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The Behaviour of Steel Fibre Chips as a Partial Replacement of Coarse Aggregate in High Performance Concrete

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Abstract The existing work describes the experimental investigation of steel fiber chip reinforced concrete with M-30 and M-35 grade of concrete in addition of steel fiber chips with different percentages. To over-come the difficulties due to optimum proportion of steel fiber chip for maximum strength in concrete & excessive overall performance concrete. The goal of this investigation work is to look into the most advantageous share of metal fiber chip on M-30 and M-35 grade concrete and enhance an excessive overall performance concrete. It is proposed to decide and evaluate compressive strength, break up tensile strength, flexural electricity & stoop check of concrete grade M-30 and M-35 having different proportion of steel fiber chip (0%, 0.5 %, 1.0 %, 1.5%, 2%, and 2.5 %). Compressive strength, cut up tensile strength, flexural energy will increase up to two percent steel fiber chip for M-30, M-35 grade of concrete. The experimental investigation is carried out on a whole no of 108 specimens for compressive strength, split tensile electricity & flexural strength each.

Key words- steel fiber chip, compressive strength. Split tensile strength. Slump value

I. INTRODUCTION

The Plain concrete has a very low tensile strength, limited ductility, and little resistance to cracking. 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 failure of the concrete. The most widely accepted remedy to this flexural weakness of concrete is the conventional reinforcement with high strength steel. Although these methods provide tensile strength to members, they however do not increase the inherent tensile strength of concrete itself. Also the reinforcement placing and efficient compaction of RCC is very difficult if the concrete is of low workability especially in the case of heavy concrete (M-30 & M-35). In plain concrete and similar brittle materials, structural cracks (micro-cracks) develop even before loading, particularly due to drying shrinkage or other causes of volume change. The width of these cracks seldom exceeds a few microns, but their two dimensions may be of higher magnitude. When loaded, the micro cracks propagate and open up, and owing to the effects of stress concentration, additional cracks form in places of minor defects. The structural cracks proceed slowly. The development of such micro crack is the main cause of inelastic deformation in concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as fibre reinforces concrete.

II. OBJECTIVE

The aim of in this project is to use the Steel Fibres chips as reinforcement to concrete and study various strength parameters with the variation in fibre content.(i.e., to study the strength properties of concrete (M-30 & M-35 Grade) for fibre content of 0 %, 0.5 %, 1.0 %, 1.5%, 2%, 2.5 % at 7, 14 & 28 days. The strength properties being studied in our thesis are as follows:

1. Slump test
2. Compressive strength
3. Split tensile Strength
4. Flexural strength

These properties are then compared to the conventional M30 & M-35 grade cement concrete.

II. LITRATURE REVIEW

Chen et al. (2020) In comparison to normal concrete, ultra-high performance concrete (UHPC) offers better hardness and impact resistance. At high temperatures, UHPC's microstructure and mechanical properties may dramatically decrease. We therefore initially examined the features of UHPC, evaluating its hardened mechanical properties after seven days with a projected 28-day compressive strength of at least 120 MPa in the fresh mix phase. Three test variables were used: the kind of cementing agent and its mixing ratio (silica ash, ultra-fine silicon powder), the type of fibre (steel fibre, polypropylene fibre), and the concentration of fibre (volume percentage). To permit comparison, discussion, and analysis, pure concrete was employed as the control group in the experiment in addition to the UHPC of the experimental group; no supplemental cementitious materials (silica ash, ultra-fine silicon powder) were used. After being exposed to various target temperatures in an electric furnace, the experimental group's UHPC-1 specimens were chosen for additional compressive, flexural, and splitting strength tests as well as SEM examinations. According to the test results, the UHPC-1 mix's 56-day compressive strength at room temperature was 155.8 MPa, exceeding the >150 MPa standard compressive strength criteria for ultra-high-performance concrete. The drying effect of heating resulted in an increase in the residual compressive strength, flexural strength, and splitting strength of the UHPC-1 specimen after exposure to 300, 400, and 500 °C. However, spalling started to happen at 600 °C, which caused the remaining mechanical strength to rapidly decrease. According to SEM findings, polypropylene fibres melt at high temperatures, creating new channels that help lower the UHPC's internal vapour pressure and preserve some residual strength.

