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A PRACTICAL INVESTIGATION ON THE BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE

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Abstract: Concrete has unlimited opportunities for innovative applications; design and construction techniques. It's great versatility and relative economy in filling wide range of needs has made it very competitive building material. In this present investigation workability, strength parameters of concrete with steel fibers in proportions of 0%, 0.5%, 1.0%, 1.5% was investigated for M35 grade concrete cubes, cylinders, prisms. Tests were performed to evaluate the workability characteristics of fresh concrete, Compressive, Split Tensile and Flexural strength were determined at the age of 7days, 28days, 56days, and 91days respectively. Durability of the concrete was tested by immersing the specimens in 1% Hydrochloric acid solution for 91 days.

Keywords: Steel fibers, concrete, compressive strength, split tensile strength, flexural strength, durability, acid treatment.

1. Introduction

In this era of world, concrete is most the used material for compressive strength for building construction. The application of the material can be overused by the inclusion of a small amount of short randomly distributed fibers and can be practiced among others that give a solution to weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc. Steel fibers have aspect ratio in the range of 20 to 100 with any of the several cross-section, and that are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedure. The random distribution results in a loss of efficiency as compared to conventional rebars, but the closely spaced fibers improve toughness and tensile properties of concrete and help to control cracking.

2. Literature Review

1. Tan et al (1994) presented an investigation study by giving low fibre dosages typically used in concrete (0.1 to 1% VOL), the presence of fibers (steel, synthetic, glass, cellulose) has a minimal, if any, impact on the creep behaviour of concrete in compression. The flexural creep performance of conventionally reinforced concrete beams incorporating steel fiber-reinforced concrete (SFRC) showed smaller long-term deflections than the reinforced concrete beams without fibers.

2. Balaguru and Kurtz (2000) highlighted the addition of fibres primarily benefits the post-crack behaviour of concrete. The post-crack creep of FRC studied by indicated that creep failure occurred in cracked micro synthetic FRC for sustained stress levels. The magnitude of load applied to a specific specimen during creep testing was based on their results of average residual strength (ARS) tests determined using ASTM C1399. Prior to creep testing, the beams were cracked by subjecting 4 x 4 x 14 in. (100 x 100 x 350 mm) beams to a deflection of 0.01 in. (0.2 mm). Specimens of the synthetic FRC mixture were creep tested at loads nominally equivalent to 20, 40, and 60% of the ARS value while the SFRC mixture was tested at loads nominally equivalent to 20, 40, 60, and 80% of the ARS value. They study concluded that, at similar loading levels, cracked synthetic FRC can be expected to experience creep coefficients twice that of SFRC.

3.Bissonnette et al (2001) have done experiment on uniaxial restrained shrinkage tests and tensile tests on large-scale SFRC specimens with fibre contents ranging from 0 to 160 lb/yd3 (0 to 100 kg/m3). Multiple parallel micro cracks altered the overall response of the SFRC beams in the hardened state.

4. Nguyen Van (2002) presented the details about one of the important properties of steel fibre reinforced concrete is its superior resistance to cracking and crack propagation. As they result of ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. Their net result of all these is to impart to the fibre composite pronounced post -cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading. They discussed about mechanic properties, technologies, and applications of SFRC

5. Bernard (2004) presented a case study about the creep of cracked FRC specimens and round panels based on ASTM C1550. High-modulus synthetic micro fibers, crimped low-modulus synthetic microfiber, and flat-end steel fiber were investigated for long-term. Creep behaviour in cracked concrete specimens. They results indicated that the high-modulus synthetic macro fibre had creep behaviour similar to the steel fiber, whereas the low modulus synthetic macro fibre experienced much higher creep.

3. Experimental Investigation

3.1 Materials:

3.1.1 Cement type:

43 Grade ordinary Portland cement of Ultra Tech Cement brand was used. Physical properties of cement are shown in table 1.

3.1.2 Coarse aggregate:

Crushed granite material with 60% passing 20mm and retained on 10mm sieve and 40% passing 10mm and retained on 4.75mm sieve having a specific gravity of 2.815 was used. The details about the coarse aggregate and their properties are shown in Table 2

3.1.3 Fine aggregate:

River sand of zone-II was used as fine aggregate. The details of fine aggregate properties are shown in Table 3.

