

Study on Structural Performance of Steel Fibre Reinforced Self Compacting Concrete

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Abstract — In Civil Engineering the fibre reinforced technology has become advanced technique and over come some of the weaknesses in concrete. Fibres may be used to enhance the properties of SCC in the same way as for normal concrete. Steel fibres are used normally to enhance the mechanical characteristics of the concrete such as flexural strength and toughness. Hence in view of the above factors a study is made on strength behavior of steel fibre reinforced self-compacting concrete of M_{60} Grade. The major steps in the production of SFRSCC are designing an appropriate mix proportion and evaluating the properties of the concrete obtained. In practice, SCC in its fresh state shows high fluidity, self-compacting ability and segregation resistance. The understanding of this value added construction material, forms the main theme of this study. The present study focuses on the SCC mix for M_{60} Grade is developed with 30% replacement of cement by fly ash and its properties in fresh state have been evaluated for different percentages of steel fibres. Super plasticizers (glenium b233) were utilized at required dosages. Experimental investigations were carried out to study the compressive strength at 3 days, & 28 days, flexural behavior strength and split tensile strength of steel fibre reinforced (at different percentages) self compacting concrete (SFRSCC) of M_{60} Grade.

Keywords- steel fibre reinforced; self-compacting; super-plasticizers; compressive strength; flexural strength; split tensile strength

I. INTRODUCTION

At present world is witnessing the construction of very challenging and difficult Civil Engineering structures. Quite often, concrete being the most important and widely used material is called upon to possess very high strength and sufficient workability properties. Efforts are being made in the field of concrete technology to develop such concrete with special characteristics. Researchers all over the world are attempting to develop high performance concrete by using various admixtures in concrete up to certain proportions. One of the most outstanding advances in the concrete technology for the last decade is “Self Compacting Concrete (SCC)”.

Self-compacting concrete was first developed in 1986 in Japan to achieve durable concrete structures. For several years, the problem of the durability of concrete structures is a major topic of interest for construction Engineers. Sufficient compaction is needed for conventional concrete and that cause segregation. With plain concrete, it is difficult to ensure uniform material quality in heavily reinforced zone where steel is not correctly surrounded by concrete and which finally leads to durability problems. By developing a concrete that self-consolidates, Professor Hajime Okamura of Kochi University of Technology, Japan, in 1986 proposed a solution to the growing durability concerns of the Japanese Government. During his research, Okamura found that the main cause of the poor durability performances of the Japanese Concrete in structures was the inadequate consolidation of the concrete in the casting operations. Okamura eliminated the main cause for the poor durability performances of their concrete by inventing SCC. By 1988 the concept was developed and ready for the first real-scale tests.

To produce SCC major work involves, designing an appropriate mix proportions and evaluating the properties of the concrete. SCC shows high fluidity, self-compacting ability and segregation resistance all of which contributing to reduce the risk of honey combing of concrete. Because of its favorable fresh concrete properties, SCC has a high production engineering, economic and architectural design potential; so, it is of high interest for practical construction project work. In addition to these through the application of SCC typical workmanship mistakes like poor compaction can be avoided. SCC has the potential to replace normal vibrated concrete in numerous cases and hence can lead to better and safer concrete structures.

SCC may be used in pre-cast applications or for concrete placed on site. It can be manufactured in a site batching plant or in a ready mix concrete plant and delivered to site by truck. It can then be placed either by pumping or pouring into horizontal or vertical structures. The elimination of vibrating equipment improves the environment on and near construction and pre-cast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. The improved construction practice and performances, combined with the health and safety benefits, makes SCC a very attractive solution for both pre-cast concrete and for concrete placed on site.

II. MIX DESIGN OF SELF-COMPACTING CONCRETE

A. Procedure for mix design

The sequence is determined as:

- Designation of desired air content (mostly 2%)
- Determination of coarse aggregate volume
- Determination of sand content
- Design of paste composition
- Determination of optimum water: powder ratio and super-plasticizer dosage in mortar
- Finally the concrete properties assessed by standard tests.