Wen et al. (2022) In recent years, interest in ultra-high-performance concrete (UHPC) has grown due to its better mechanical characteristics and exceptional durability. In addition to reviewing the effects of volume fraction, shape, type, aspect ratio, and hybrid fibre combinations on the static and dynamic mechanical properties, fiber-matrix bonding behaviour, and durability of UHPC, this paper introduces the enhancement mechanisms of various fibres on concrete materials. Additionally, a summary is provided of the theoretical models and empirical formulas used to forecast the characteristics of UHPC. The findings suggest that fibres can significantly improve the tensile and fracture strengths of UHPC, and that the ideal fibre volume percentage may depend on the type of fibre used. The properties of UHPC are not significantly impacted by aspect ratio, whereas the impact of hybrid fibre combinations appears to be uncertain and dependent on the synergistic interaction of various fibre types. The results may also be affected by changes in the water/binder ratio, mix proportion, and curing system. The theoretical models and empirical formulas compiled in this paper can also be used to further the design theory of UHPC and make suggestions for future studies.

Fang et al. (2022) We suggested a novel three-dimensional (3D) packing model, taking into account the random distributions of coarse aggregates (CA) and steel fibres, to better understand the damage characteristics of ultra-high performance concrete (UHPC) including coarse aggregates (CA) under load effects. A 3D meso scale model was created based on the packing model to simulate the quasi-static compression characteristics of UHPC. The model considers UHPC to be a four-phase composite made up of steel fibers, CA, interfacial transition zones, and homogeneous mortar matrix. Additionally, using numerical analysis, we looked at the failure characteristics of UHPC specimens with various mix ratios. The simulation and experiment yielded results that concurred with one another, demonstrating the viability of using the mesoscopic model and 3D packing modelling approach to study the mechanical behaviours of UHPC.

IV. MATERIALS USED

The materials used in this investigation were: Portland cement, coarse aggregate of crushed rock with a maximum size of 20 mm, fine aggregate of clean river sand and portable water & Steel chip-Fibres is used. The detailed properties are given in subsequent contents.

A. CEMENT

Portland cement of 43 grades conforming to IS 8112-1989 was used. Tests were carried out on various physical properties of cement and the results are shown in Table -1

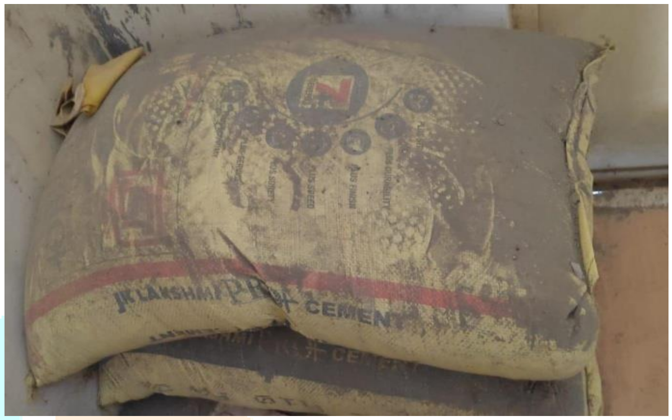


Image 1 Cement

B. FINE AGGREGATE

Natural river sand was used as fine aggregate. The properties of sand were determined by conducting tests as per IS: 2386 (Part- I). The results are shown in Table 3.2. The results obtained from sieve analysis are furnished in Table 3.3. The results indicate that the sand conforms to Zone II of IS: 383 – 1970

C. COURSE AGGREGATE

Crushed granite stones obtained from local quarries were used as coarse aggregate. The maximum size of coarse aggregate used was 20 mm. The properties of coarse aggregate were determined by conducting tests as per IS: 2386 (Part – III). The results are tabulated in Table 3

Image 2 coarse & fine aggregate

D. WATER

Water plays an important role in the formation of concrete as it participates in chemical reaction with cement. Potable water is generally considered satisfactory for mixing. Potable water free from salts was used for casting and curing of concrete as per IS: 456 – 2000 recommendations.

