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Mechanical Behavior of High Strength Fibre Reinforced Concrete

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ABSTRACT
The use of High Strength Concrete (HSC) is on rise. It is observed that HSC is relatively brittle material. Fibres are added to improve its ductility. Experimental study is carried out to assess mechanical properties of high strength fibre reinforced concrete (HSFRC) of grade M80. In addition to normal materials, silica fume, fly Ash and two types fibres viz. Hooked end steel Fibre (0.4×25mm) and Hooked end steel Fibre (1×60mm)having different aspect ratio, are used to produce concrete. The content of silica fume and fly ash is 5% and 10% respectively by weight of cement. Water to cementitious material ratio was 0.25. Mixes are produced by varying types of fibres and for each type of fibre its volume fraction is varied from 0.5% to 4.0 % with an increment of 0.5% by weight of cementitious materials. 147 specimens each of cubes (100×100×100mm), cylinders (100×200mm) and prisms (100x100x500mm) are tested to study the effect fibres on compressive strength, split tensile strength and flexural strength of HSFRC. The results indicated significant improvement in mechanical properties of HSFRC.
Keywords– High Strength Fibre Reinforced Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength, Steel Fibres, Polypropylene Fibres.

I. INTRODUCTION

Concrete is a commonly used construction material. It traditionally consists of cement, fine aggregate, coarse aggregate and water, however modern concrete is produced by adding mineral and chemical admixtures also. IS 456-2000 suggested the use of fly ash, silica fume, ground granulated blast furnace slag (ggbfs), metakaoline, rice husk ash (RHA) in the production of concrete. Concrete has been categorized as ordinary, standard and high strength based on characteristic compressive strength at the age of 28 days. High strength concrete is being produced due to growing demand for taller and larger structures. As per IS 456, High strength concrete is a concrete with strength between 60 to 80 MPa. Such a concrete demands the use of supplementary cementitious materials (SCM) and super plasticizer in order to reduce cement consumption, increase strength, decrease permeability, and improve durability. It is noticed that high strength concrete is a relatively brittle material possessing lower tensile strength. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres in the concrete would act as crack arresters and would substantially improve its flexural strength. The toughness of HSFRC depends upon the percentage content of silica fume, fly ash, types of fibre, its volume fraction and aspect ratio. Such a concrete is in demand wherein resistance to cracking is a performance requirement of the structure e.g. liquid storage structures.

1.2. Literature Review:

Various researchers have carried out **e**xperimental investigation to study the mechanical behaviour of high strength fibre reinforced concrete. The markable investigation carried out on mechanical properties of high strength fibre reinforced concrete (HSFRC) by P.S.Song and S. Hwang that the brittleness with low tensile strength and strain capacities of high strength concrete (HSC) can be reduce by the addition of steel fibres [1]. It is reported that the use of steel fibres in concrete decrease the workability of concrete but increase split tensile strength,flexural strength, modulus of elasticity and poisons ratio [3,4]. P.Balaguru and Mahendra Patel studied the flexural toughness of steel fibre reinforced concrete by using deformed and hooked end fibres. The results indicated that hooked end fibres provided better results than deformed fibre [5]. The experimental investigation is carried out to study the influence of fibre content on the compressive strength, modulus of rupture, toughness and splitting tensile strength [6,7,12]. S.P.Singh and S.K.Kaushik carried out an experimental program to study fatigue strength of steel fibre reinforced concrete (SFRC), in which they obtained the fatigue-lives of SFRC at various stress level and stress ratio. There results indicated that the statistical distribution of equivalent fatigue-life of SFRC is in agreement with the two-parameter Weibull distribution. The coefficient of the

fatigue equation were determined corresponding to different survival probabilities so as to predict the flexural fatigue strength of SFRC for the desired level of survival probability [9]. The use of mineral admixtures such as silica fume and fly ash in high strength concrete gives the smaller paste porosity as compared to controlled concrete which increases the compressive strength, split tensile strength and flexural strength [10, 11, 13, 14, 17]. The production of good concrete can be done using automation and controlled environment but it not possible to alter its inherent brittle nature and the lack of any tensile strength. The addition of polypropylene fibres in plane concrete, it has increased the ductility and energy absorption capacity of concrete [18].
In the present investigation mechanical behaviour of HSFRC is studied by incorporating various types of fibres.

