MECHANICAL PROPERTIES OF HIGH STRENGTH FIBER REINFORCED CONCRETE USING STEEL FIBERS AND SILICA FUME

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High Strength Concrete (HSC) is characterized by low strain failure and hence exhibit a rather brittle mode of failure. This marked brittleness can be overcome by the addition of steel fibers. This paper investigates the mechanical properties of high-strength steel fiber-reinforced concrete. Corrugated steel fibers are added in the volume fractions of 0.5%, 1.0%, and 1.5% and the Silica Fume content is varied as 6%, 8%, 10% and 12%. The results indicated that there is substantial increase in the compressive and tensile strengths of concrete with the increasing volume fraction of fibers. The experimental investigations involved measurement of compressive and splitting tensile strengths, stress-strain behaviour and postcracking behaviour.

Keywords : High Strength, fibers, Silica Fume, Compression, Tension, cracking.

1 Introduction

In recent years, HSC is receiving increasing attention because of its rapid application in bridges, tall structures, pavements and marine structures. But HSC is more brittle than normal strength concrete and has low rate of increase in tensile strength. These features of HSC are not suitable for its application in earthquake zones, as ductility is an important criteria for earth quake resistant design. With widely increasing application of HSC in large scale constructions world wide, the need for improving the ductility of HSC is felt. This can be achieved by addition of steel fibers to concrete. To study the role of Silica Fume with steel fibers, an experimental investigation is carried out by replacing cement with 0%, 6%, 10% and 12% Silica Fume and addition of Corrugated steel fibers in the volume fractions of 0.5%, 1.0%, and 1.5%. This paper presents in detail the experimental work and the effect of volume fraction of fibers and Silica Fume.

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2. Experimental Program

The experimental work involves casting and testing of 63 cubes of size 100 x 100x 100 mm, 12 cylinders of 150 mm diameter and 300 mm height and 4 beams of 100 x 220 mm c/s and 2.2 m span. The details of the specimens cast are given in table 1.

Table 1 Details of specimens

Specimen	% of Silica fume	% of Steel fibers	No. of cubes	No. of Cylinders	No. of beams
Varying % of fiber content with 10 % Silica Fume					
FRC 10/0	10	0	9	-	-
FRC 10/0.5	10	0.5	9	-	-
FRC 10/1.0 *	10	1.0	9	-	-
FRC 10/1.5	10	1.5	9	-	-
Varying % of Silica Fume with 1.0 % fiber content					
FRC 0/1.0	0	1.0	9	3	1
FRC 6/1.0	6	1.0	9	3	1
FRC 10/1.0 *	10	1.0	9	3	1
FRC 12/1.0	12	1.0	9	3	1

* Same specimens

2.1 Materials

Ordinary Portland cement of specific gravity 3.15 was used. River sand is used as fine aggregate and maximum size of the coarse aggregate was limited to 10 mm. Portable water was used in the work for both mixing and curing. Corrugated steel fibers of diameter of 0.6 mm and aspect ratio 80 were used. Superplasticizer (SP), Glenium V233 was used for workability. The silica fume with Specific surface area of 20 m^2/Kg was used.

2.2 Preparation and testing of Specimens

First, weighed quantities of cement and Silica Fume are mixed thoroughly in dry state in the machine mixer. Fine aggregate and coarse aggregate are then mixed together in the mixer separately and then, to this mixture cement blended with Silica Fume is added. After a few minutes of rotation, steel fibers are added uniformly with special care so that no balling of concrete takes place. Superplasticizer in measured quantity is added to the water and mixed well. The water is then added to the concrete and the mixing is continued until a thorough mix is obtained with sufficient workability. The specimens are cast and after 24 hrs they are cured in curing tank and tested for gain in compressive strength at 3 days and 7 days and 28 days strength.

3. Results and Discussions

3.1 Compressive strength (Table 3)

Table 3 Experimental results for varying fiber content and Silica Fume Volume

Specimen	% of Silica Fume	% of Steel Fibers	Compressive Strength (MPa)		
			3 days	7 days	28 days
FRC 10/0	10	0	28.7	31.6	40.6
FRC 10/0.5	10	0.5	31.2	41.0	49.2
FRC 10/1.0	10	1.0	32.0	42.9	58.6
FRC 10/1.5	10	1.5	33.8	54.0	63.2
FRC 0/1.0	0	1.0	24.2	28.0	42
FRC 6/1.0	6	1.0	32.0	38.4	51.6
FRC 12/1.0	8	1.0	28.4	38.6	48.0