B. Mix proportioning

In designing the mix it is most useful to consider the relative proportions for the key components by volume rather than by mass. Indicative typical ranges of proportions and quantities in order to obtain self-compact ability are given below. Further modifications will be necessary to meet strength and other performance requirements.

- Water/powder ratio by volume of 0.80 to 1.10
- Total powder content – 160 to 240 liters (400-600 kg) per cubic meter.
- Coarse aggregate content normally 28 to 35 per cent by volume of the mix.
- Water: cement ratio is selected based on requirements in EN 206. Typically water content does not exceed 200 litre/m³.
- The sand content balances the volume of the other constituents

Generally, it is advisable to design conservatively to ensure that the concrete is capable of maintaining its specified fresh properties despite anticipated variations in raw material quality. Some variation in aggregate moisture content should also be expected and allowed for at mix design stage. Normally, viscosity-modifying admixtures are a useful tool for compensating for the fluctuations due to any variations of the sand grading and the moisture content of the aggregates. Laboratory trials should be used to verify properties of the initial mix composition. If necessary, adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale at the concrete plant or at site.

In the event that satisfactory performance cannot be obtained, then consideration should be given to fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate.

- Using additional or different types of filler, (if available);
- Modifying the proportions of the sand or the coarse aggregate;
- Using a viscosity modifying agent, if not already included in the mix;
- Adjusting the dosage of the superplasticizer and/or the viscosity modifying agent;
- Using alternative types of superplasticizer (and/or VMA), more compatible with local materials;
- Adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

III. REQUIREMENTS FOR CONSTITUENT MATERIALS

A. Cement

All typical of cements conforming to IS 12269 are suitable, Selection of the type of cement will depend on the overall requirements for the concrete, such as strength, durability etc.,

The typical content of cement is 350-450 kg/m³.

More than 500 kg/m³ cement can be dangerous and increase the shrinkage.

Less than 350 kg/m³ may only be suitable with the inclusion of other fine filler, such as fly ash, pozzolana, etc.,

B. Sand

All normal concreting sands are suitable for SCC. Either crushed or rounded sands can be used. Siliceous or calcareous sands can be used.

The amount of fines less than 0.125 mm is to be considered as powder and is very important for the rheology of the SCC. A minimum amount of fines (arising from the binders and the sand) must be achieved to avoid segregation.

C. Coarse Aggregates

All types of aggregates are suitable. The normal maximum size is generally 16-20 mm; however particle sizes up to 40mm or more have been used in SCC. Consistency of grading is of vital importance. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of the interlocking of the angular particles, whilst rounded aggregates improve the flow because of lower internal friction. Gap graded aggregates are frequently better than those continuously graded, which might experience greater internal friction and give reduced flow.

D. Admixtures

The most important admixtures are the superplasticizers (high range water reducers), used with a water reduction greater than 20%. The use of a Viscosity Modifying Admixture (VMA) gives more possibilities of controlling segregation when the amount of powder is limited. This admixture helps to provide very good homogeneity and reduces the tendency to segregation.

E. Fibers

Very fine synthetic fibers may prevent flow and generally the content should not exceed 1kg/m³.

IV. MIX DESIGN OF M₆₀ GRADE

Table 1: Batching Proportions for M60 Grade of SCC per Cubic Meter

Sl. No:	% Steel Fibres	Cement kg/cum	Fly ash kg/cum	F.A.	C.A.	Water ml/cum	Glenium B-233 ml/100 kg of Cement +Fly ash	V.M.A. ml/cum	Steel Fibres kg/cum
1.	0.00	411.80	176.50	735.45	735.45	223.60	800	312.50	--
2.	0.25	411.80	176.50	735.45	735.45	223.60	900	375.00	9.625
3.	0.50	411.80	176.50	735.45	735.45	223.60	925	437.50	39.250
4.	0.75	411.80	176.50	735.45	735.45	223.60	975	468.75	58.875
5.	1.00	411.80	176.50	735.45	735.45	223.60	1050	531.75	78.500
6.	1.25	411.80	176.50	735.45	735.45	223.60	1075	593.75	98.125

