committee report to achieve the compressive strength of the order of M-60 trial concrete mixes were prepared using different constituents like cement, silica fume, fine aggregates, coarse aggregates, and super plasticizer in different proportions, table 3.1 Mix no – 1 corresponding to C : SF : FA : CA : SP w/c ratio 0.35 provided compressive strength corresponding to 68.84 MPa at 28 days and therefore Mix no – 1 was considered in the present investigation as controlled mix.

Table 3.1 Composition of HPC and HPC-SF(steel fibre)

Mix No.	C (kg/m^3)	SF (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	SP (L/m^3)	Steel Fibre (%)	Steel Fibre (kg/m^3)	Water (L/m^3)	w/c ratio
1	430	43	660	1050	10.8	0	0	162	0.35
2	430	43	660	1050	10.8	1	23.51	162	0.35
3	430	43	660	1050	10.8	2	47.03	162	0.35
4	430	43	660	1050	10.8	3	70.54	162	0.35

C – cement, SF – silica fume, FA – fine aggragates, CA – coarse aggregates, SP – super plasticizer

Materials : Cement : In the present study Ordinary Portland Cement (43 grade) conforming to IS: 8112 was used. The cement was tested in accordance to test methods specified in IS: 4031 and results obtained are shown in Table 3.2

Table 3.2 Test Results of Cement Sample

S.No.	Name of Test	Experimental value	Requirements as per IS: 8112-1989
1.	Normal Consistency (%)	28	-
2.	Specific gravity	3.15	3.15
3.	Initial setting time (min)	95	More than 30
4.	Final setting time (min)	215	Less than 600
5.	Fineness (%)	5	10
6.	Soundness (mm)	2.55	Less than 10
7.	Compressive strength (MPa)		
(i)	3 days	26.10	Greater than equal to 23
(ii)	7 days	36.69	Greater than equal to 33
(iii)	28 days	46.56	Greater than equal to 43

3.4.2 Silica Fume The silica fume used was obtained from Orkla India (Pvt) Ltd (Brand name: Elkem Microsilica 920-D), Navi Mumbai. Physical and chemical properties of silica fume are shown in Table 3.3 & 3.4

Table 3.3 Physical Properties of Silica Fume (Source : Test Report)

Physical Properties	Test Results
Color	Light Grey
Specific Gravity	2.26

Table 3.4 Chemical properties of Silica Fume (Source : Test Report)

Chemical properties	Percentage by weight
Calcium oxide(CaO)	0.426
Silica(SiO_2)	93.80
Alumina(Al_2O_3)	0.206
Iron oxide(Fe_2O_3)	0.096
Magnesium oxide(MgO)	0.222
Sodium oxide (Na_2O)	0.107
Potassium oxide(K_2O)	0.337

3.4.3 Super Plasticizer : Super plasticizer **STRUCTURO 100(M)** (Fosroc chemicals) was used as admixture. Structuro 100(M) combines the properties of water reduction and workability retention. Specifications of super plasticizer are shown in Table 3.5

Table 3.5 Specifications of Super plasticizer (Source : Fosroc Chemicals)

Particulars	Properties
Appearance	Light yellow
Basis	Aqueous solution of Carboxylic ether polymer
pH	6.5
Density	1.06 kg/litre
Chloride content	Nil to IS:456
Alkali content	Less than 1.5g Na_2O equivalent per litre of admixture
Optimum dosage	0.5 to 3.0 litres per 100kg of cementitious material

3.4.4 Aggregates: Aggregates constitute bulk of the major portion of concrete. The characteristics of aggregates affect the properties of HPC. Fine and coarse aggregates used in the present study were tested and results are tabulated below.

3.4.4.1 Fine aggregates: Locally available natural river sand was used as the fine aggregate. Its sieve analysis and physical properties are shown in Tables 3.6 and 3.7

Table 3.6 Sieve Analysis of Fine Aggregate

IS sieve size (mm)	% Passing
10.0	100
4.75	96.6
2.36	92.6
1.18	85.25
600 µ	77.15
300 µ	22.4
150 µ	5.65

Fineness modulus = 2.6 **Sand conforms to Grading Zone III as per IS: 383-1970.**

Table 3.7 Physical Properties of Fine Aggregate

Particulars	Observed Value
Specific gravity	2.67
Fineness modulus	2.20
Bulk density (loose), Kg/m^3	1590
Bulk density (compacted), Kg/m^3	1780

3.4.4.2 Coarse aggregates : Crushed stone aggregates conforming to IS: 383-1970 was used as coarse aggregate. The sieve analysis and physical properties are shown in Tables 3.8 and 3.9 respectively.