3.1.1 Effect of Silica Fume

From the results obtained, it is observed that, the replacement of cement with Silica Fume increases the compressive strength of concrete considerably. Replacement of cement with silica fume in volume fractions of 6%, 10% and 12% and with steel fibers content being 1.0%, resulted in increase in strength upto 53%. Addition of 6% SF increased the compressive strength at 3 days by 32.2%. For 10% Silica Fume the increase in compressive strength was 35.5% while with further increase in volume of Silica Fume to 12% the increase in the stress is 17.3%. Similarly, on 7 days curing, the increase in compressive strength is found to be 37.1%, 53.2% and 37.95 % for 6%, 10% and 12% Silica Fume respectively, while after 28 days, the increase is 22.8%, 39.5%, 14.3%. However beyond 10 % with further increase in replacement with a Silica Fume, there is decreasing trend in the compressive strength of concrete, (Figure 1). The percentage variations are shown in Figures 2 & 3

3.1.2 Effect of fiber content

The experimental results of cube testing indicated that, by replacement with 10% silica fume and addition of steel fibers with various volume fractions of 0%, 0.5%, 1.0%, and 1.5%, the compressive strength enhanced. Addition of 0.5% steel fibers increased the compressive strength at 3 days by 8.7%. For 1.0% fiber volume the increase was 11.5% while with further addition of fibers to 1.5% the increase in the stress is 17.7%, clearly indicating the increase in the strength with increase in fiber content as shown in Figure 4. After 7 days, the increase in strength is 29.7%, 35% and 70% for fiber contents of 0.5%, 1.0% and 1.5% respectively. And after 28 days, the results showed that the increase in compressive strength for 05%, 1.0% and 1.5% fiber content was 21.8%, 44.3% and 55.7% respectively, indicating that the addition of steel fibers increases the compressive strength of concrete(Figure 4).

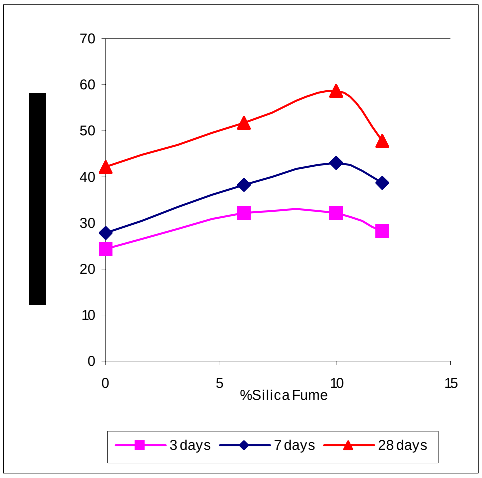

Figure 1 Effect of Silica Fume on Compressive strength

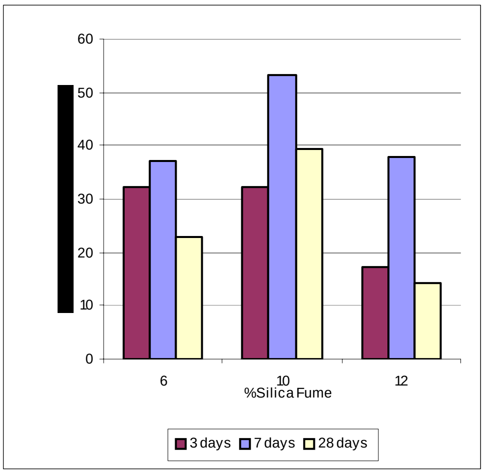

Figure 2 % variation of compressive strength with Silica Fume

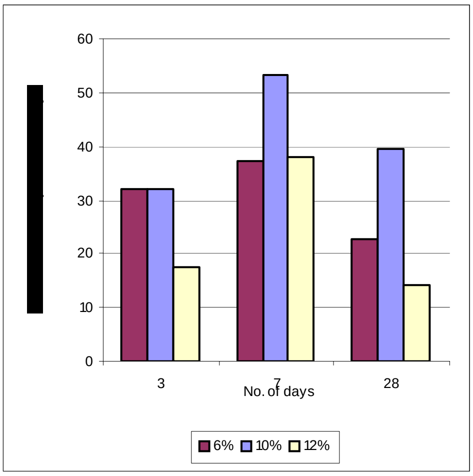

Figure 3. % increase in Compressive strength with Silica Fume

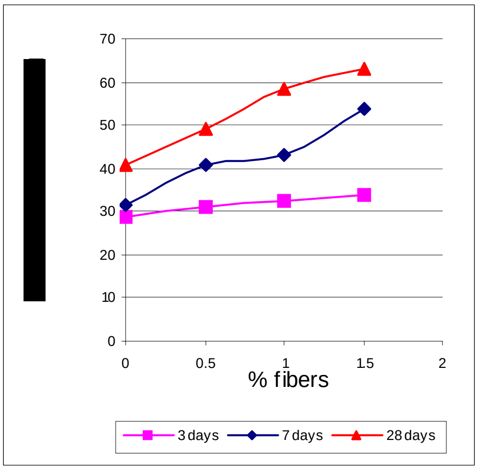

Figure 4 Effect of fiber content on Compressive strength

3.2 Split Tensile Strength

Table 4 Split Tensile Strength of Cylinders

S.No	Specimen	% of Silica fume	% of Steel Fibers	Split Tensile Strength 28 days (Mpa)
1	FRC 0/1.0	0	1.0	4.2
2	FRC 6/1.0	6	1.0	5.0
3	FRC 10/1.0	10	1.0	6.7
4	FRC 12/1.0	12	1.0	6.3