E. STEEL FIBRE CHIP

Stainless steel chips were taken as steel fibres for this study. These are industrial waste of high-grade stainless steel to handle toughest jobs. Since each chip is made of a single strand of stainless steel, they will not tear or splinter. Also, they will not corrode. It has a good tensile strength and the fibre strips length vary by 25 to 50 mm. These fibers will improve toughness, durability and tensile strength of concrete.

Image 3 Sample of steel fibre chip

TABLE.1 PHYSICAL PROPERTIES OF 43 GRADE PORTLAND CEMENT

S.No.	Physical Properties	Values of Portland Cement used	Requirements as per IS 8112-1989
1	Standard Consistency	29.2 %	-
2	Initial Setting Time	45 Minutes	Minimum of 30 minutes
3	Final Setting Time	265 Minutes	Maximum of 600 minutes
4	Specific gravity	3.15	-
5	Compressive strength in N/mm2 at 3 days	29	Not less than
6	Compressive strength in N/mm2 at 7 days	38.5	Not less than
7	Compressive strength in N/mm2 at 28 days	48	Not less than

TABLE.2 SIEVE ANALYSIS OF FINE AGGREGATE

I.S. Sieve Size	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative Percentage Weight Retained	Cumulative Percentage Weight Passing
10 mm	2	2	0.4	99.6
4.75 mm	6	8	1.6	98.4
2 mm	20	28	5.6	94.4
1.18 mm	76	104	20.8	79.2
850 microns	224	328	65.6	34.4
425 microns	114	442	88.4	11.6
150 microns	54	496	99.2	0.8
<150 microns	4	500	100	0.0

TABLE.3 PHYSICAL PROPERTIES OF FINE AGGREGATE

(TESTS AS PER IS: 2386 – 1968: PART III)

S. no	Physical properties	Values
1	Specific gravity	2.65
2	Fineness Modulus	2.83
3	Water Absorption	0.84%
4	Bulk density (kg/m3)	1654

TABLE. 4 PHYSICAL PROPERTIES OF COURSE AGGREGATE

(TESTS AS PER IS: 2386 – 1968 PART III)

S. No	Physical properties	Values
1	Specific gravity	2.65
2	Fineness Modulus	2.73
3	Water Absorption	0.68%
4	Bulk density (kg/m3)	1590
5	Aggregate Impact value (%)	11.2
6	Aggregate Crushing value (%)	25.12

COMPRESSIVE STRENGTH

According to Indian Standard specifications (IS: 516–1959) the compressive strength on each 150×150×150 Cubic specimen was determined in accordance with Compression testing machine. The testing was hydraulic controlled with a maximum capacity of 2000 KN. Load was applied to the specimen at a constant loading rate of 0.5 N until complete failure occurred. The maximum load is recorded and the compressive stress computed by dividing the maximum load by the cross sectional area of the specimen. The type of fracture was also recorded. Figure shows a cube in the testing machine before test.

Image 4. Compression test machine

FLEXURAL STRENGTH TEST

Flexural strength test was conducted as per recommendations IS: 516 – 1959, The flexural strength test was done in Universal testing machine (UTN) on 150×150×700mm beam specimen at each age and the average strength was computed. Before testing, the two loading surfaces were ground evenly by using a grinding stone to ensure that the applied load was uniform. The flexural strength was calculated according to the type of fracture in the beam as follows:

Figure 5. Flexural test setup

Figure shows a typical setup of the beam during testing. If the fracture initiates in the tension surface within the middle third of the span length, then modulus of rupture is calculated as follows:

$$R = \frac{PL}{bd^2}$$

Where R = modulus of rupture (mm³);
P = maximum applied load indicated by the testing machine (N);
L = span length (mm);
b = average width of specimen (mm) at the fracture; and
d = average depth of specimen (mm) at the fracture.