V. EXPERIMENTAL RESULTS

Table 2: Workability Parameters of Steel Fiber Reinforced SCC for M 60 Grade

Sl. No	Test method	property	unit	EFNARC Values		% of Fibres by volume of concrete (aspect ratio =50)						
				Min.	Max.	0	0.25	0.50	0.75	1.00	1.25	1.50
1.	Slump flow	filling	mm	650	800	780	720	715	700	690	680	650
2.	T 50 cm slump	viscosity	sec	2	5	2.30	2.90	2.70	3.30	3.40	3.68	4.78
3.	V – Funnel	filling	sec	6	12	6.00	7.00	8.00	9.20	9.60	10.00	11.20
4.	V – Funnel 5 min.	segregation	sec	11	15	11.00	12.10	12.90	13.10	13.90	14.30	15.00
5.	L - Box	passing	%	0.80	1.00	1.00	0.94	0.90	0.88	0.84	0.82	0.81
6.	T – 20 sec		sec	1.00	2.00	1.00	1.20	1.30	1.50	1.60	1.65	2.00

Table 3: Compressive Strength of M-60 Grade of Steel Fibre Self Compacting Concrete at 3 & 28 Days

Sl. No	Description	Cross Sectional Area (Sq.mm)	Load (KN) in compression testing Machine in 3days		Compressive strength in 3days (MPa)		Load (KN) in compression testing Machine in 28days		Compressive strength in 28 days (MPa)	
			Cube no.1	Cube no.2	Cube no.1	Cube no.2	Cube no.1	Cube no.2	Cube no.1	Cube no.2
I	Plain Concrete Cubes	150 x 150 = 22500	693.0	679.5	30.8	30.2	1487	1573	66.1	69.9
					Average = 30.5				Average = 68.0	
II	% 0.25 of steel Fibres Concrete Cubes	150 x 150 = 22500	742.5	657.0	33.0	29.2	1364	1809	60.6	80.4
					Average = 31.1				Average = 70.5	
III	0.50% of Steel Fiber Concrete Cubes	150 x 150 = 22500	798.8	657.0	35.5	29.2	1638	1649	72.8	73.3
					Average = 32.4				Average = 73.1	

IV	0.75 % Steel Fiber Concrete cubes	150 x 150 = 22500	785.3	681.8	34.9	30.3	1751	1649	77.8	73.3
					Average = 32.6				Average = 75.6	
V	1.0 % Steel Fiber Concrete Cubes	150 x 150 = 22500	776.3	717.8	34.5	31.9	1872	1737	83.2	77.2
					Average = 33.2				Average = 80.2	
VI	1.25 % Steel Fiber Concrete Cubes	150 x 150 = 22500	816.8	713.3	36.3	31.7	1987	1908	88.3	84.8
					Average = 34.0				Average = 86.6	
VII	1.5% Steel Fiber Concrete Cubes	150 x 150 = 22500	515.3	726.8	22.9	32.3	1589	1559	70.6	69.3
					Average = 27.6				Average = 70.0	