The results obtained (Table 4) show that there is a considerable increase in tensile strength. Replacement of cement with silica fume in volume fractions of 6%, 10% and 12% and with steel fiber content being 1.0% resulted in increase in strength. Addition of 6% SF increased the tensile strength at 28 days by 19.0%. For 10% SF the increase in tensile strength was 59.5% while with further increase in volume of SF to 12% the increase in strength is 50.0%. (Figure 5).

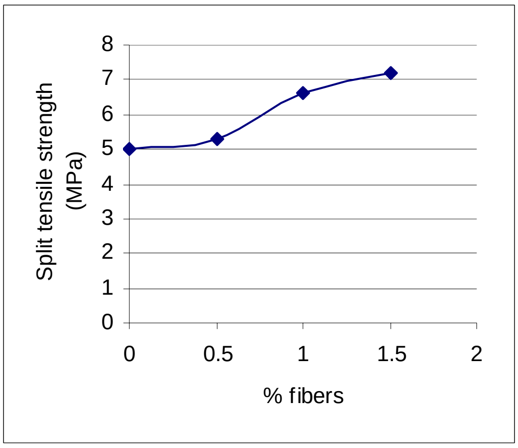

Figure 5 Split tensile strength at 28 days

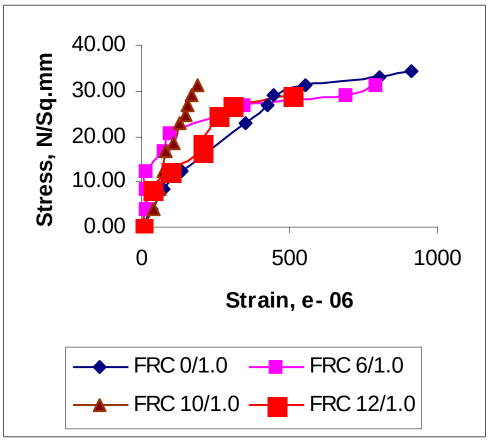

Figure 6 Stress –Strain curves for different % of Silica Fume.

3.3 Stress –Strain Behaviour

The HSC possesses a steeper descending stress-strain curve in compression than does the normal strength concrete. The Figure 6 clearly indicates that with the increase in the strength of the concrete, the member becomes more stiff and the stress-strain curve has become more steeper. The addition of steel fibers effectively restrain the initiation and propagation of cracks under stress and improve the toughness of HSC.

3.4 Cracking Behavior

3.4.1 Under Compression

- At about 25-30% of the ultimate strength, random cracking (usually in transition zone around large aggregates) occurred.
- At about 50% of ultimate strength, cracks grow stably from transition zone into paste. Also, microcracks start to develop in the paste.
- At about 75% of the ultimate strength, paste cracks and bond cracks start to join together, forming major cracks. The major cracks keep growing while smaller cracks tend to close.
- At the ultimate load, failure occurs when the major cracks link up along the vertical direction and split the specimen

3.4.2 Under Flexure

All beams exhibited vertical flexural cracks on both the front and back face of the beams. Following the formation of the first flexural crack, the number of cracks near the maximum bending moment increased with increased load, most of the flexural cracks occurred at about 40% to 60% of the ultimate load. The inclusion of steel fibers in concrete beams resulted in reduced crack width at all stages of loading upto to failure. The number of cracks and ductility increased. The effectiveness of steel fibers in reducing cracks can be attributed to the average spacing of fibers inside the matrix. The increased volume of steel fibers increased the cracking arresting capacity of concrete, thus enhancing the energy absorption of the specimen.

4. Conclusions

1) Silica Fume and steel fibers can be effectively used to produce High Strength Concrete with increased ductility.
2) The compressive strength increased upto 55%, while the split tensile strength increased upto 44% for 10% Silica fume replacement and 1.5% fiber volume.
3) The addition of Silica fume contributed to the early strength of concrete. There is substantial gain in strength in the first 3-7 days.
4) The compressive strength increased with the content of Silica Fume and beyond, 1.0% replacement with Silica Fume, there is slight decrease in strength, but still remaining 17.4% more that the initial value.
5) The compressive strength of HSC increased with fiber fraction and showed a maximum at 1.0% fraction of fibers but at 1.5% fraction there is slight decrease compared to 1.0%.
6) Steel fibers improved the crack arresting mechanism and made the concrete more ductile improving serviceability conditions.

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