Experimental Study on Behavior of Steel and Glass Fiber Reinforced Concrete Composites

Kavita S Kene, Vikrant S Vairagade and Satish Sathawane

Abstract--- *Concrete is most widely used construction material in the world. Fiber reinforced concrete (FRC) is a concrete in which small and discontinuous fibers are dispersed uniformly. The fibers used in FRC may be of different materials like steel, G.I., carbon, glass, aramid, asbestos, polypropylene, jute etc. The addition of these fibers into concrete mass can dramatically increase the compressive strength, tensile strength, flexural strength and impact strength of concrete. FRC has found many applications in civil engineering field. Based on the laboratory experiment on fiber reinforced concrete (FRC), cube and cylinders specimens have been designed with steel fiber reinforced concrete (SFRC) containing fibers of 0% and 0.5% volume fraction of hook end Steel fibers of 53.85, 50 aspect ratio and alkali resistant glass fibers containing 0% and 0.25% by weight of cement of 12mm cut length were used without admixture. Comparing the result of FRC with plain M20 grade concrete, this paper validated the positive effect of different fibers with percentage increase in compression and splitting improvement of specimen at 7 and 28 days, analyzed the sensitivity of addition of fibers to concrete with different strength.*

Keywords--- *Compressive Strength, Fiber Reinforced Concrete, Glass Fibers, Split Tensile Strength, Steel Fibers*

I. Introduction

CEMENT concrete is characterized by brittle failure, the nearly complete loss of loading capacity, once failure is initiated. This characteristic, which limits the application of the material, can be overcome by the inclusion of a small amount of short randomly distributed fibers (steel, glass, synthetic and natural) and can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc [1,4].

The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cemetitious material, aggregate and water and by adding some special ingredients [5]. Hence concrete is very well suited for a wide range of applications. However concrete has some deficiencies as low tensile strength, low post cracking capacity, brittleness and low ductility, limited fatigue life, not capable of accommodating large deformations, low impact strength [3].

The presence of micro cracks at the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibers in the mix [22]. Different types of fibers, such as those used in traditional composite materials have been introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibers help to transfer loads at the internal micro cracks. Such a concrete is called fiber-reinforced concrete (FRC). Thus fiber-reinforced concrete is a composite material essentially consisting of conventional concrete or mortar reinforced by fine fibers [10].

The fibers can be imagined as an aggregate with an extreme deviation in shape from the rounded smooth aggregate [4]. The fibers interlock and entangle around aggregate particles and considerably reduce the workability, while the mix becomes more cohesive and less prone to segregation. The fibers are dispersed and distributed randomly in the concrete during mixing and thus improve concrete properties in all directions. Fibers help to improve the post peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength and eliminate temperature and shrinkage cracks [6].

Essentially, fibers act as crack arrester restricting the development of cracks and thus transforming an inherently brittle matrix, i.e. cement concrete with its low tensile and impact resistances, into a strong composite with superior crack resistance, improved ductility and distinctive post-cracking behavior prior to failure [2,3].

Hence, this study explores the feasibility of used of metallic and synthetic fibers; aim to do parametric study on compressive strength, tensile strength study etc. for a given grade of concrete, aspect ratio and various percentages of fibers.

II. Literature Survey

Presently, a number of laboratory experiments on mechanical properties of SFRC have been done. Shah Surendra and Rangan [07], in their investigations conducted uni-axial compression test on fiber reinforced concrete specimens. The results shown the increase in strength of 6% to 17% compressive strength, 18% to 47% split tensile strength, 22% to 63% flexural strength and 8% to 25% modulus of elasticity respectively. Byung Hwan Oh [11], in their investigations, the mechanical properties of concrete have been studied, these results shown the increase in strength of 6% to 17% compressive strength, 14% to 49% split tensile