3.1.4 Steel fibers:

Hooked End steel fiber of size 0.90mm dia, 60mm length and aspect ratio of 65 was incorporated in percentages of 0%, 0.5%, 1%, 1.5% in concrete.

Table 1 Physical properties of cement:

S.NO.	Property	Value
1.	Specific Gravity	3.14
2.	Fineness of cement (By sieving)	3.2%
3.	Standard Consistency	32%
4.	Setting Time i) Initial setting time	134 min
	ii) Final setting time	232 min
5.	Compressive Strength i) 3 Days ii) 7 Days iii) 28 Days	 24.39 N/mm^2 36.24 N/mm^2 48.40 N/mm^2

Table 2 Physical Properties of Coarse Aggregate:

S.NO.	Property	Value
1.	Specific Gravity	2.815
2.	Bulk Density i) Loose State ii) Compacted State	 1564.54 Kg/m^3 1724.07 Kg/m^3
3.	Water absorption	0.57%
4.	Flakiness Index	13.54%
5.	Elongation Index	21.70%

6.	Crushing Value	19.73%
7.	Aggregate Impact Value	17.35%
8.	Fineness Modulus	6.65

Table 3 Physical Properties of Fine aggregate (Natural Sand):

S.NO.	PROPERTY	VALUE
1.	Grading of Sand	Zone II as per IS 383
2.	Specific Gravity	2.59
3.	Bulk Density i) Loose State ii) Compacted State	 1553.51 Kg/m^3 1705.82 Kg/m^3
4.	Fineness Modulus	2.786
5.	Water Absorption	1.20%

3.1.5 Super plasticizer

The super plasticizer used in the study was FOSROC Conplast SP 430.

3.1.6 Mix Proportion

Mix design is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible. The M35 grade concrete Mix design is made as per IS10262:2009. The table 4 below shows the mix design.

Table 4- Mix Proportions

Water (litres)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (20 mm + 10 mm) (kg/m^3)
168	420	656.78	1257.08 (754.248+ 502.832) (60% + 40%)
0.40	1	1.563	2.993

4. Test Procedure

4.1 Slump cone Test

Slump cone test is a preliminary test conducted to determine the workability. In this thesis, slump test was conducted on the mix containing cement, fine aggregate, steel fiber and coarse aggregate. The mix was prepared according to the proportions obtained from mix design. The prepared mix was then placed in slump cone in three layers with simultaneous tamping with a tamping rod for each layer. The slump cone is lifted and the change in slump is observed. The change in slump is measured with a steel rule and is noted down.

4.2 Compaction Factor Test

Compaction factor test is another test conducted to determine the workability of the prepared mix. In this test the mix is poured into the upper hopper of the compaction factor apparatus, and then the lever is pulled, which makes the mix fall down in to the lower hopper and then in to the cylinder under the action of gravity. Now the cylinder is weighed and the weight is noted down. The cylinder is now placed on the vibrator table and then compacted. The cylinder is again weighed and the weight of fully compacted cylinder is noted down. The compaction factor is found out with the help of the formula below.

$$\text{Compaction factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weihght of fully compacted concrete}}$$

4.3 Vee-Bee Consistometer Test

In this test, the mix is placed in the cone in three layers with simultaneous compaction. After the cone has been removed the circular glass plate attached to the apparatus is placed on the mix. The machine is switched on and the stopwatch is started. The time taken for the cone shaped to mix to transform into a cylindrical shaped mix is noted down. This time recorded is known as Vee-Bee time.

4.4 Compressive Strength Test

In this test, the cubes that have been cast in the cubical mould of dimensions 150mmx150mmx150mm, placed in curing tank for 7, 28, 56, and 91 days and then dried until it is free from moisture are tested in a compression testing machine. The cubes are placed in the machine and then load is applied until failure. The load obtained is recorded and the compressive strength is calculated using the formula below. Figure 1 depicts the placing of concrete cube in compression testing machine.

$$\text{Compressive strength} = \frac{P}{A}\ (\text{N/mm}^2).$$

Where,

P = load applied to the specimen.