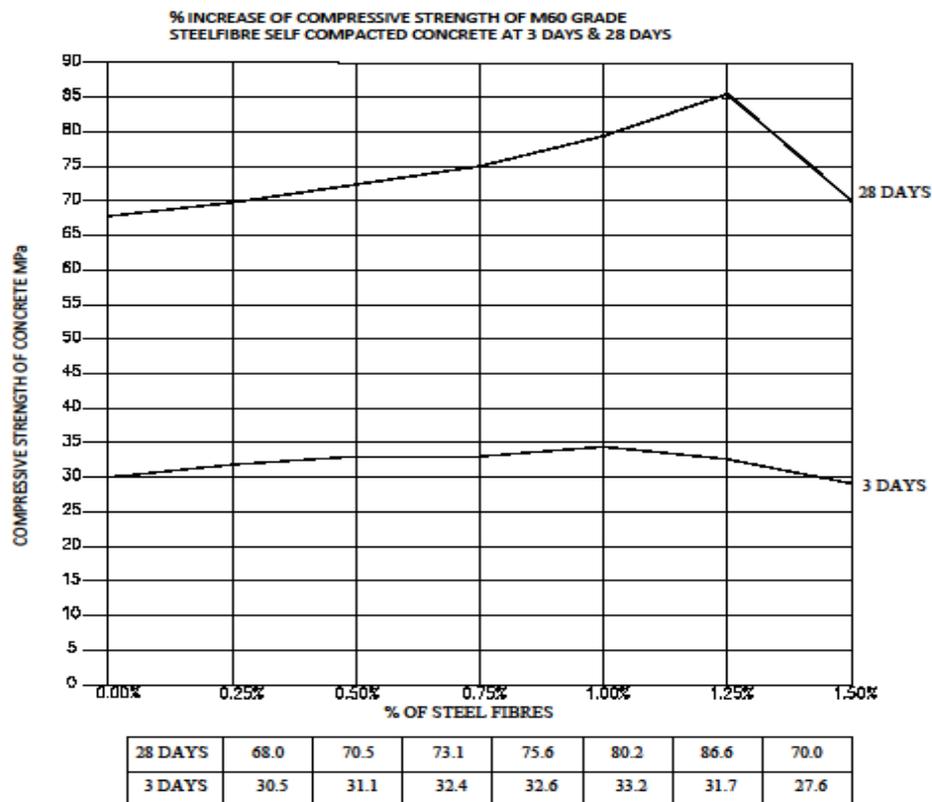


Fig 1: Compressive Strength Vs Percentage of steel

RELATION SHOWING % INCREASE OF COMPRESSIVE STRENGTH MPa
 Vs PERCENTAGE OF STEEL FIBRES(0% TO 1.5%) @ 28 DAYS

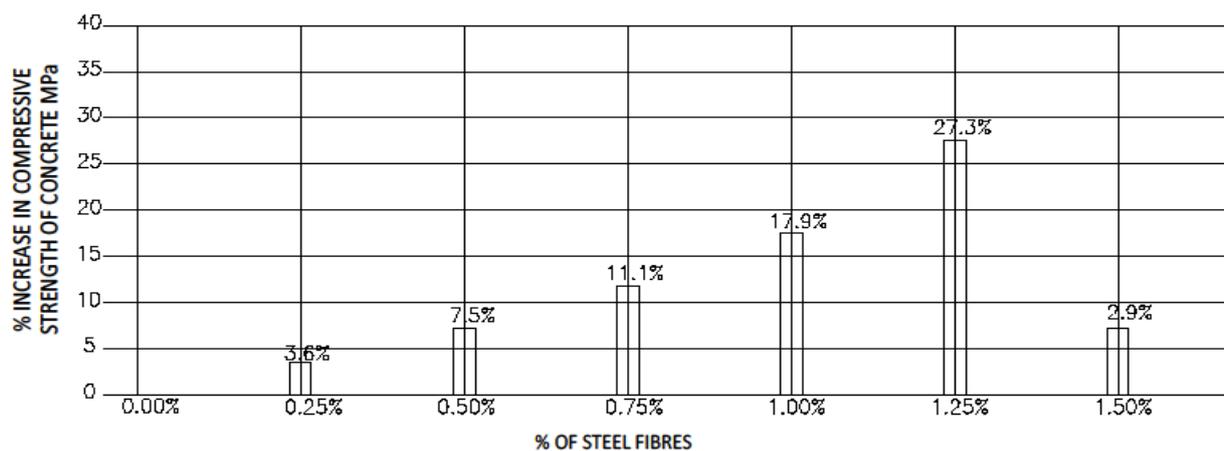


Fig 2: Percentage Increase in Compressive Strength Vs Percentage of steel

The compressive strength results are given in table 3, Fig.1 shows the compressive strength at 3 days, and 28 days of SCC at various % of steel fibers. Fig.2 shows the percentage increase of compressive strength at various % of steel fibers with conventional SCC of M₆₀ grade.