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strength, 25% to 55% flexural strength and 13% to 27% modulus of elasticity respectively. Barrows and Figueiras [12], in their investigations the mechanical properties of concrete have been studied. These results shown the increase in strength of 7% to 19% compressive strength, 19% to 48% split tensile strength, 25% to 65% flexural strength and 7% to 25% modulus of elasticity respectively. Chen S. [13] investigated the strength of 15 steel fiber reinforced and plain concrete ground slabs. The slabs were 2x2x0.12m, reinforced with hooked end steel fibers and mill cut steel fibers. Dwaraknath and Nagaraj [14] predicted flexural strength of steel fiber concrete by these parameters such as direct tensile strength, split cylinder strength and cube strength. James and Beaudoin [15] stated that the minimum fiber volume dosage rate for steel, glass and polypropylene fibers in the concrete matrix was calculated approximately 0.31%, 0.40% and 0.75%. Patton and Whittaker [16] investigated on steel fiber concrete for dependence of modulus of elasticity and correlation changes on damage due to load. Rossi et. al [17], analyzed that the effects of steel fibers on the cracking at both local level (behavior of steel fibers) and global level (behavior of the fiber/cement composite) were dependent to each other. Sener et. al[18], calibrated the size effect of the 18 concrete beams under four-point loading. Swami and Saad [26], had done an investigation on deformation and ultimate strength of flexural in the reinforced concrete beams under 4 point loading with the usage of steel fibers, where consists of 15 beams (dimensions of 130x203x2500mm) with same steel reinforcement (2Y-10 top bar and 2Y-12 bottom bar) and variables of fibers volume fraction (0%, 0.5% and 1.0%). Tan et. al [9] concluded some investigation on the shear behavior of steel fiber reinforced concrete. Six simply supported beams were tested under two- point loading with hooked steel fibers of 30mm long and 0.5mm diameter, as the fiber volume fraction increased every 0.25% from 0% to 1.0%. Vandewalle [8], had done a similar crack behavior investigation, which based on combination of five full scale reinforced concrete beams (350x200x3600mm) with steel fibers (volume fraction of 0.38% and 0.56%).In his investigation, the experimental results and theoretical prediction on the crack width was compared.

III. EXPERIMENTAL PROGRAM

A. Material Used

Cement, sand, coarse aggregate, water, steel and glass fibers were used.

Cement: The cement used was Ordinary Portland cement (43 Grade) with a specific gravity of 3.15. Initial and final setting time of the cement was 20 min and 227 min, respectively. Ordinary Portland cement of 43 grade was used, conforming to I.S-8112- 1989 [24].

Sand: Good quality river sand was used as a fine aggregate. Locally available sand, confirming to zone II with specific gravity 2.45, water absorption 2% and fineness modulus 3.18, conforming to I.S. – 383-1970 [21].

Coarse aggregate: Crushed granite stones of maximum 20 mm size having specific gravity of 2.67, fineness modulus of 7.10, conforming to IS 383-1970 [21]

Water: Potable water was used for the experimentation.

Fibers: In this work, effects on strength of concrete with two hook end steel fibers and alkali resistance glass fibers at low volume fraction were studied.

Mild steel wire form, Hook end 35 mm and 50 mm length having density of 7.85 g/cm^3 and minimum tensile strength as 345 MPa, at 0.5% by volume of concrete collected from Stewols Pvt. Ltd. Nagpur, Maharashtra, India, were used. The different aspect ratios adopted were 53.85 and 50 with diameter of fibers 0.93 and 0.7 mm respective.

Physical Properties of used fibers were shown in table1.

Table 1: Description of Different Fibers

Fibre Designation	*Length (mm)*	*Description*	*Dosage of Fibers*	*Aspect Ratio (L/D)*
S1 (Steel)	50	Hook End	0.5% by vol	53.85
S2 (Steel)	35	Hook End	0.5% by vol	50
G (Glass)	12	Alkali Resistance	0.25% by wt	-----

B. Concrete Mix Proportions

The mixture proportioning was done according the Indian Standard Recommended Method IS 10262- 2009[20] and with reference to IS 456-2000 [19]. The target mean strength was 26 MPa for the OPC control mixture, the total binder content was 383 Kg/m^3, fine aggregate was taken 672 Kg/ m^3 and coarse aggregate was taken 1100 Kg/m^3. The water to binder ratio was kept constant as 0.5. The total mixing time was 5 minutes, the samples were then casted and left for 24 hrs before demoulding. They were then placed in the curing tank until the day of testing cement, sand and coarse aggregate were properly mixed together in the ratio 1:1.75:2.87 by weight before water was added and properly mixed together to achieve homogenous material. Water absorption capacity and moisture content were taken into consideration. Cube and cylindrical moulds were used for casting. Compaction of concrete in three layers with 25 strokes of 16 mm rod was carried out for each layer. The concrete was left in the mould and allowed to set for 24 hours before the specimens were demoulded and placed in curing tank. The specimens with and without fiber were cured in the tank for 7 and 28days.