If the fracture occurs in the tension surface outside of the middle third of the span length by not more than 5% of the span length, then modulus of rupture is calculated as follows:

$$R = \frac{3Pa}{bd^2}$$

Where R = modulus of rupture (mm³);
P = maximum applied load indicated by the testing machine (N);
a = average distance between line of fracture and the nearest support measured on the tension surface of the beam (mm);
b = average width of specimen (mm) at the fracture; and
d = average depth of specimen (mm) at the fracture.

If the fracture occurs in the tension surface outside of the middle third span length by more than 5% of the span length, discard the results of the test. Figure shows a typical failed beam specimen after the flexural test.

SPLITTING TENSILE STRENGTH TEST

The Split tensile strength test was carried out on the compression testing machine. The casting and testing of the specimens were done as per IS 5816: 1999. The splitting tensile strength of concrete was done in accordance with Indian Standard on cylindrical specimens (150×300mm). Four lines were drawn along the centre of the cylinder to mark the edges of the loaded plane and to help align the test specimen before the application of load. Figure shows a typical setup of the cylinder during testing. A strip of wood, 3-

mm thick and 25-mm wide, was inserted between the cylinder and the platens; this helped the applied force to be uniformly distributed. Load was applied and increased under a controlled rate until failure by indirect tension in the form of splitting along vertical diameter took place.

Image 7. Splitting tensile setup

Figure shows a typical failed sample. The splitting tensile strength of a cylinder specimen was calculated using the following equation:

$$T = \frac{2P}{\pi LD}$$

Where T = splitting tensile strength of cylinder (mm³);
P = maximum applied load (N);
L = average length of cylinder (mm); and
D = average diameter of cylinder (mm).