From Fig.1 it is observed that compressive strength increases linearly up to 1.25 % of steel fibers. The SFRSCC at 1.25 % of steel fibers by volume of concrete has shown greatly compressive strength (28 days) i.e. 86.60 N/mm² and 1.25 % of steel fibers addition is selected as optimum value.

From Fig.1 it is observed that compressive strength (3 days) increases linearly up to 1.25% of steel fibers. The SFRSCC at 1.25% of steel fiber by volume of concrete has shown greatly compressive strength 3 days is 34.00 N/mm² and 1.25% of steel fiber addition is selected as optimum value.

From Fig.2 it is observed that % of increase of compressive strength up to 27.3 @1.25% steel fibers for 28 days.

Table 4: Flexural Strength of M-60 Grade of Steel Fibre Self Compacting Concrete at 28 Days

Sl. No	Specimen size In mm	% of steel fibers of aspect ratio 50.	SPAN. (mm)	Distance of Flexure in cm		Load in KN		Flexural Strength in N/mm ²		Average strength. N/mm ²
				B-1	B-2	B-1	B-2	B-1	B-2	
I	100*100*500	0.00%	400	25.5	25.5	11.7	10.8	4.68	4.32	4.50
II	100*100*500	0.25%	400	21.0	18.0	16.0	16.5	6.40	6.60	6.50
III	100*100*500	0.50%	400	20.0	22.0	16.5	17.0	6.60	6.80	6.70
VI	100*100*500	0.75%	400	21.0	22.0	14.40	20.9	5.76	8.36	7.04
V	100*100*500	1.00%	400	17.80	18.6	15.50	21.30	6.20	8.52	7.36
VI	100*100*500	1.25%	400	18.4	18.8	17.10	21.45	6.84	8.58	7.71
VII	100*100*500	1.50%	400	19.0	19.60	16.40	16.10	6.56	6.44	6.50