Table 3.8 Sieve Analysis of Coarse Aggregate

IS sieve size (mm)	% Passing
20	100
16	100
12.5	97.5
10	49.64
4.75	0.54
2.36	0.0

Fineness modulus = 6.52 **Coarse aggregate conforms to IS: 383-1970.**

Table 3.9 Physical properties of Coarse Aggregate

Particulars	Properties
Specific gravity	2.67
Fineness modulus	6.52
Bulk density(Loose),kg/m³	1460
Bulk density(compacted),kg/m³	1650
Maximum size, mm	12.5

3.4.5 Fibres: The various types of fibres like carbon, glass, synthetic, steel etc. can be used in reinforcing concrete. In this study, steel fibres were incorporated in concrete. Crimped Steel fibres were added in different proportions of 0, 1, 2, and 3 % by volume of concrete mass fig 3.1. Physical properties of steel fibres used are shown in Table 3.10.

Table 3.10 Physical Properties of Steel Fibres

Particulars	Properties
Shape	Cylindrical
Type	Crimped
Length, mm	40
Diameter, mm	0.5
Aspect Ratio	80

Mixing of Specimens : Hand mixing is adopted throughout the experimental work. First the materials cement, fine aggregate, coarse aggregate, steel (hooked end) fibres weighed accurately as per the above mentioned calculations.Then cement is added to the sand and mixed thoroughly to get a uniform colour. The coarse aggregate is spread on the ground and then the cement-sand mixture is mixed with it to get a uniform matrix. The steel (hooked end) fibres of 60mm lengths are dispersed in the water. The water along with the fibre is added to the mixture and mixed thoroughly to get a uniform mass in colour and consistency. After mixing the fresh concrete is tested for the workability using compaction factor and slump tests.

RESULTS

Tests Results of Fresh Concrete

Compaction factor Test : The compacting factor is calculated for various percentages of steel (hooked end) fibres. As per IS 6461-1972, workability is defined as “the ease which it can be mixed, transported, placed and compacted easily.”

Table 3.11 Compaction Factor Results

Percentage of Fiber Added	Compaction Factor
0	**0.82**
1	**0.79**
2	**0.77**
3	**0.71**

Slump Test :

Table 3.12 Slump Test Results

Percentage of Fiber Added	Slump Value (in cm)
0	2.1
1	1.2
2	0.7
3	0.0

Tests Results of Hardened Concrete

Compression Strength Test Results : The mix HPC-SF was used as control mix i.e. fibre content as 0% and compressive strength at 28 days was 68.72 MPa.

Table 4.1 Compression Test Results

Sr. No.	Designation	Percentage of Fibre	Average load (kN)	Average Compressive Strength (N/mm2)
1.	HPC-SF	0	1546.272	68.72
2.	HPC-1SF	1	1677.060	74.36
3.	HPC-2SF	2	1716.572	76.29
4.	HPC-3SF	3	1806.838	80.30

Compressive strength of HPC-1SF, HPC-2SF and HPV-3SF was found to increase by 8%, 11% and 17% of HPC-SF at 28 days, respectively.