A = Cross-sectional area of cube on which the load is applied (150mm x 150mm)

Fig 1. Testing of cube

4.5 Splitting Tensile Strength

In this test, cylinders of dimension 150mm x 300mm have been cast in cylindrical moulds, placed in curing tank for 7, 28, 56 and 91 days and dried until free from moisture. These cylinders are placed in the testing machine and the load is applied until failure. The ultimate load is recorded and then the splitting tensile strength is calculated according to the formula given below. The placing of the cylinder in the testing machine is depicted in Fig 2.

$$F_t = \frac{2P}{\pi\ x\ D\ x\ L}\ \text{N/mm}^2$$

Where, P= Maximum load applied to the specimen.

D = Cross sectional dimension of cylinder on which load is applied.

L = Length of specimen in mm.

F_t = Split tensile strength. (N/mm^2)

Fig 2. Testing of cylinder

4.6 Flexural Strength

In this test, prisms of dimensions 500mm x 100mm x 100mm were cast in the appropriate moulds, placed in curing tank for 7, 28, 56 and 91 days, and then dried until free form moisture. Before the testing of these prisms, two lines with a gap of 5 cm from each of the ends are drawn. Now from this 5 cm lines, two more lines with a gap of 13.33 cm are drawn. This is for the purpose of three point loading. The prism is placed in the testing machine and then load is applied on the roller plate placed on the lines drawn on the prism. The prism is loaded until failure and the ultimate load is recorded. The flexural strength is calculated with the help of the formula given below. Fig 3 depicts the placing of the prism in the universal testing machine.

$$F_b = P\,x\,\frac{L}{B\,x\,D\,x\,D}\ \text{N/mm}^2 \text{ (when tensile crack length is greater than 13.33cm)}$$

$$F_b = \frac{3Pa}{B\,x\,D\,x\,D}\ \text{N/mm}^2 \text{ (when tensile crack length is between 11.0cm to 13.33cm)}$$

Where,
F_b = Flexural strength of the specimen.
P = maximum load applied to the specimen.
L = Length in mm of the span on which the specimen was supported.
B = width of the specimen.
D = depth of specimen.

Figure 3. Testing of Prism

4.8 Durability

Durability is defined as the ability of concrete to withstand factors of weathering, abrasive actions, and exposure to freeze and thaw characteristics. In this thesis main focus was given to the resistance of concrete with steel fiber towards acid attack. HCl was chosen for the test as it causes leaching in concrete structures and it is the major concern.

4.8.1 Hydrochloric Acid Attack on Concrete:

Hydrochloric acid is very aggressive in nature. The reaction given below causes leaching of calcium hydroxide from the cement that has been set. The concrete specimens were exposed to 1% HCl concentration. 1% diluted HCl is prepared and to make 30 litres solution of 1% concentrated HCl, the stock solution required is 675ml.

$$CaOH_2 + 2HCl \longrightarrow CaCl_2 + 2H_2O$$

5. Discussion of Test Results

5.1 Workability

The values of Slump cone test, Compaction factor and Vee-Bee time obtained from present investigation are presented in Table 5, 6 & 7 respectively. The Slump cone test and Compaction factor are decreasing, and Vee-Bee time is increasing as the quantity of steel fiber is increasing.

Table 5 Workability in terms of Slump Cone test:

S.No.	M35 Mix ID	Steel Fibre (%)	Slump (mm)	Admixture (%)
1	SFC0.0	0.0	36	0.5
2	SFC0.5	0.5	48	0.7
3	SFC1.0	1.0	40	0.8
4	SFC1.5	1.5	28	0.9

Table 6 Workability in terms of Compaction Factor

S.No.	M35 Mix ID	Steel Fibre (%)	Compaction Factor	Admixture (%)
1	SFC0.0	0.0	0.826	0.5
2	SFC0.5	0.5	0.87	0.7
3	SFC1.0	1.0	0.85	0.8
4	SFC1.5	1.5	0.83	0.9

Table 7 Workability in terms of Vee-Bee time

S.No.	M35 Mix ID	Steel Fibre (%)	Vee-Bee Time (Sec)	Admixture (%)
1	SFC0.0	0.0	14.4	0.5
2	SFC0.5	0.5	7.4	0.7
3	SFC1.0	1.0	8.7	0.8
4	SFC1.5	1.5	10.0	0.9

5.2 Compressive strength

The results of compressive strength are obtained and are presented in table 8. The variation of compressive strength with respect to steel fiber content is shown in figure 4.