Concrete for M20 grade were prepared as per I.S.10262:2009 with w/c 0.5 [20].

Table 2: Details of Quantity of Constituent Materials

Material	*Quantity*	*Proportion*
Cement	383 Kg/ m^3	1
Sand	672 Kg/ m^3	1.75
Coarse Aggregates (20 mm)	1100 Kg/ m^3	2.87
Water	192 Kg/ m^3	0.5

IV. METHODOLOGY

The tests have been performed to determine the mechanical properties such as compressive strength and splitting tensile-strength of concrete mix with steel fibers 0%, 0.5% by volume of concrete and alkali resistance glass fibers, 0.25% by weight of cement.

A. Compressive Strength Test

The strength of concrete is usually defined and determined by the crushing strength of 150mm x 150mmx150mm, at an age of 7 and 28days. It is most common test conducted on hardened concrete as it is an easy test to perform and also most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. Steel mould made of cast iron dimension 150mm x 150mmx150mm used for casting of concrete cubes filled with steel fibers 0%, 0. 5% by volume of concrete and alkali resistance glass fibers, 0% and 0.25% by weight of cement. The mould and its base rigidly damped together so as to reduce leakages during casting. The sides of the mould and base plates were oiled before casting to prevent bonding between the mould and concrete. The cube was then stored for 24 hours undisturbed at temperature of l8°C to 22°C and a relative humidity of not less than 90% (IS 516-1959).

It also stated in IS 516-1959 that the load was applied without shock and increased continuously at the rate of approximately 140 Kg/sq cm/ min until the resistance of specimen to the increasing loads breaks down and no greater load can be sustained. The maximum load applied to the specimen was then recorded as per IS: 516-1959. The testing of cube and cylinders under compression were shown in figure 1.

The compressive strength was calculated as follows:

Compressive strength (MPa) = Failure load / cross sectional area.

Figure 1: Compression Test on Cube and Cylinders

B. Split Tensile Strength Test

The test was conducted as per IS 5816:1999 [23]. For tensile strength test, cylindrical specimens of dimension 100 mm diameter and 200 mm length were cast. The specimens were demoulded after 24 hours of casting and were transferred to curing tank where in they were allowed to cure for 7 and 28 days. In each category, three cylinders were tested and their average value was reported [10]. The split tension test was conducted as shown in figure 2 using digital compression machine having 2000 kN capacity.

Split tensile strength was calculated as follows:

Spilt Tensile strength (MPa) = 2P / π DL
Where, P = Failure Load (kN)
D = Diameter of Specimen (100 mm)
L = Length of Specimen (200 mm)

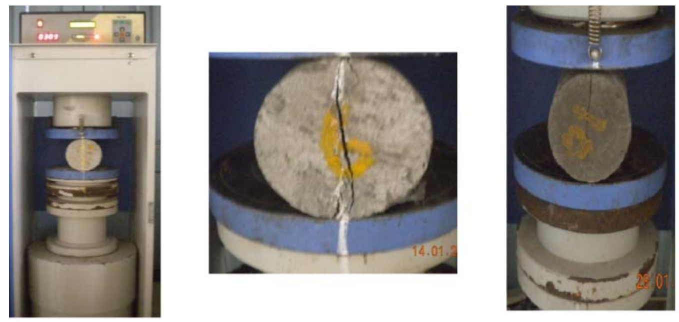


Figure 2: Cylinders under Split tension

V. EXPERIMENTAL RESULTS

A. Compressive Strength Test Results

The compressive strength test is consider the most suitable method of evaluating the behavior of steel fiber reinforced concrete for underground construction at an early age, because in many cases such as in tunnels, steel fiber reinforced concrete is mainly subjected to compression.

Compressive strength of control concrete and concrete with various fibers was calculated by above formula as per I.S. 516:1959 [25]. It is observed that when fibres in discrete form present in the concrete, propagation of crack is restrained which is due to the bonding of fibres in to the concrete and it changes its brittle mode of failure in to a more ductile one and improves the post cracking load and energy absorption capacity [10].

Results of compressive strength for M20 grade of concrete on cube and cylinder specimens with steel fibers 0%, 0.5% by volume of concrete and alkali resistance glass fibers, 0.25% by weight of cement was shown in figure 3 as below.