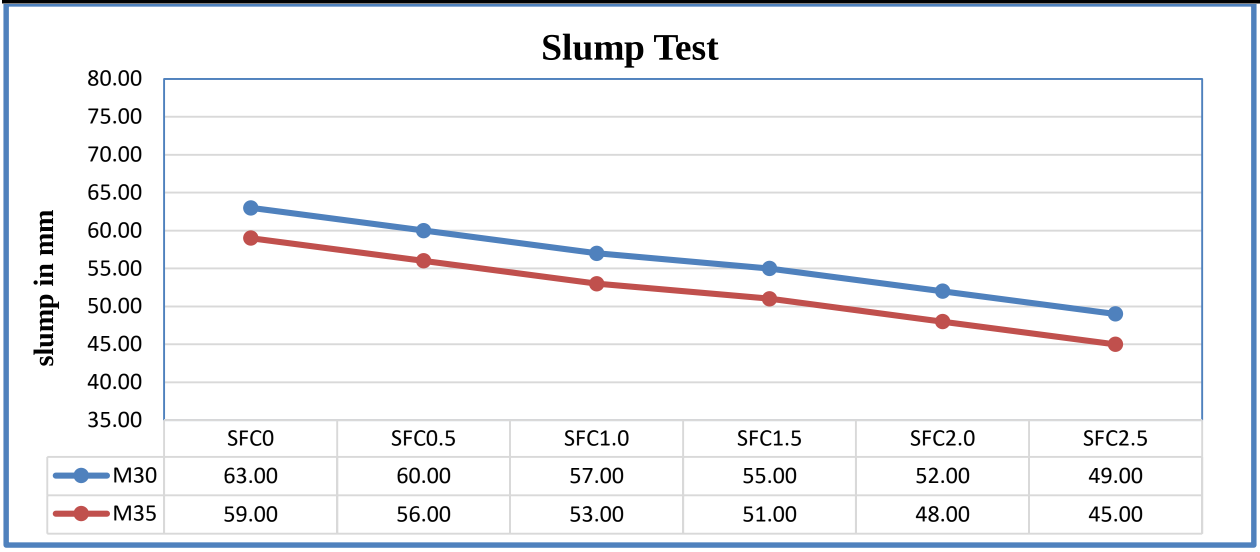
IV. RESULTS AND DISCUSSION

Fresh mix characteristics are more emphasized in fibre concrete compared to the plain concrete. Generally increasing weight fraction of fibres results in further reduction of fresh concrete workability, in this study, fibres as steel fibre chips of different volume fractions like 3 %, 6 %, and 9 % and length of fibre lengths is 25mm to 40 mm.

SLUMP TEST

TABLE 5 SLUMP TEST RESULTS

S. No.	% Replacement of Steel fibre chip	Slump for M30	Slump for M35
1	M25SFC0	63	59
2	M25SFC0.5	60	56
3	M25SFC1.0	57	53
4	M25SFC1.5	55	51
5	M25SFC2.0	52	48
6	M25SFC2.5	49	45



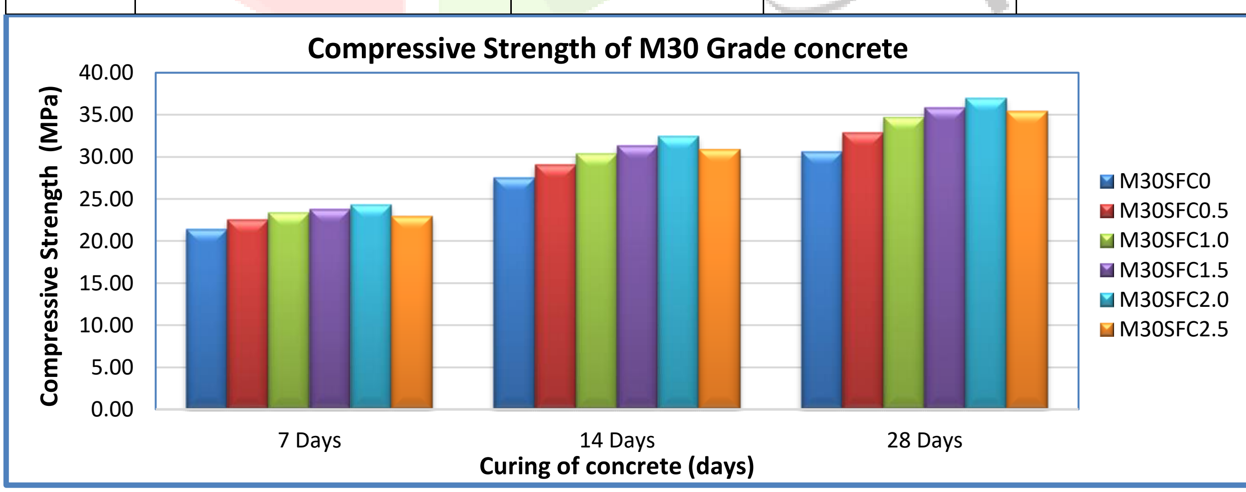
Graph -1 slump value with steel fiber (Grade M-30 & M-35)

CUBE COMPRESSIVE STRENGTH

Totally 72 cube specimens of size 150 mm x150 mm x 150 mm with 3 mixes were casted and tested. Three volume fractions were considered for steel fibre chips (3%, 6% and 9% of steel fibres chip). Results for compressive strength based on the average values of three test data are shown in Table-6, 7 and 8. A sample comparisons graph for steel fibres chip concrete is plotted to study the effect of fibre reinforcement on conventional concrete strength which is shown in Graph..2, and 3