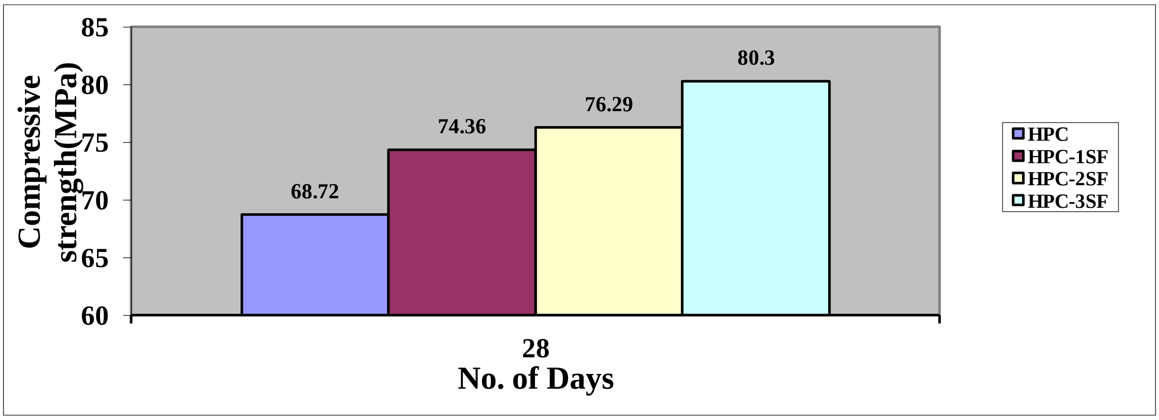

Fig. 4.1 Comparison of Compressive Strength

4.2.2 Split Tensile Strength Test Results: The split tensile strength of HPC-SF was 6.573 MPa. Split tensile strength of HPC-1SF, HPC-2SF and HPC-3SF was found to increase by 15%, 31% and 43% at 28 days respectively, when compared to M_1

Table 4.2 Split Tensile Strength Test Results

Sr. No.	Designation	Percentage of Fiber	Average load (kN)	Average Split Tensile Strength (N/mm2)
1.	HPC-SF	0	465.129	6.573
2.	HPC-1SF	1	534.226	7.546
3.	HPC-2SF	2	607.266	8.580
4.	HPV-3SF	3	662.288	9.372

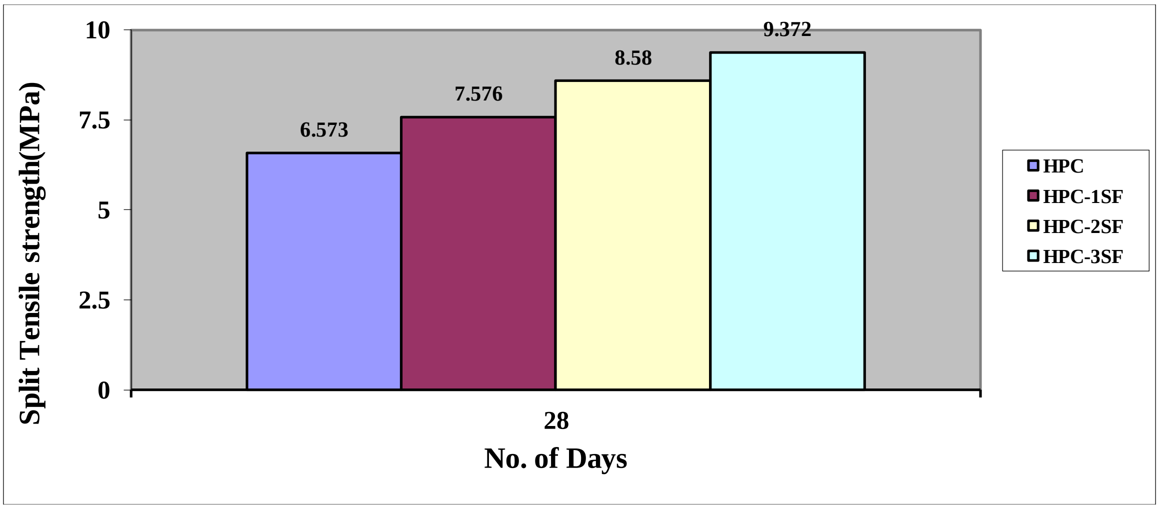

Fig. 4.2 Comparison of Split Tensile Strength

4.2.3 Flexural Strength Test Results: The strength of HPC-SF at 28 days was 12.516 MPa. Flexural strength of HPC-1SF, HPC-2SF and HPC-3SF was increased by 41%, 69% and 95% at 28 days respectively, when compared to HPC-SF.

Table 4.3 Flexural Strength Test Results

Sr. No.	Designation	Percentage of Fibre	Average load (kN)	Average Flexural Strength (N/mm2)
1.	HPC-SF	0	60.375	12.516
2.	HPC-1SF	1	85.750	17.688
3.	HPC-2SF	2	95.200	21.136
4.	HPC-3SF	3	104.850	24.460