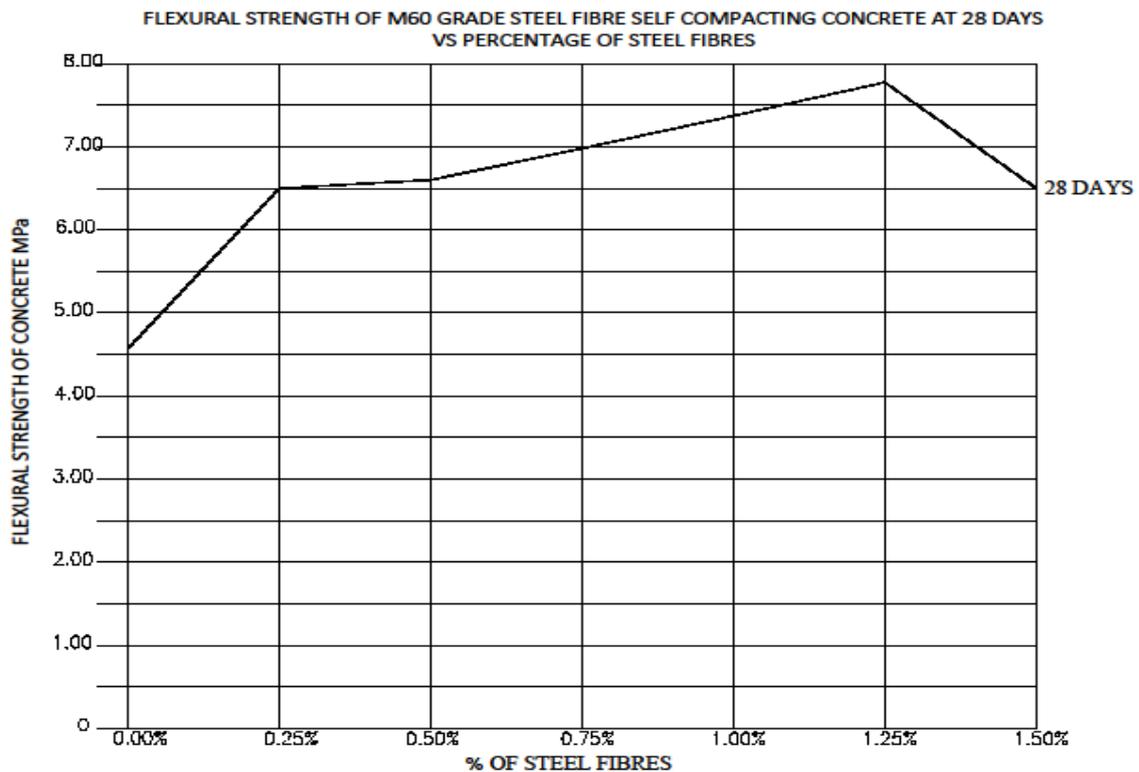


Fig 3: Flexural Strength (28 Days) Vs Percentage of Steel Used

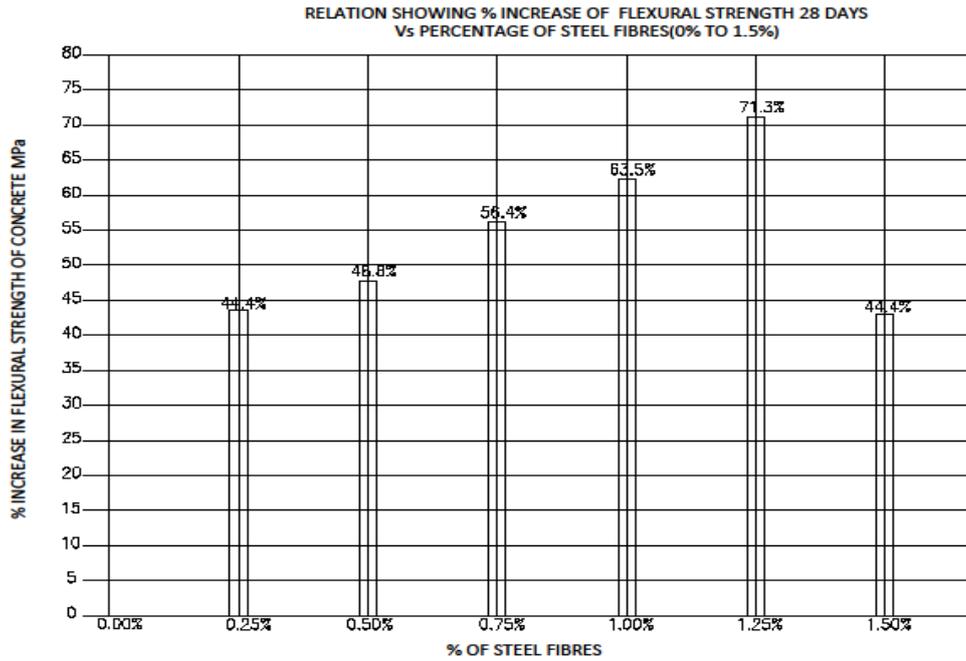


Fig 4: Percentage increase of Flexural Strength (28 days) Vs Percentage of Steel Fibres

The results are given in table 4. The obtained conventional SCC, flexural strengths are 4.5 N/mm^2 and it shows brittle failure.