Table 6 – Compressive Strength of M30 Grade concrete in N/mm^2

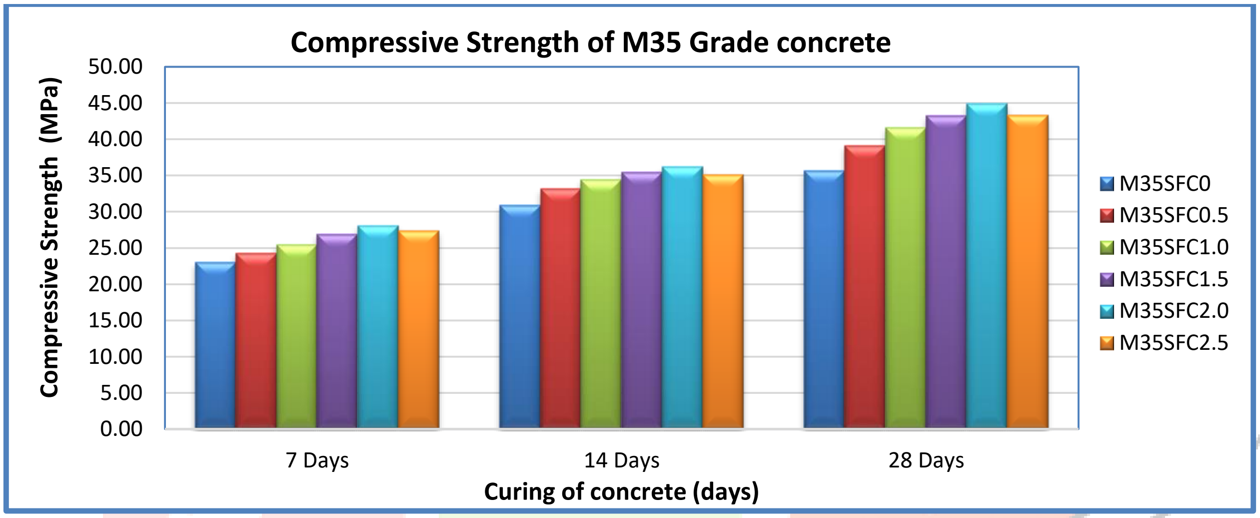
S. No.	% of Steel fibre chip	Grade of Concrete		
		7 Days	14 Days	28 Days
1	M30SFC0	21.40	27.50	30.60
2	M30SFC0.5	22.54	29.10	32.90
3	M30SFC1.0	23.35	30.40	34.70
4	M30SFC1.5	23.78	31.30	35.86
5	M30SFC2.0	24.30	32.43	36.98
6	M30SFC2.5	22.93	30.87	35.43



Graph 2 – Compressive Strength of M30 Grade concrete

Table 7 – Compressive Strength of M35 Grade concrete in N/mm²

S. No.	% of Steel fibre chip	Grade of Concrete		
		7 Days	14 Days	28 Days
1	M35SFC0	23.00	30.92	35.66
2	M35SFC0.5	24.26	33.16	39.12
3	M35SFC1.0	25.45	34.44	41.62
4	M35SFC1.5	26.88	35.47	43.25
5	M35SFC2.0	28.10	36.25	44.94
6	M35SFC2.5	27.35	35.10	43.36