1.3. Need for Investigation

The higher compressive strength and ductility are the most important parameters in the design of RCC structures. However, it is observed that ductility of concrete reduces with higher compressive strengths. Inclusion of fibres may arrest the cracks and improve tensile strength of concrete and thus ductility.

1.4. Objectives and Scope

The investigation is focused to study the effect of same types of fibres with different aspect ratio on compressive strength, split tensile strength and flexural strength of HSC. The water to cementitious material ratio considered for the study of HSFRC was 0.25. The content of silica fume and fly ash in every mix was 5% and 10% by the weight of cementitious material. Six types of fibres considered for the study include, Two types of Hook Ended Steel Fibres (HESF) having dimensions (0.45 × 25mm) and 1×60mm). Dosage of fibre was varied from 0.5% to 4% at an interval of 0.5% by weight of cementitious material. Type of cement, fine aggregate, coarse aggregate, type of superplasticiser and its dosage are kept constant in every mix.

II. Experimental Program

There are 8 mixes cast using single type of fibre. Thus there are in all 16 mixes cast using two types of fibres.

The details of the experimental programme are given in Table 2.1

Table 2.1: Schedule of Experimental Program

Sr. No.	Mix designation of M80 grade HSFRC	Fibre content (%)	No. of specimen (cubes, cylinders and prisms each) using types of Fibres	
			HESF (0.45×25mm)	HESF (1×60mm)
1	M0	0.0	3	
2	M1	0.5	3	3
3	M2	1.0	3	3
4	M3	1.5	3	3
5	M4	2.0	3	3
6	M5	2.5	3	3
7	M6	3.0	3	3
8	M7	3.5	3	3
9	M8	4.0	3	3

2.1. Materials

Ordinary Portland Cement of 53 Grade conforming to IS: 12269-1987 was used in the investigation. The properties of cement are presented in Table 2.2 .

Table 2.2: Physical Properties of Ordinary Portland Cement (OPC).

Sr. No.	Description of Test	Results
01	Fineness of cement (residue on IS sieve No. 9)	6%
02	Specific gravity	3.15
03	Standard consistency of cement	30 %
04	Setting time of cement a) Initial setting time b) Final setting time	 118 minute 322 minute
05	Soundness test of cement (with Le-Chatelier's mould)	1mm
06	Compressive strength of cement (a) 3 days (b) 7 days (c) 28 days	 41.03 N/mm^2 55.44 N/mm^2 77.82 N/mm^2

Crushed stone metal with a maximum size of 12.5 mm from a local conforming to the requirements of IS: 383-1970 was used. Locally available river sand passing through 4.75 mm IS sieve conforming to grading zone-II of IS: 383-1970 was used.The properties of aggregates are presented in Table 2.3

Table 2.3: Physical Properties of Fine and Course Aggregate

Sr. No	Property	Results	
		Fine Aggregate	**Course aggregate**
1.	Particle Shape, Size	Rounded, 4.75 mm down	Angular, 10mm down
2.	Fineness Modulus	2.38	6.87
3.	Silt content	2%	-----------
4.	Specific Gravity	2.624	2.684
5.	Bulking of sand	4.16%	0.4%
6.	Bulk density	1586.26 kg/m^3	1565 kg/m^3
7.	Surface moisture	Nil	Nil

Sulphonated melamine based super plasticizer supplied by Roff. Chemicals India Pvt. Ltd. Mumbai is used as water reducing and self retarding admixture in the experimental work. The properties comply with the requirements of IS 9103-1999 (Amended 2003) as well as ASTM C 494-type F.