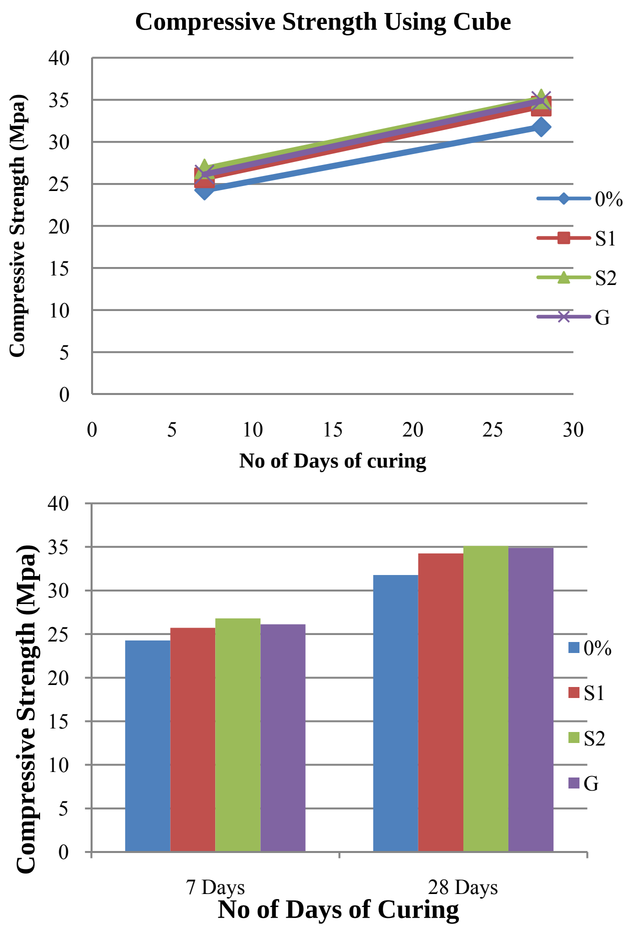
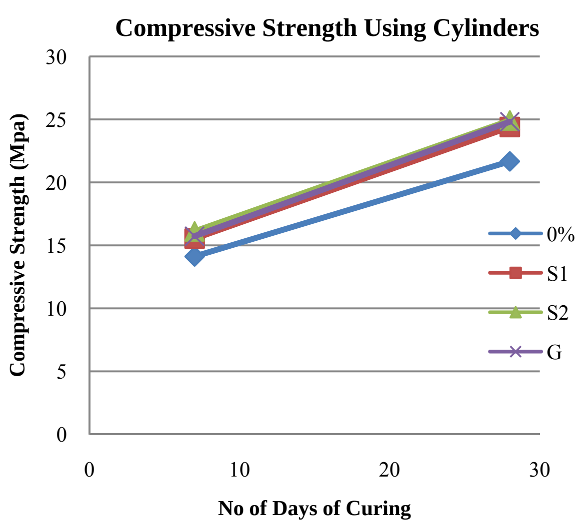


Figure 3: Compressive Strength Using Cube Specimens

Figure 3 indicates the results of compression test on cube for M20 grade of concrete using various fibers at different volume fractions.

It was observed that, addition of 0.5%, 50 mm length, hook end (S2) steel fiber gives max compressive strength in comparison with all other fibers.