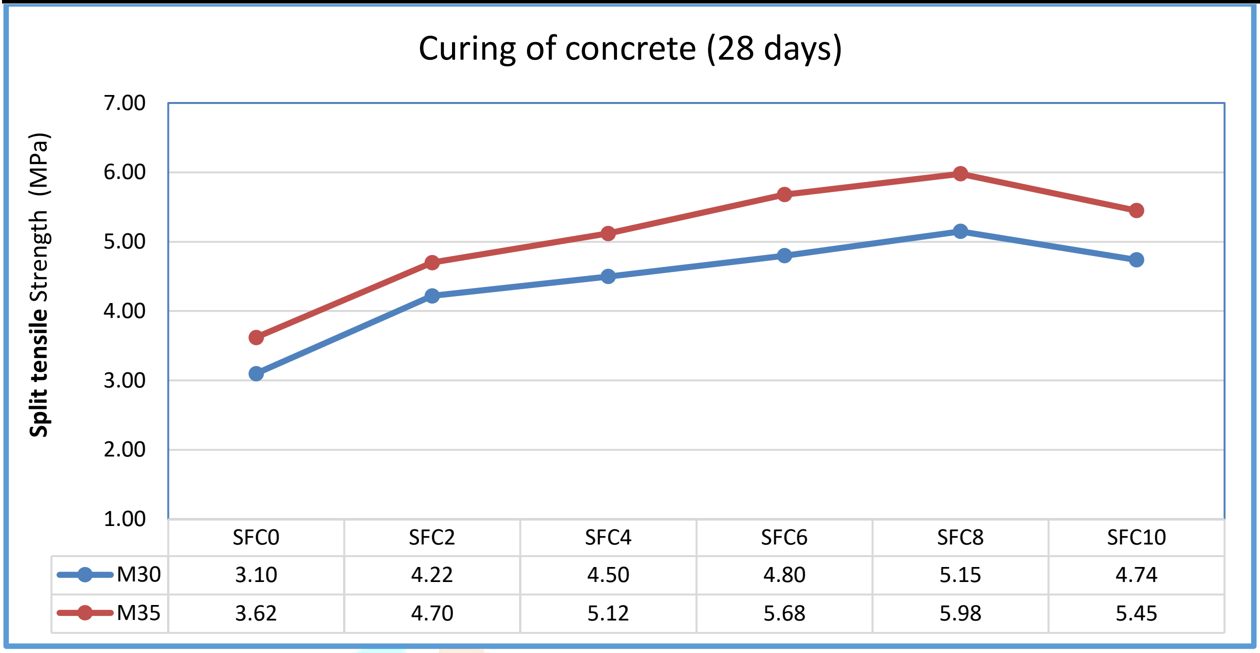
Graph 3 – Compressive Strength of M35 Grade concrete

SPLIT TENSILE STRENGTH

Totally 72 cylinder specimens of size 100 mm diameter and 300 mm height with 3 different % mixes were casted and tested. Three weight fractions were considered for steel chip fibres of constant length. Results for split tensile strength based on the values of test data. A sample comparison graph for steel fibres chip concrete is plotted to study conventional concrete strength which is shown in Graph..The values of the split tensile strength of different mixes are shown in Table

Table 8 – 28 days Split tensile strength of Cylinder in N/mm²

S. No.	% of Steel fibre chip	Grade of Concrete	
		M30	M35
1	SFC0	3.10	3.62
2	SFC0.5	4.22	4.70
3	SFC1.0	4.50	5.12
4	SFC1.5	4.80	5.68
5	SFC2.0	5.15	5.98
6	SFC2.5	4.74	5.45



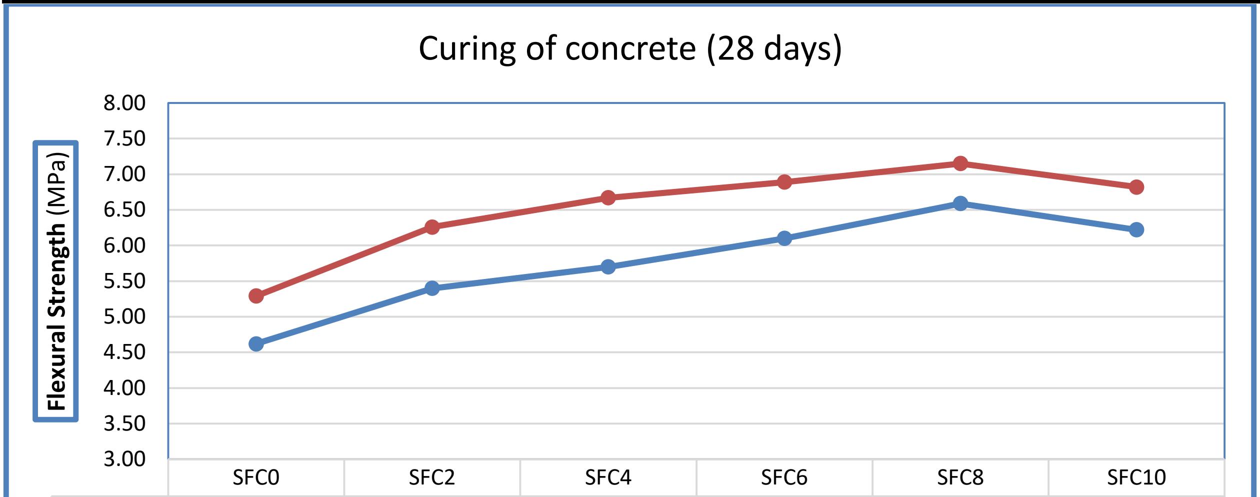
Graph 4 – 28 days Split tensile strength of Cylinder