The fly ash are used which available from Nashik. The specific gravity of fly ash was 2.3. The properties of fly ash are presented in Table 2.4

2.4: Physical Properties of Fly Ash

Sr. No.	Description of Test	Results
01	Specific Gravity	2.3
02	Colour	Grayish white
03	Bulk Weight	Approx. 0.9 metric ton per cubic meter
04	Specific density	Approx. 2.3 metric ton per cubic meter
05	Average Particle size	0.14mm
06	Particle shape	Spherical

The properties of various types of fibres considered for the study are presented in Table 2.4

Table 2.4: Properties of Fibres used

Sr. No.	Property	Values of various types of fibres	
		HESF (0.45×25mm)	**HESF (1×60mm)**
2.	Length (mm)	25	1
4.	Diameter (mm)	0.45	60
6.	Aspect Ratio	55.55	60
7.	Colour	White	White
8.	Specific Gravity	7.85	7.85
9.	Density kg/m^3	1.36	1.36
10.	Tensile strength MPa	400	1000
11.	Melting point	$253\,^{o}C$	$253\,^{o}C$
10	Young's modulus kN/mm^2	25.19	25.19
13.	Water absorption	0.04%	0.04%
14.	Minimum elongation	8%	8%
15.	Resistance to alkali in high strength concrete	Excellent	Excellent
16.	% Elongation	8	8
17.	Effective Diameter mm	0.456	0.456

2.2: **Production of HSFRC Concrete**

The high strength concrete of M80 grade was designed as per DOE method. Table 2.5 shows the weights of various constituents of HSFRC.

Table 2.5: Mix Proportion

Sr. No	Material	Weight of material in Mass kg/m^3
1	Ordinary Portland Cement (85 % of CM)	472.6
2	Silica fume (5 % of CM)	27.8
3	Fly Ash (10 % of CM)	55.6
4	Fine Aggregate	702
5	Coarse Aggregate	1042
6	Water	150
7	Superplasticizer	18 ml per kg of Cement
8	Water Binder Ratio	0.25

3. RESULT AND DISCUSSION

3.1. Compressive strength

For compression test, cube specimens of dimensions (100×100×100mm) were cast. and tested at the age of 28 days. The compressive strength results for each type of fibre and its volume fraction are shown in Table 3.1

Table 3.1: Compressive Strength at 28 Days

Sr. No	Fibres Volume Fraction *Vf* (%)	Compressive Strength of HSFRC at 28 Days in N/mm^2 for two types of fibres	
		HESF (0.45×25mm)	HESF (1×60mm)
1	0	82.50	82.50
2	0.5	82.67	83.33
3	1.0	86.16	83.67
4	1.5	92.50	87.00
5	2.0	93.50	91.33
6	2.5	95.50	96.83
7	3.0	99.67	97.50
8	3.5	81.67	96.33
9	4.0	75.83	87.50

3.2. Split Tensile Strength

For split tensile strength test, cylinder specimens of dimensions (100×200mm) were cast in concrete laboratory. Split tensile strength was calculated as,

Split Tensile strength (N/mm^2) = $\frac{2P}{\pi}$ DL,

where P= failure load, D= diameter of cylinder, L=Length of cylinder. The average results of split tensile strength are shown in Table 3.2

Table 3.2: Split Tensile Strength at 28 Days

Sr. No	Fibres Volume Fraction *Vf* (%)	Split Tensile Strength At 28 Days (N/mm^2)	
		HESF (0.45×25mm)	HESF (1×60mm)
1	0	4.66	4.66
2	0.5	5.51	6.36
3	1.0	6.36	6.5
4	1.5	6.64	6.79
5	2.0	6.79	6.8
6	2.5	6.93	7.07
7	3.0	6.79	7.14
8	3.5	6.36	5.58
9	4.0	5.23	5.44

3.3. Flexural Strength

For flexural strength test, prisms of dimensions (100 × 100 × 500 mm) were cast in concrete laboratory. Flexural strength was calculated as,

Flexural strength (N/mm^2) f_t = $\frac{2P_l}{\pi DL}$, where P= failure load, D= depth of prism, L=Length of prism. The average results of flexural strength are shown in Table 3.3