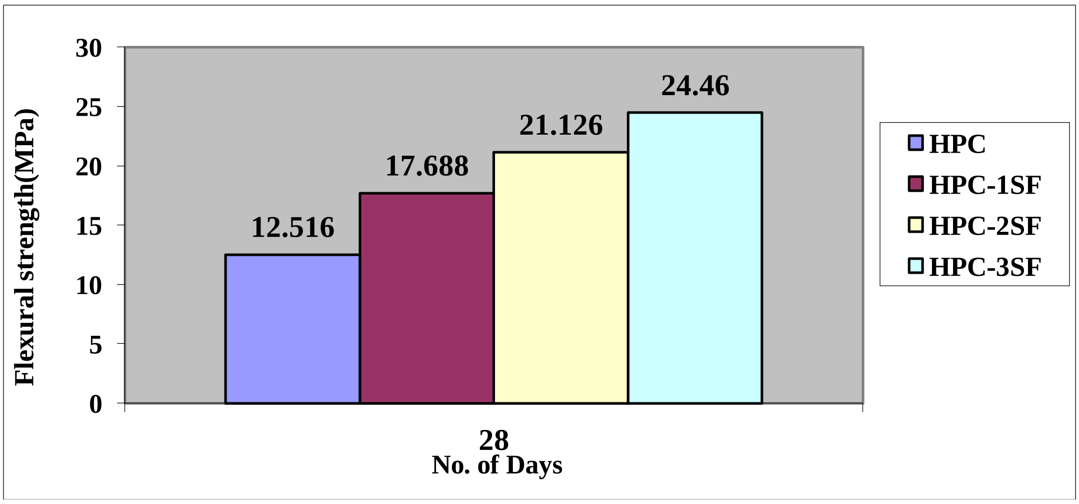

Fig. 4.3: Comparison of Flexural Strength

CONCLUSION

The variation in the compressive stress and split tensile stress with respect to changes in the fibre content can be observed. From the results obtained, it is clear that the compressive and split tensile strength of concrete is maximum when the fibre content is 3% of the concrete.

1. The 28-day compressive strength of HPC mixes with fibre content of 1%, 2% and 3%, were found to be increased by 8%, 11% and 17%, when compared to strength at 0% fibre content.
2. The 28-day split tensile strength of HPC mixes with fibre content of 1%, 2% and 3%, were found to be increased by 15%, 31% and 43%, when compared to strength at 0% fibre content.

3. The 28-day flexural strength of HPC mixes with fibre content of 1%, 2% and 3%, were found to be increased by 41%, 69% and 95%, when compared to strength at 0% fibre content.
4. The steel fibres are free from water absorption.

The Steel fibres (hooked end) used in this project has shown considerable improvement in all the properties of concrete when compared to conventional concrete like:

- Compressive strength by 17% for 3% of steel fibres.
- Split Tensile strength by 43% for 3% of steel fibres.
- Flexural strength (Modulus of Rupture) by 95% for 3% of steel fibres.

It could be concluded that higher the percentage of fiber content in concrete increases the strength of the concrete in all respects. Moreover flexural strength gives the more satisfactory results as compared to the split tensile and compressive strength.

With improved understanding of the link between fibre characteristics and composite or structural performance, the tailoring of fibres for use in high volume construction market exists, particularly for load carrying structural systems and for several applications especially in Earthquake prone areas. The time is not far that such materials will be used in building better and safe constructions for the future.

FUTURE SCOPE

1. Further study can be made by increasing the percentage of fibre content.
2. Different types of fibres like synthetic fibre, carbon fibres, or glass fibres may be used for future investigation.
3. In durability properties, HPC mixes containing fibres exposed to freezing and thawing cycles, can be investigated.
4. Further study can be done on HPC mixes containing fibres subjected to elevated temperatures.
5. Further study can be done for determining the deflections and durability of concrete.
6. Further study on the seepage characteristics of the steel fibres.
7. As the failure of SFRC is ductile, further studies on retrofitting of damaged structures constructed of this concrete can be undertaken.
8. The study can be done using different types of fibres such as polyproplyne, carbon, GI, HDPE (high density poly ethylene) fibres in ternary blended combinations when subjected to different sustained elevated temperatures.
9. The study can also be made on the effect of sustained elevated temperatures on steel fibre reinforced tertiary blended concrete with combinations like (FA+SF+GGBFS), (FA+SF+MK), (FA+SF+RHA).
10. Effect of sudden cooling, gradual cooling and intermittent cooling on the properties of steel fibre reinforced ternary blended concrete when subjected to sustained elevated temperatures.
11. Effect of grade of concrete on the properties of steel fibre reinforced ternary blended concrete when subjected to sustained elevated temperatures.
12. Effect of different aspect ratios and different volume fractions on the properties of steel fibre reinforced ternary blended concrete when subjected to sustained elevated temperatures.

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