Table 8 compressive strength (MPa) of M35 Grade Concrete with different proportions of STEEL Fiber

Mix ID	SFC0.0	SFC0.5	SFC1.0	SFC1.5
% of Steel Fiber	0	0.5	1.0	1.5
7 days (MPa)	29.83	31.23	33.47	32.46
28 days (MPa)	44.52	46.87	48.32	47.64
56 days (MPa)	47.02	49.72	52.5	51.08
91 days (MPa)	48.52	50.22	53.12	52.28

From the charts it can be observed that for 28days, with the increase in the quantity of fiber up to 1.0%, the compressive strength has increased by 8.53% over plain concrete. At 0.5% fiber the compressive strength has increased by 5.27% and at 1.5% fiber the compressive strength has increased by 7.0% respectively. Hence 1.0% of fiber can be taken as optimum content. Also, it can be observed that on 1.5% addition of fiber the compressive strength has decreased when compared to that at 1.0% fiber. This phenomenon is due to the balling effect that place due to the increase in the fiber volume.

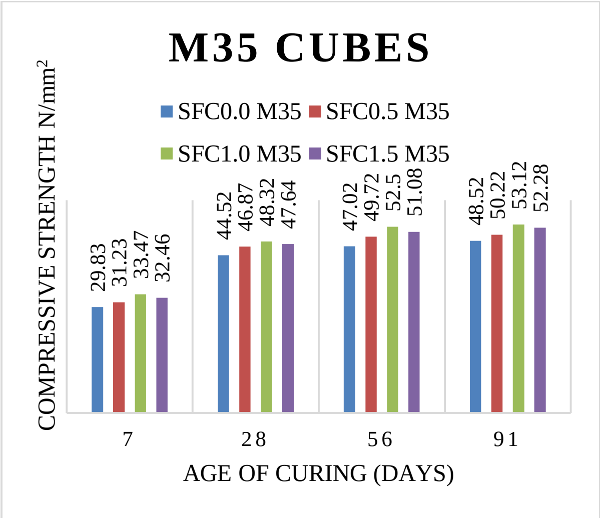

Fig 4. Variation of compressive strength for M35 grade concrete

5.3 Split Tensile strength

The results of split tensile strength are obtained and are presented in table 9. The variation of split tensile strength with respect to steel fiber content is shown in figure 5.

Table 9 Split Tensile Strength (MPa) of M35 Grade Concrete with different proportions of steel Fiber

Mix ID	SFC0.0	SFC0.5	SFC1.0	SFC1.5
% of Steel Fiber	0	0.5	1.0	1.5
7 days (MPa)	2.90	3.20	3.43	3.36
28 days (MPa)	3.30	3.43	3.58	3.49
56 days (MPa)	3.48	3.51	3.66	3.54
91 days (MPa)	3.61	3.70	4.01	3.96

From the charts it can be observed that for 28 days, with the increase in the percentage of fiber up to 1.0%, the split tensile strength has increased by 8.48% over plain concrete. At 0.5% fiber the split tensile strength has increased by 3.93% and at 1.5% fiber the split tensile strength has increased by 5.75% respectively. Hence 1.0 % of fiber can be taken as optimum content. Also, it can be observed that on 1.0% addition of fiber the split tensile strength has increased when compared to that at 1.5% fiber.