4.3.3 FLEXURAL STRENGTH OF CONCRETE:

The determination of flexural strength of the prepared samples is carried out as per IS code. The following table shows the flexural strength of various samples using different percentage of steel fibre chips.

Table 9 – Flexural Strength of concrete Beam in N/mm^2

S. No.	% of Steel fibre chip	Grade of Concrete	
		M30	M35
1	SFC0	4.62	5.29
2	SFC0.5	5.40	6.26
3	SFC1.0	5.70	6.67
4	SFC1.5	6.10	6.89
5	SFC2.0	6.59	7.15
6	SFC2.5	6.22	6.82



	SFC0	SFC2	SFC4	SFC6	SFC8	SFC10
M30	4.62	5.40	5.70	6.10	6.59	6.22
M35	5.29	6.26	6.67	6.89	7.15	6.82

Graph 5 – Flexural Strength of concrete Beam

V. CONCLUSION

Based on the experimental investigation the following conclusion is given within the limitation of the test result.

- The Slump of the concrete mix reduces from 63mm to 49mm on increasing the percentage of steel fiber (from 0% to 2.5%) for M-30 Concrete mix.
- The Slump of the concrete mix reduces from 59 mm to 45mm on increasing the percentage of steel fiber (from 0% to 2.5%) for M-35 Concrete mix.
- The Compressive strength of M30 concrete mix increases from 30.60N/mm^2 to 36.98N/mm^2 on increasing the percentage of steel fiber (from 0% to 2%) and decreases from 36.98 N/mm2 to 35.43 N/mm2 with addition of 2% to 2.5% of steel fiber chips.
- Compressive strength of M35 concrete mix increases from 35.66N/mm^2 to 44.94N/mm^2 on increasing the percentage of steel fiber (from 0% to 2%) and decreases from 44.94 N/mm^2 to 43.36 N/mm^2 with addition of 2% to 2.5% of steel fiber chips.
- The Tensile strength of M30 concrete mix increases from 3.1N/mm^2 to 5.15N/mm^2 on increasing the percentage of steel fiber (from 0% to 2%) and decreases from 5.15 N/mm2 to 4.74 N/mm^2 with addition of 2% to 2.5% of steel fiber chips
- The Tensile strength of M35 concrete mix increases from 3.62 to 5.98 N/mm^2 on increasing the percentage of steel fiber (from 0% to 2%) and decreases from 5.98 N/mm2 to 5.45 N/mm^2 with addition of 2% to 2.5% of steel fiber chips
- The Flexural strength of M30 concrete mix increases from 4.62N/mm^2 to 6.59N/mm^2 on increasing the percentage of steel fiber (from 0% to 2%) and decreases from 6.59 N/mm2 to 6.22 N/mm^2 with addition of 2% to 2.5% of steel fiber chips
- The Flexural strength of M35 concrete mix increases from 5.29N/mm^2 to 7.15N/mm^2 on increasing the percentage of steel fiber (from 0% to 2%) and decreases from 7.15 N/mm2 to 6.82 N/mm^2 with addition of 2% to 2.5% of steel fiber chips

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