Effects of Steel Fibers on Mechanical Properties of High Strength Fiber Reinforced Concrete

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Abstract

The effect of high temperature on the mechanical properties of concrete reinforced by high strength steel fibers with various aspect ratios has been investigated in this detailed study. Now a days from industrial point of view a great attention has been given to the use of additive materials such as high strength steel fibers in concrete and cement products. On Investigations it has been revealed that the addition of high strength steel fibers into normal concrete impart significant improvement for controlling its surface cracking, along with increasing their tensile strength, durability and flexural strength. Considering the advantages of these additive materials, high strength concrete samples were resulted with different mix designs. The tests show that mixed use of steel fibers give excellent results in terms of improving mechanical strength , structural characteristics of the concrete material developed. In all samples, the surface cracking of concrete was decreased significantly by adding suitable fibers in terms of sort, diameter, and length. So that, these newly developed structural concrete have promising potentials for further research, development as well as an structurally important building block material.

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1. Introduction

In recent decades due to huge demand for concrete in construction activities, it has become an essential material. With addition the need for a type of concrete which have high performance and durability. To improve mechanical properties of concrete high strength steel fibers reinforced in it is known for many decades [1].

Research and design of steel fiber reinforced concrete and began to increase about 50 years ago. Various types of steel fibers have been developed by researcher. They differ in size, shape and surface structure. Adding fibers enhances the compressive, tensile and shear strengths, flexural toughness, durability and resistance to impact. It has been increasingly used in applications of structural engineering which shown in fig 1. the surface cracking of concrete was decreased significantly by adding these steel fibers in terms of sort, diameter, and length to develop structurally important material[2][3]. When the compressive strength of concrete is 60-240 Mpa, it is called "High Strength Concrete" and it is used for the construction of important structures such as thermal power stations, bridges, highway pavements, high rise buildings, blast resistant structures and others. For making high-strength concrete, High-Strength Concrete (HSC) has been utilized widely in the structural engineering with high-strength demands [4][5]. With the vigorous development of construction engineering, high-performance concretes (HPC) such as steel fiber-reinforced concrete was applied gradually in various important engineering structures[6-10]. high-performance concretes(HPC), for the advantages of low cost, easy fabrication materials, and performance improvements, so that steel fiber-reinforced concrete was used widely in the current structure engineering field [9, 10]. In this study, samples were cast according to current standard provisions and tested at different ages in order to examine the mechanical properties of produced concrete. The samples were cured at the ages of 7 days and 28 days in order to study the influence of the properties of concrete. Results obtained showed that some properties of HSC are influenced by curing conditions at a variation of steel fiber content, and these properties are highlighted in the paper.

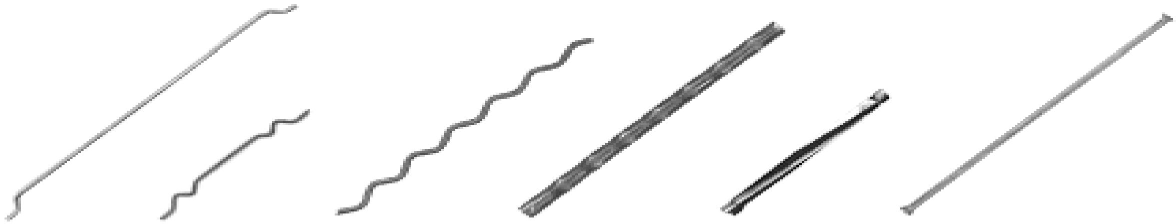


Fig 1 Different types of steel fibers

2.Experimental procedure

2.1. Materials and mixture proportions

2.1.1 Ordinary Portland Cement (OPC): The cement used in the experiments was Ordinary Portland Cement of Grade 53, which conforms to IS12269:1987. The specific gravity of OPC (OPC) cement is 3.15; the initial setting time is 30 minutes. The normal consistency of cement is 30% and the particle size range lies between 31µm and 7.5µm.

2.1.2 Fine Aggregate: In concrete technology, the specific gravity of aggregate is used in the design calculation of concrete mixes. The Standard specification in IS: 2386 part III of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates. In this study, artificial sand dust was used. The specific gravity is 2.6.

2.1.3 Coarse Aggregate: The ideal coarse aggregate should be clean, cubical, angular, and 100% crushed aggregate with a minimum of flat and elongated particles, ACI 363R, 1992. The specific gravity of aggregate is used in the design calculation of concrete mixes in concrete technology. The Standard specification in IS: 2386 part III of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates. In this study, as a coarse aggregate, less than 10 mm of aggregate was used. The specific gravity of this aggregate is 2.82.