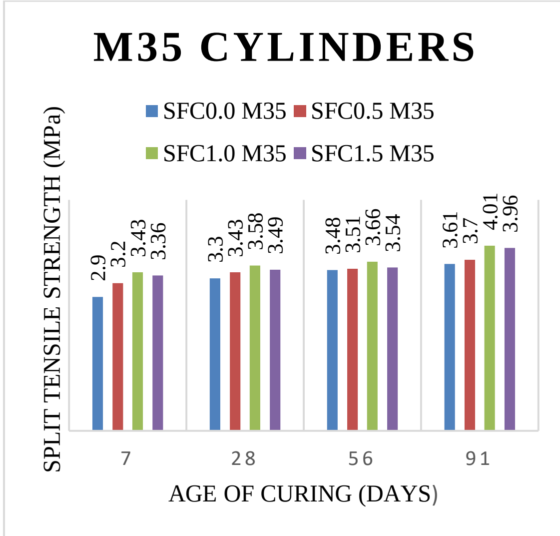

Fig 5. Variation of Split Tensile strength for M35 grade concrete

5.4 Flexural Strength

The results of flexural strength are obtained and are presented in table 10. The variation of flexural strength with respect to fiber content is shown in figure 6.

Table 10 Flexural Strength (MPa) of M35 Grade Concrete with different proportions of Steel Fiber

Mix ID	SFC0.0	SFC0.5	SFC1.0	SFC1.5
% of Steel Fiber	0	0.5	1.0	1.5
7 days (MPa)	5.5	5.68	5.86	5.79
28 days (MPa)	6.23	6.36	6.58	6.43
56 days (MPa)	6.58	6.71	6.92	6.84
91 days (MPa)	6.73	6.84	7.11	6.93

From the charts can be observed that with the increase in the percentage of fiber up to 1.5%, the flexural strength has increased by 3.21% over plain concrete. At 0.5% fiber the flexural strength has increased by 2.08% and at 1.0% fiber the flexural strength has increased by 5.61% respectively. Hence 1% of fiber can be taken as optimum content.

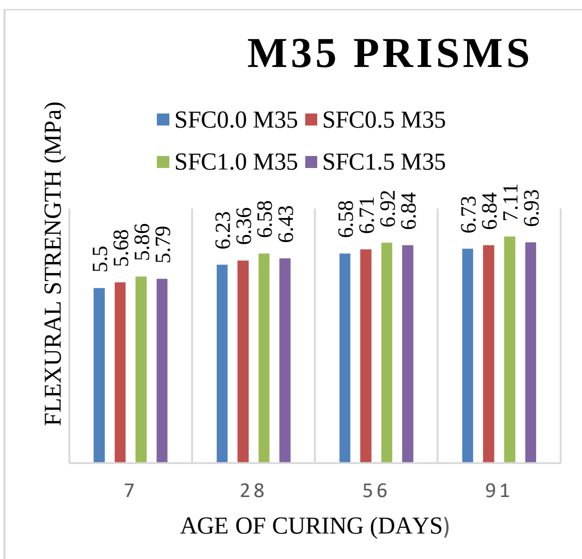

Fig 6. Variation of flexural strength for M35 grade concrete

5.5 Compressive Strength of Acid treated Specimens

The comparison of 28 days compressive strength with 91 days acid treated compressive strength, with the increase in quantity of steel fiber for M35 grade concrete is tabulated in the table 11 and is shown in fig.7

Table 11 compressive strength (MPa) of M35 Grade Concrete with different proportions of STEEL Fiber with acid treatment.

Mix ID	SFC0.0	SFC0.5	SFC1.0	SFC1.5
% of Steel Fiber	0	0.5	1.0	1.5
Before acid treatment (MPa)	44.52	46.87	48.32	47.64
After Acid treatment (MPa)	42.62	44.77	46.35	45.48

From the charts can be observed that with the increase in the quantity of fiber up to 1.0%, the compressive strength has decreased by 4.07 %. At 0.5% fiber the compressive strength has decreased by 4.48 % and at 1.5% fiber the compressive strength has decreased by 4.53% respectively. Hence 1.0% of fiber can be taken as optimum content. Also, it can be observed that on 1.5% addition of fiber the compressive strength has decreased

when compared to that at 1.0% fiber. This phenomenon is due to the balling effect that place due to the increase in the fiber volume