Fig.4 shows the percentage increase of flexural strength at various % of steel fibers with conventional SCC of M_{60} grade. Fig.3 shows the flexural strength of SCC at different % of steel fibers. The SFRSCC at 1.25% fiber has shown greater flexural strength of 7.71 N/mm^2 increase of Flexural strength at various % of steel fibers with conventional SCC of M_{60} grade. Optimum values @ 1.50% steel fibers. Moreover ductile cracks are observed with SFRSCC, where as sudden failure of brittle failure is noticed in conventional SCC specimen beams (with out steel fibers). Even a small addition of Steel fiber at 0.25% of volume of concrete, increase in the flexural strength of SCC up to 44.40%, which is considerable.

Table 5: Split Tensile Strength of M-60 Grade of Steel Fibre Self Compacting Concrete at 28 Days

Sl.No.	Specimen size mm	% of steel Fibres of aspect ratio 50.	Load in kN		AVG. Load In KN	AVG Split tensile Strength in N/mm^2 ($2P/\pi ld$)
I	150x150	0.00%	128.2	132.0	130.1	3.68
I	150x150	0.25%	139.1	137.4	138.3	3.91
III	150x150	0.50%	152.0	153.5	152.8	4.32
IV	150x150	0.75%	161.8	163.5	162.7	4.60
V	150x150	1.00%	186.1	188.0	187.1	5.29
VI	150x150	1.25%	220.1	218.3	219.2	6.20
VII	150x150	1.50%	187.2	186.2	186.7	5.28