2.1.4 Water: The requirement for water conforming to IS: 10262:2019 is found to be suitable for making concrete. The minimum water requirement for 10mm aggregate is 200kg/m3, as confirmed by IS: 10262:2019 table-7 (clause 6.2.4).A water reducing agent was used for this investigation. 30% water reduced by super-plasticizer and 10% water reduced by fly ash, a total of 40% water reduced from the total amount of water in cubic meter.

2.1.5 Fly Ash: Fly ash acts as a cementitious material and reduces the 10% requirement of water. In this present work, fly ash was used as a cementitious material. Confirming IS: 10262: 2019 table no. 9 (clause 6.2.6), 15% fly ash is used with the replacement of cement.

2.1.6 Silica Fume: It is a very fine non-crystalline SiO_2 is a by-product of producing silicon metal or ferrosilicon alloys. It acts as an excellent pore filling material. It can be used in proportions of 5-10% of the cement content in a mix. Confirming IS: 10262:2019, table no. 9 (clause 6.2.6). For this experimental investigation, 5% silica fume was used.

2.1.7 Super-plasticizer: For the present investigation, High Range Water Reducer (HRWR) super-plasticizer has been used, which is based on poly-carboxylate ether (PCE) for obtaining workable concrete at a low water to binder ratio. The specific gravity of PCE-based super-plasticizer is 1.10. For this investigation, a 1% dose of SP was used by weight of cement, which reduces the requirement of water by 30%.

2.1.8 Steel Fiber: Steel fibers were used in this experiment to enhance the ductility of the concrete. Steel fiber was used in this research work at a variation of 0-3.5% at an interval of 0.5% by weight of cementitious material. Flat end crimped steel fiber with a length of 35mm and a thickness of 2mm is used.

Table 1. Mix proportions of concrete

Sr.No	1	2	3	4	5	6	7	8
MATERIALS	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (l/m^3)	Silica Fume(kg/m^3)	Fly Ash (kg/m^3)	Super-plasticizer (l/m^3)	w/c ratio
QUANTITY	400	813.15	1136.85	120	25	75	5	0.24

Mix proportion are shown in Table 1.For High Strength Concrete, the chosen grade of concrete was M_{60} and the mix design was made for a suitable proportion based on the test results of the materials.

Table 2. Properties of Steel Fiber

1	2	3	4	5	6	7	8
Type of fiber	Material	Length of fiber	Thickness of fiber	Specific gravity	Tensile strength	Appearance	Applications
Flat end crimped	Low carbon drawn flat wire	35mm	2mm	7.8	500-750mpa	Clear, bright, flat end crimped steel fiber	Tunnel shot create, industrial flooring road and pavement

3.Test methods

Initially, the specimens were cast using a 0.24 water to binder ratio. Below 10 mm of aggregate, artificial sand dust was used as fine aggregate, while fly ash (15%) and silica fume (5%) were used as cementitious materials. The High-Range Water Reducer PCE based super-plasticizer was used at a 1% dose of cementitious material and gave variation to the concrete by the addition of steel fibers from 0 to 3.5 % by weight of cement at an interval of 0.5%. In this experimental work, the behavior of mechanical properties of high strength concrete such as compressive, split tensile, flexural, and additional bond strength were observed. For the compressive test, cube molds of size 100mm×100mm×100mm were used for the casting of specimens. 48 specimens were cast at different steel fiber variations for 7 days and 28 days of curing before compressive strength tests could be performed. Similar to compressive strength, the split tensile strength of specimens was also tested. The specimens used were cast by using cylindrical molds with a diameter of 150 mm and a length of 300 mm. For the flexural strength test, beams or prisms of size 100mm×100mm×500mm were used, and to check the bond strength between concrete and steel, the pull out test was carried out on 150mm cube molds and 16mm bars were used.

4. Result and Discussion

During the curing periods of 7 and 28 days, three specimens for each curing period were tested for their compressive strength(fc), and their average compressive strength was shown in table 3. From the table, it was identified that the mix of 2.5% steel fiber has a higher compressive strength than other steel fiber content. The graphical representation of the test results is given fig2.

Table-3: Average compressive strength (N/mm²) at 7days and 28days curing period.