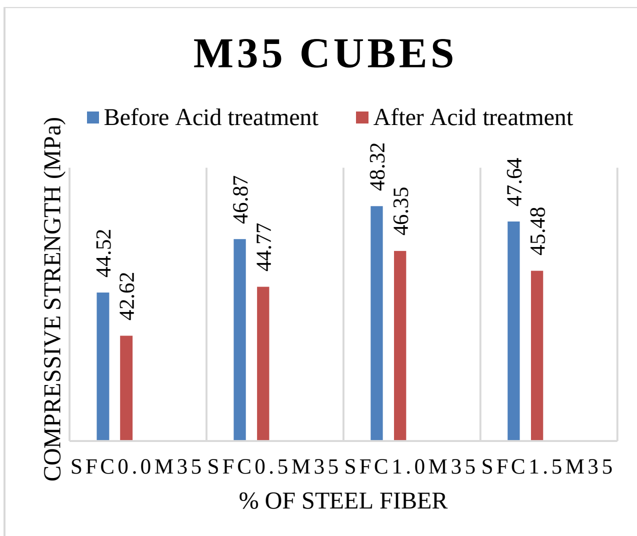

Fig 7. 91 days acid treated compressive strength

5.6 Split tensile strength of Acid treated Specimen

The comparison of 28 days split tensile strength with 91 days acid treated split tensile strength, with the increase in quantity of steel fiber for M35 grade concrete were tabulated in the table 12 and is shown in fig.8.

Table 12 Split tensile strength (MPa) of M35 Grade Concrete with different proportions of STEEL Fiber with acid treatment

Mix ID	SFC0.0	SFC0.5	SFC1.0	SFC1.5
% of Steel Fiber	0	0.5	1.0	1.5
Before acid treatment (MPa)	3.30	3.43	3.58	3.49
After Acid treatment (MPa)	2.95	3.08	3.29	3.13

From the charts can be observed that with the increase in the percentage of fiber up to 1.0%, the split tensile strength has decreased by 8.1% over plain concrete. At 0.5% fiber the split tensile strength has decreased by10.20% and at 1.5% fiber the split tensile strength has decreased by 10.31% respectively. Hence 1.0 % of fiber can be taken as optimum content. Also, it can be observed that on 1.0% addition of fiber the split tensile strength is more when compared to that at 1.5% fiber.

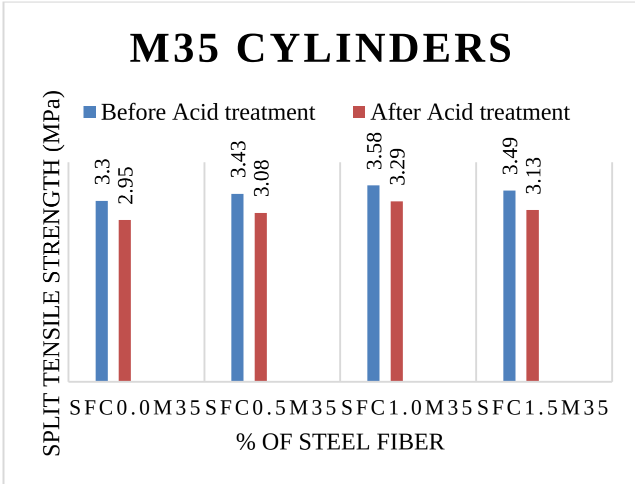

Fig 8. 91 days split tensile strength

5.7 Flexural Strength of Acid Treated Specimens

The comparison of 28 days flexural strength with 91 days acid treated flexural strength, with the increase in quantity of steel fiber for M35 grade concrete were tabulated in the table 13 and is shown in fig.9.