Table 3.3: Flexural Strength at 28 Days

Sr. No	Fibres Volume Fraction *Vf* (%)	Flexural Strength At 28 Days (N/mm^2)	
		HESF (0.45×25mm)	HESF (1×60mm)
1	0	16.3	16.3
2	0.5	16.53	16.41
3	1.0	17.16	16.53
4	1.5	17.53	16.56
5	2.0	18.06	17.067
6	2.5	18.36	18.76
7	3.0	17.43	19.43
8	3.5	15.76	15.56
9	4.0	15	15.43

The discussion on each result is presented in the following sections

3.4. Effect of fibres content (%) on Compressive Strength of High Strength Concrete

The effect of Silica fume, fly ash and the two types fibres on compressive strength of concrete as shown in figure 3.1. The fibre volume fraction is indicated on X-axis and compressive strength is on Y-axis. The compressive strength increases significantly due to the addition of fibres compared with normal high strength concrete. In general, the compressive strength of the concrete having Hooked End Steel Fibres (HESF (0.45×25mm) was higher than that of concrete with other fibres at the same volume fractions of fibres up to the limit. The compressive strength of concrete with all fibres is increased up to the 3 % of fibres volume fraction and then decreases. The maximum values of compressive strength at 3 % fibres volume fraction are 99.67 N/mm^2 and 97.5 N/mm^2 for HESF (0.45 × 25mm) and HESF (1×60mm) respectively.

3.5. Effect of fibres content (%) on Split Tensile Strength of High Strength Concrete

The effect of Silica fume, fly ash and six types of fibres on split tensile strength of a high strength fibres reinforced concrete has been shown in figure 3.2. The fibre volume fraction is indicated on X-axis and split tensile strength is on Y-axis.The result from Table 2.4 shows that the cylinder split tensile strength of concrete increases considerably with an increase in fibres content. A continuous increase in strength is observed up to a limit. The 3.5 % of fibres content has given maximum increase in split tensile strength as compared to that of normal concrete. The Hooked End Steel Fibres (HESF 0.45×25mm) gives maximum split tensile strength of 6.67N/mm^2 than that of other type of Fibres.

3.6. Effect of fibres content (%) on Flexural Strength of High Strength Concrete

The effect of Silica fume, fly ash and six types of fibres on flexural strength of a high strength fibres reinforced concrete has been shown in figure 3.3. The fibre volume fraction is indicated on X-axis and flexural strength is on Y-axis.The result from Table 2.4 shows that the prism flexural strength of concrete increases considerably with an increase in fibres content. A continuous increase in strength is observed up to a limit. The 3.5 % of fibres content has given maximum increase in flexural strength as compared to that of normal concrete. The Hooked End Steel Fibres (HESF 1×60mm) gives maximum flexural strength of 19.43N/mm^2 than that of other type of Fibres.