Sr.No.	1	2	3	4	5	6	7	8
Steel fiber	0%	0.5%	1%	1.5%	2%	2.5%	3%	3.5%
7 Days	40.66	41.33	42.50	43.33	44.16	45.66	40.16	38.33
28 Days	68.83	69.16	70.83	71.66	73.00	74.16	69.00	65.83

Table-3 shows The relationship between the compressive strength and steel fiber volume fraction and aspect ratio. It clearly demonstrates that the compressive strength increases with increasing fiber volume fraction and aspect ratio. However, it shows a relatively lower rate of increase. Test results show the compressive strength varied from 40.66 to 45.66 in periods of 7 days and 68.83 to 74.16 in periods of 28 days. The ultimate strength of concrete is mainly controlled by the strength of the lightweight coarse aggregate itself.

When the compressive load reached a certain level of strength, concrete failure occurred. Which shown in Table3.The incorporation of steel fiber into matrix serves to increase the compressive strength by the resultant arresting growth of cracks based on the bond of steel fiber and cement paste. In the test, it was found that the dispersion of fiber became very difficult, when the fiber volume fraction was further increased to 2.5%, and for this reason, concrete was not fully compacted. Concrete compressive strength increased with increasing ratio of the fiber,

Fig.2 compressive strength at the age of 7 and 28days curing

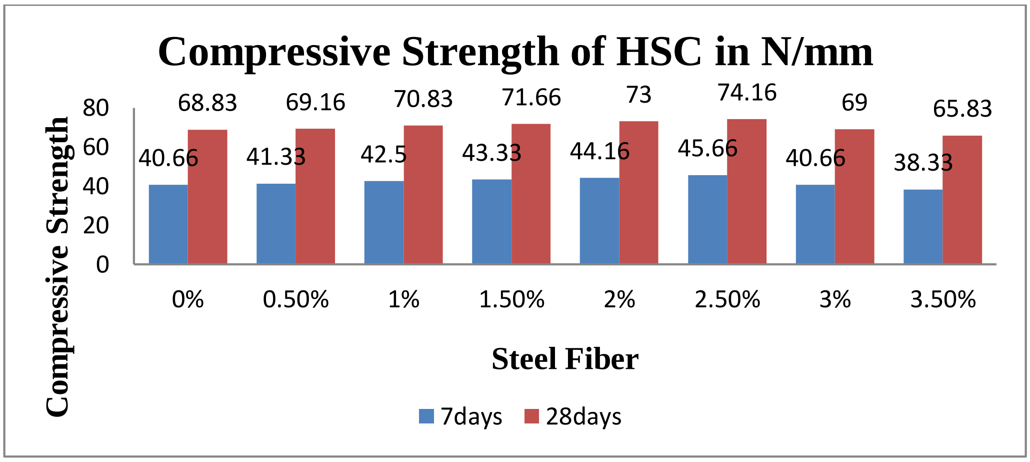


Table-5: split tensile strength (N/mm²) at 7days and 28days curing period.

Sr.No	1	2	3	4	5	6	7	8
Steel fiber	0%	0.5%	1%	1.5%	2%	2.5%	3%	3.5%
7days	2.40	2.90	3.37	3.77	4.29	3.85	3.62	2.92
28days	3.70	4.48	5.28	5.80	6.60	4.85	4.71	4.62

with self-consolidating properties however mixtures with steel fibers volume were more difficult to place them in the molds then non steel fibre. After the 28 curing days, the samples were tested to investigate its tensile behavior.

When the fiber volume fraction increased from 0% to 2%, the splitting tensile strength also increased .The rate of increase of splitting tensile strength is 9-78%, depending on the various fiber volume fraction and aspect ratios. For a lower fiber volume fraction, any improvement in the splitting tensile strength of concrete is hardly effective. Therefore, in order to improve the splitting tensile strength of steel fiber-reinforced the high-strength the split tensile strength test was conducted on HSC cylinders at the ages of 7 and 28 days of curing and the results obtained are presented in Table-3. According to Figure 2, 2.5% steel fiber yields the best results