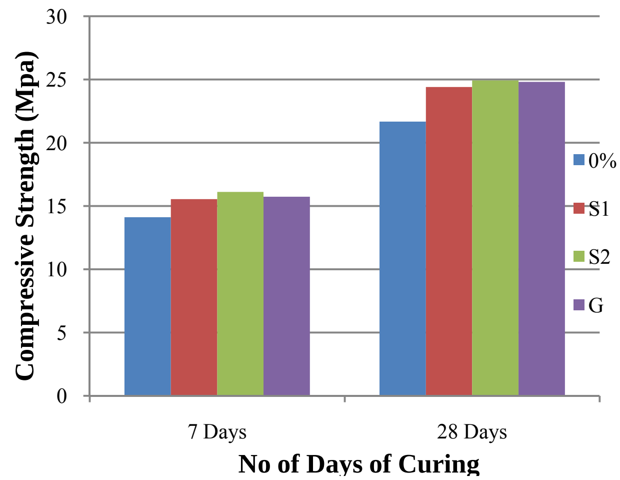


Figure 4: Compressive Strength Using Cylindrical Specimens

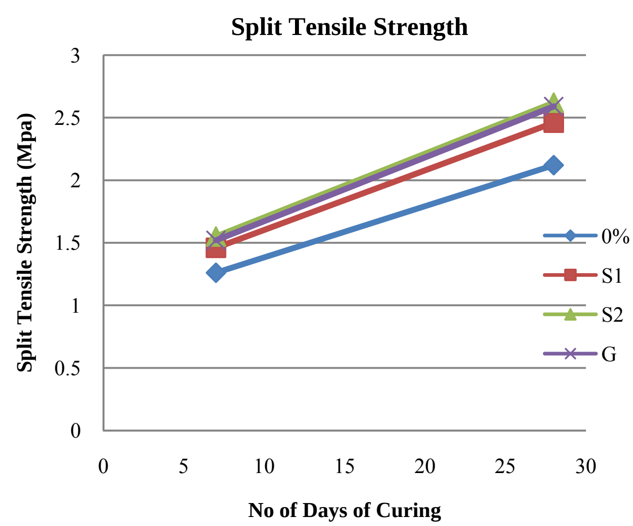
Figure 4 indicates the results of compression test on cylinders for M20 grade of concrete using different fibers at different volume fraction.

It was observed that, addition of 0.5%, 50 mm length, hook end (S2) steel fibers gives max compressive strength using cylinder specimens among all the fibers.

B. Split Tensile Strength Results

Under axial tension, control concrete specimen split into two parts, but FRC specimen shows development of cracks along its longitudinal axis. This may be attributed to the fact that fibers suppress the localization of micro-cracks and consequently the apparent tensile strength of the matrix increases.

Test Results of splitting tensile strength for M20 grade of concrete with steel and glass fibers for given volume fractions as shown in figure 5 below.



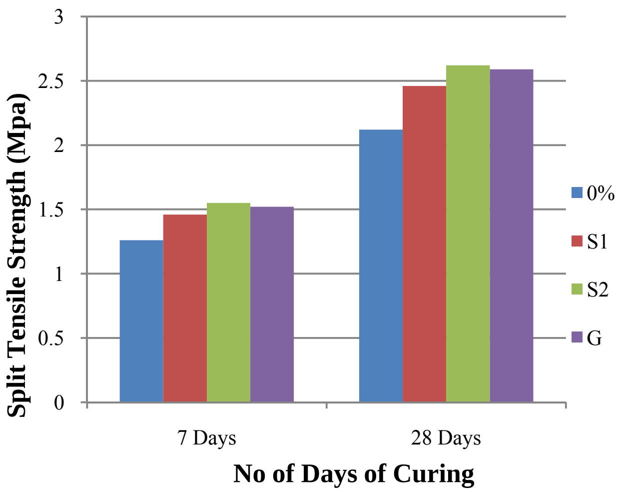


Figure 5: Split Tensile Strength at 7 and 28 days

Figure 5 indicates the results of split tensile strength for M20 grade of concrete using various fibers at different volume fractions.

It was observed that addition of 0.5%, 50 mm length, hook end (S2) steel fibers gives max split tensile strength in comparison with all other fibers.

VI. CONCLUSIONS

The study on the effect of fibers with different sizes and properties can still be a promising work as there is always a need to overcome the problem of brittleness of concrete.

The paper concluded that the addition of steel fibers at 0.5 % by volume of concrete reduces the cracks under different loading conditions.

The brittleness of concrete can also be improved by addition steel fibers than glass fibers. Since concrete is very weak in tension, the steel fibers are beneficial in axial-tension to increase tensile strength.

The following conclusions could be drawn from the present investigation.

1. Max compressive strength for M20 grade of concrete was obtained by addition of 0.5%, 50 mm length, hook end (S2) steel fibers.
2. Max split tensile strength for M20 grade of concrete was obtained by addition of 0.5%, 50 mm length, hook end (S2) steel fibers.
3. Ratio of compressive strength of cylinders to the compressive strength of cube was found to be nearly 3:4.
4. Workability of concrete affected by addition of fibers. Addition of S2 fiber reduces workability of concrete in comparison to other fibers for different volume fraction.

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