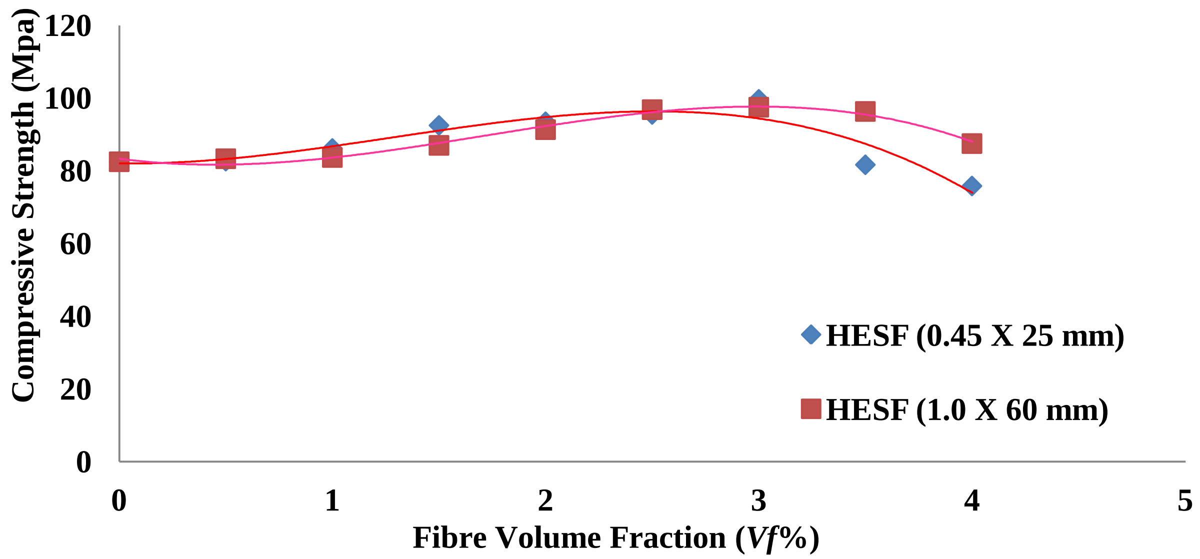

Fig. 3.1 Variationof Compressive Strength at 28 Days With to Percentage Fibre Volume Fraction

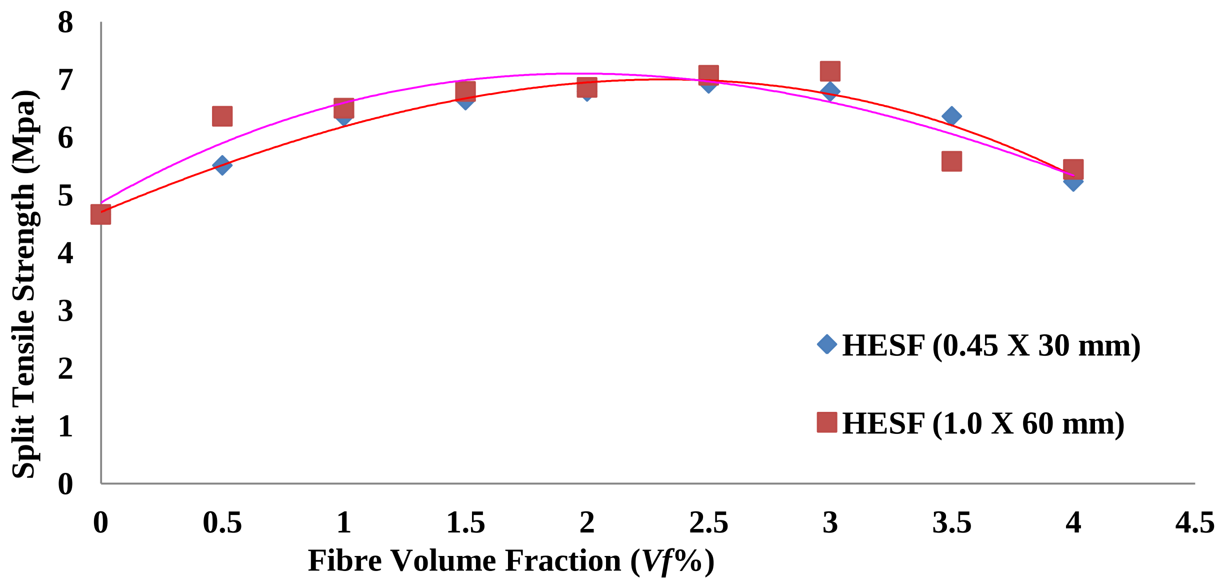

Fig. 3.2 Variation at Split Tensile Strength at The Age of 28 days With Respect to Percentage Fibre Volume Fraction