Fig-3: Split Tensile Strength at the age of 7 and 28days curing

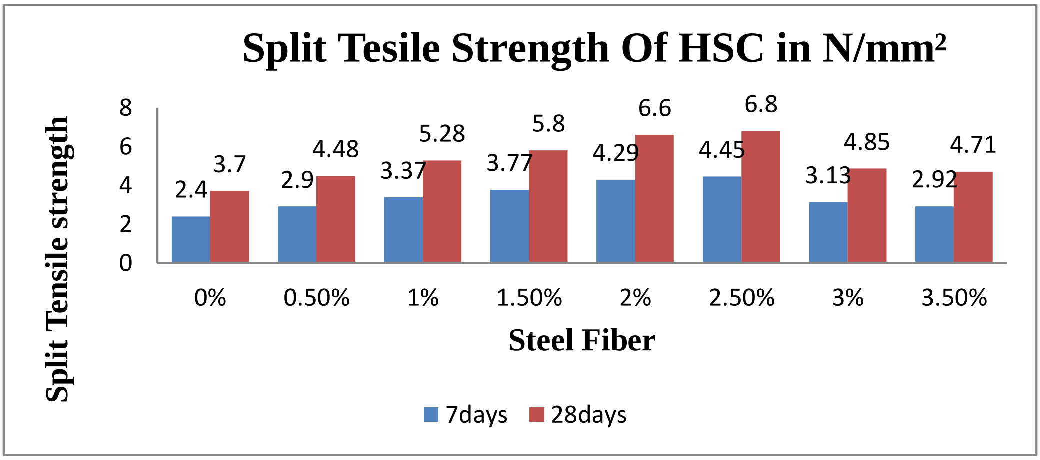


Table-6: Flexural strength (N/mm²) at 7days and 28days curing period.

Sr.No.	1	2	3	4	5	6	7	8
Steel fiber	0%	0.5%	1%	1.5%	2%	2.5%	3%	3.5%
7 Days	2.50	2.81	2.94	3.09	3.30	3.54	2.72	2.58
28 Days	3.78	4.32	4.37	4.58	4.80	5.17	4.13	3.98

When the fiber volume fraction increased from 0 to 2.5%, flexural strength increased from 2.50 to 3.57 in 7 days and 3.78 to 5.17 Mpa in 28 days. The rate of increase of flexural strength is 9.6 to 90%, depending on the fiber volume fraction and aspect ratio. The fracture process of steel fiber-reinforced concrete consists of progressive bonding of fiber, during which slow crack propagation occurs. Final failure occurs due to unstable crack propagation when the fiber pull out and the interfacial shear stress reach the ultimate bond strength. The reason for the increase in flexural strength is that, after matrix cracking, fibers will carry the load that the concrete sustained until cracking by interfacial bond between fibers and matrix. At higher aspect ratios, the advantage of fibers in increasing flexural strength of concrete seems to be more pronounced.

Fig-4: Flexural Strength at the age of 7 and 28days curing

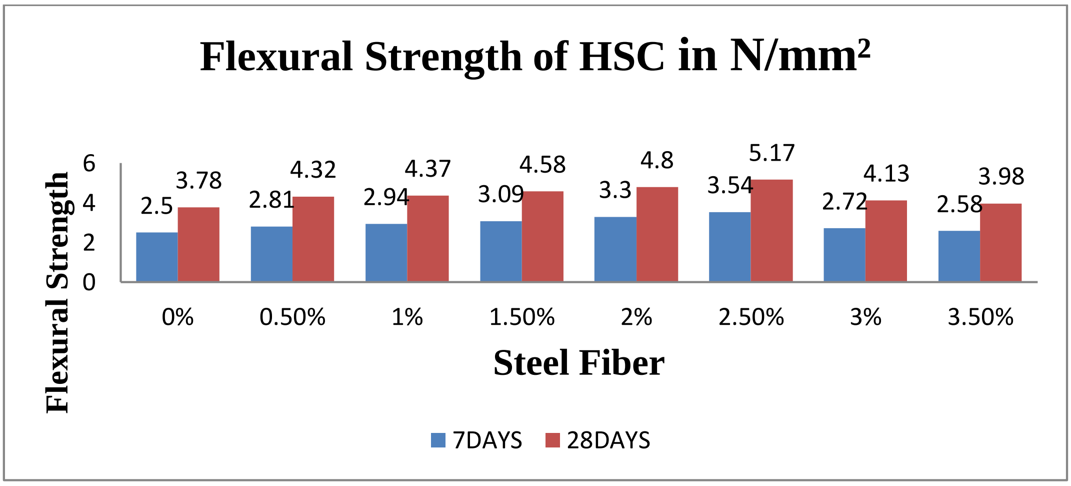
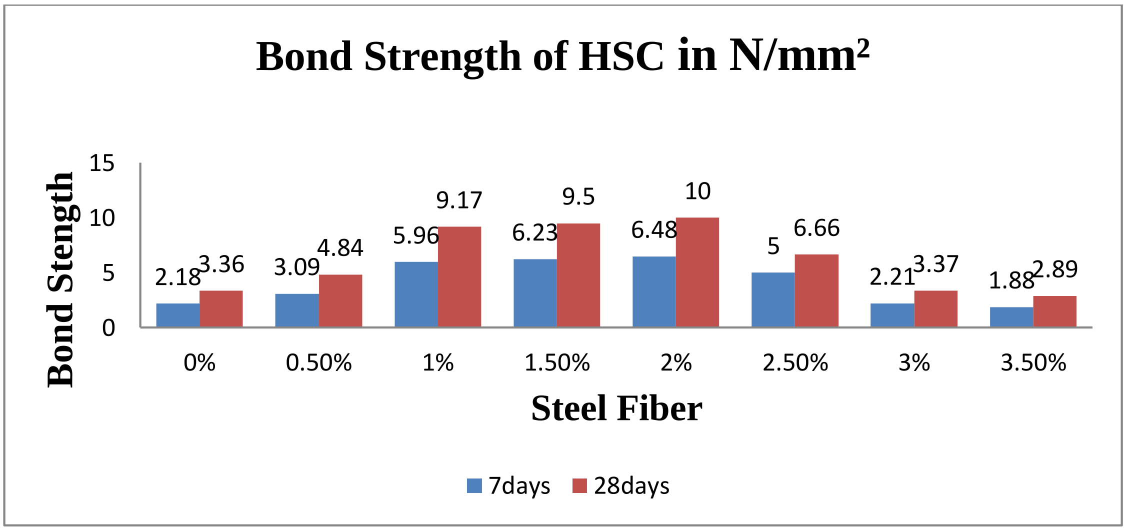