Table 5.10 flexural strength (MPa) of M35 Grade Concrete with different proportions of STEEL Fiber with acid treatment

Mix ID	SFC0.0	SFC0.5	SFC1.0	SFC1.5
% of Steel Fiber	0	0.5	1.0	1.5
Before acid treatment (MPa)	6.23	6.36	6.58	6.43
After Acid treatment (MPa)	5.84	5.97	6.23	6.08

From the charts can be observed that with the increase in the quantity of fiber up to 1.0%, the Flexural strength has decreased by 5.13 %. At 0.5% fiber the flexural strength has decreased by 6.13 % and at 1.5% fiber the flexural strength has decreased by 5.44 % respectively. Hence 1.0% of fiber can be taken as optimum content. Also, it can be observed that on 1.5% addition of fiber the compressive strength has decreased when compared to that at 1.0% fiber. This phenomenon is due to the balling effect that place due to the increase in the fiber volume.

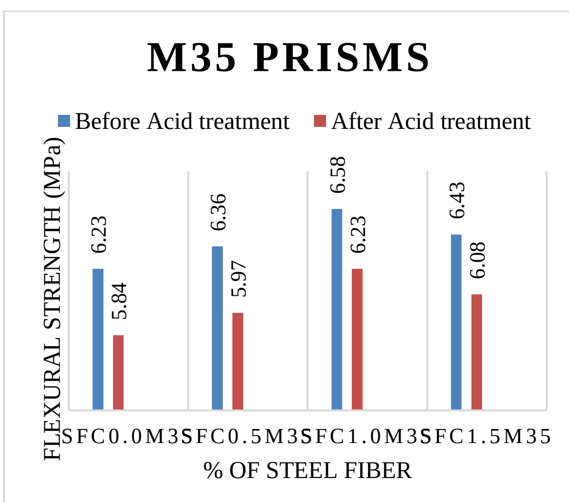

Fig 9. 91 days flexural strength

6. Conclusions

1. From slump cone test, it can be concluded that as the percentage of steel fibre increases, the slump value decreases. Hence it can be concluded that with the increase in the fiber content workability also decreases.
2. From compaction factor test, it can be concluded that as the percentage of steel fiber increases, the compaction factor decreases. Hence it can be concluded that with the increase in the fiber content workability decreases.
3. From Vee-Bee time test, it can be concluded that as the percentage of steel fiber increases, the Vee-Bee time increases. Hence it can be concluded that with the increase in the fiber content workability decreases.
4. From the experimental results, the optimum percentage of steel fibre recommended is 1.00%, for achieving maximum benefits in compressive strength, split tensile strength and flexural strength at any age for the characteristics of steel fibre reinforced concrete.
5. The compressive strength of SFRC M35 mixes at 28 days increased with the addition of steel fibre up to 1.00% when compared to that of plain concrete. The maximum percentage increased over plain concrete is 8.53 % and the percentage increase ranges from 5.27% to 8.53% over conventional mix.
6. The split tensile strength of SFRC M35 mixes at 28 days increased with the addition of steel fibre up to 1.00% when compared to that of plain concrete. The maximum percentage increase over plain concrete is 8.48% and the percentage increase ranges from 3.93% to 8.48% over conventional mix.
7. The flexural strength of SFRC M35 mixes at 28 days increased with the addition of steel fibre up to l.00% when compared to that of plain concrete. The maximum percentage increase over plain concrete is 5.61% and the percentage increase ranges from 2.08% to 5.61% over conventional mix.
8. The compressive strength of SFRC M35 mixes with the addition of steel fibre up to 1.00% after acid treatment is more resistant when compared to that of plain concrete. The percentage decrease for the optimum percentage is 4.07 % and the percentage decrease ranges from 4.07% to 4.53% over conventional mix.
9. The Split tensile strength of SFRC M35 mixes with the addition of steel fibre up to 1.00% after acid treatment is more resistant when compared to that of plain concrete. The percentage decrease for the optimum percentage is 8.10% and the percentage decrease ranges from 8.10% to 10.60% over conventional mix.
10. The Flexural strength of SFRC M35 mixes with the addition of steel fibre up to 1.00% after acid treatment is more resistant when compared to that of plain concrete. The percentage decrease for the optimum percentage is 5.31 % and the percentage decrease ranges from 5.31% to 6.26% over conventional mix.

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28. IS:516-1959 Specifications for Method of Tests of Strength of concrete.