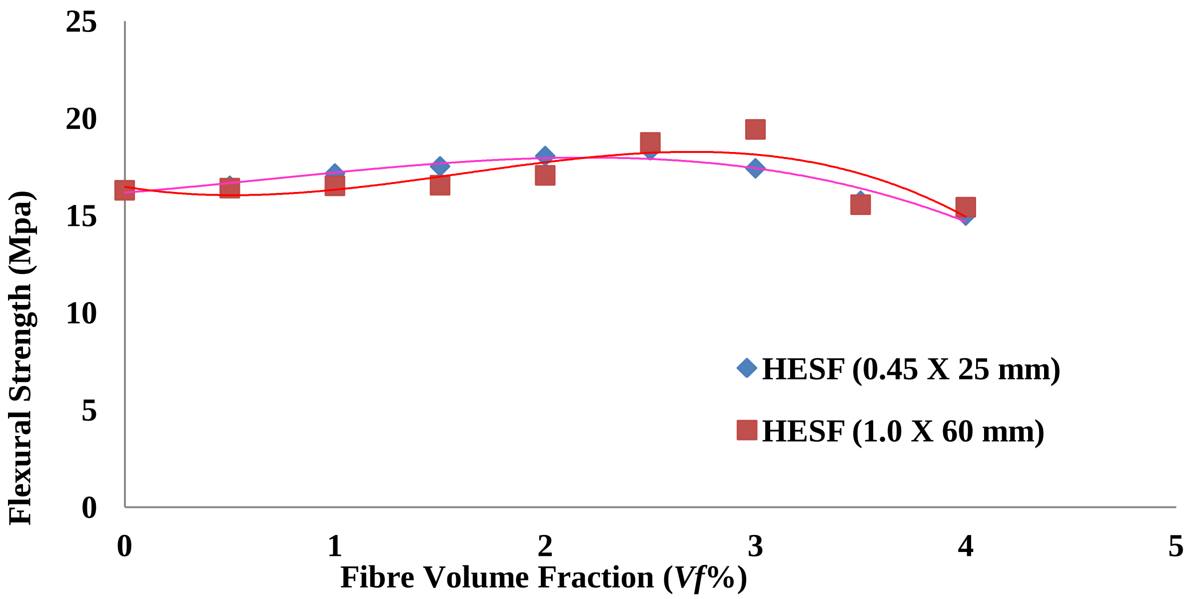

Fig.3.3 Variation of Flexural Strength at 28 Days With Respect to Percentage Volume Factor

4. Conclusion

From the results discussed in the previous section, following conclusions are drawn.

1) HSC without fibres is relatively brittle and fails suddenly when compared with HSFRC with different types of fibres.
2) The compressive strength of HSC improves with addition of fibres. The maximum strength was occurred at 3% of volume fraction of each fibres. The obtained strength for two types of fibres viz. Hooked end steel fibre (0.45×25mm), Hooked end steel fibre (1×60mm) is as follws i.e 99.67 and 97.50. From the results the higher compressive strength is obtained 99.67 Mpa for Hooked end steel fibre (0.45×25mm).
3) The split tensile strength of HSC improves with addition of fibres. The maximum strength was occurred at 3% of volume fraction of each fibres. The obtained strength for six types of fibres viz.,
4) Hooked end steel fibre (0.45×25mm), Hooked end steel fibre (1×60mm), Flat steel fibre and waving steel fiber is as follows i.e 6.79 and 7.14. From the results the higher compressive strength is obtained 7.14 Mpa for Hooked end steel fibre (1×60mm).
5) The flexural strength of HSC improves with addition of fibres. The maximum flexural strength was occurred at 2.5% of volume fraction of hooked end steel fibre (0.45×25mm) i.e. 18.36 Mpa and 3% of volume fraction of hooked end steel fibre (1×60mm) is as follows i.e 19.43 Mpa. From the results the higher Flexural strength is obtained 19.43 Mpa for hooked end steel fibre (1×60mm).
6) The results obtained in the study are plotted in graphs for each types of test of HSFRC. The study of graph has been concluded that the maximum variations are obtained in split tensile strengths graph as compared to compression and flexural strengths graph.

From this study it is concluded that the use of fibres in HSC can increase the mechanical properties of HSFRC for split tensile strength as compare to compressive and flexural strength.

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