Table-7: Bond strength (N/mm²) at 7days and 28days curing period.

Sr.No.	1	2	3	4	5	6	7	8
Steel fiber	0%	0.5%	1%	1.5%	2%	2.5%	3%	3.5%
7 Days	2.18	3.09	5.96	6.23	6.48	5.00	2.21	1.88
28 Days	3.36	4.84	9.17	9.50	10	6.66	3.37	2.89

The pull out test was conducted on HSC cubes of size 150mm150mm150mm and a bar of 16mm in diameter, confirming IS: 2770-1967 for bond strength. The results are presented in table-5 and the graph is represented in figure-4. The higher bond strength resulted from the 2% addition of steel fiber

Fig-5: Bond Strength at the age of 7 and 28days curing



5. Conclusions:

Steel Fibres play an important role in reaching a definite load bearing capacity after the matrix fracture, depending on allocation, orientation and embedded length. All these features are influenced by concrete composition (aggregate size and shape, concrete content, w/c-ratio, admixtures), fibre type As it was shown in this study, there is a clear dependence of the post-cracking load on the fibre content. Strength of fibers have a direct influence on the load bearing capacity. Using high-strength fibres resulted in a clearly better ductile behaviour and higher load levels in the post-cracking range, compared to normal strength ones.

In this case the contribution of fibres to the load bearing capacity of beams. Experiments show that using high-strength fibres in bar reinforced HSC beams compared to beams with normal-strength fibres, was observed. In cases of fibre contents of 0 and 20 kg/m3 the specimens, containing bar reinforcement of 1%, failed in shear or compression. For specimens with fibre content of 40 kg/m3 primary compression failure was observed. For fibre content of 60 kg/m3 the HSC beams with longitudinal reinforcement ratio of 1% failed in compression only.

Following are the conclusion drawn from the above research work

1. At 2.5%, addition of steel fiber gives optimistic compressive strength
2. At 2.5%, addition of steel fiber gives optimistic flexural strength
3. At 2.5%, addition of steel fiber gives optimistic split tensile strength
4. At 2%, addition of steel fiber gives optimistic bond strength
5. The use of steel fiber in concrete could enhance the strength in concrete.
6. Use of steel fiber in high strength concrete it provides ductility to concrete.
7. These experimental studies were carried out on high-strength concrete (HSC). The addition of steel fiber to high-strength concrete improves mechanical properties and makes the material attractive for applications in construction. One of the most important roles of steel fibers in high-strength concrete structures and elements is to provide the ductile behaviour required for proper structural response to dynamic loadings. Fiber also limits crack development and propagation in structural concrete elements.

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