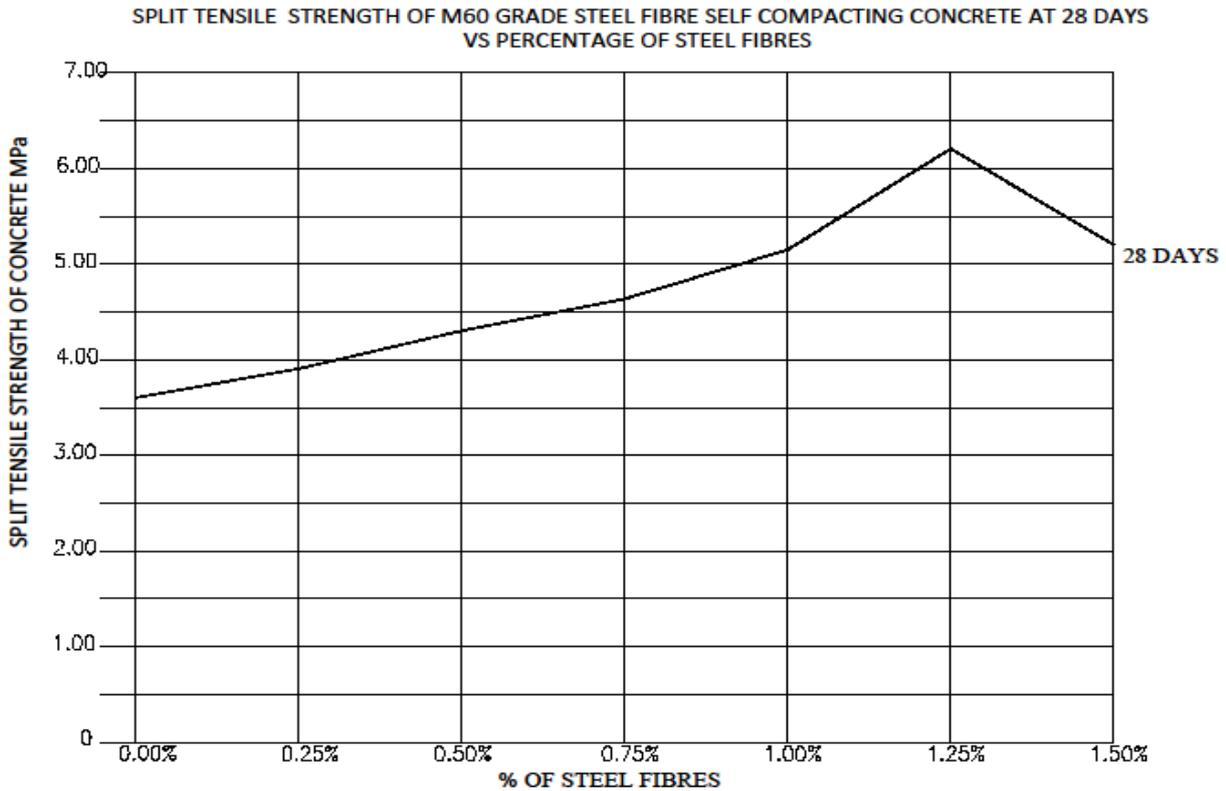


Fig 5: Split Tensile Strength (28 days) Vs Percentage of Steel Fibres used

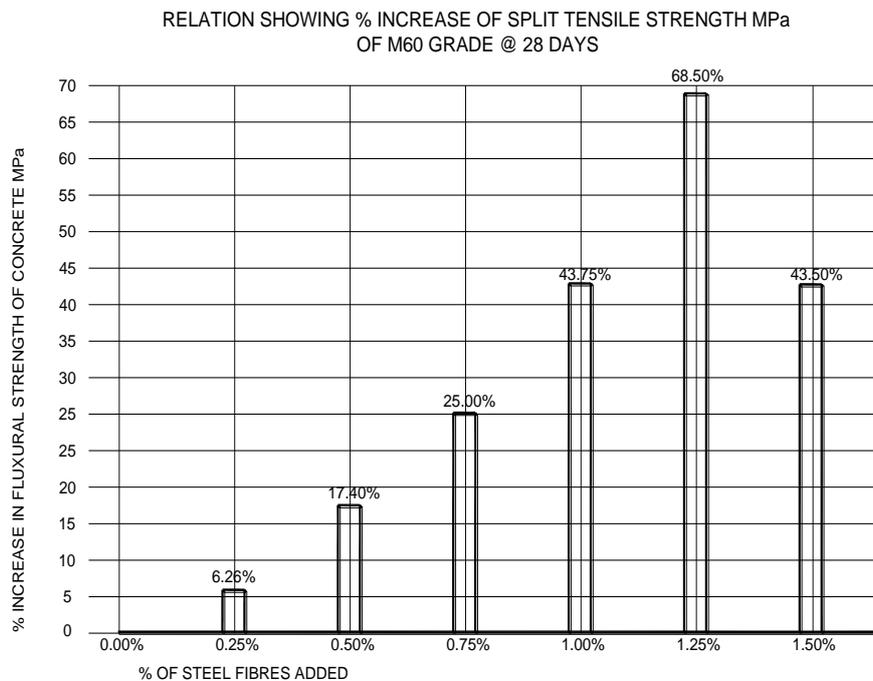


Fig 6: Percentage Increase in Split Tensile Strength (28 days) Vs Percentage of steel

The results are given in table 5. The obtained conventional SCC, Split tensile strength is 3.68 N/mm^2 . Fig.5 shows split tensile strength at various % of steel fibers. It is observed that the strength increases linearly up to 1.25% of Steel fibers addition. The SFRSCC at 1.25% fiber has shown greater split tensile strength of 6.20 N/mm^2 . Fig.6 it is observed that split tensile strength increases linearly upto 68.50% at 1.25% steel fibres.

VI. CONCLUSIONS

- Steel Fiber SCC mix requires high powder content, lesser quantity of coarse aggregate, high range super-plasticizer and viscosity modifying agent to give stability and fluidity to the concrete mix.
- The improvement in Compressive strength of Steel fiber SCC for M_{60} at 28 days in comparison with ordinary SCC was found to be 5.08% for 0.25% Steel fiber, 18.70% for 0.50% Steel fiber, 19% for 0.75% Steel fiber, 19.70% for 1.00% Steel fiber, 13.21% for 1.25% Steel fiber, 9.56% for 1.50% Steel fiber with aspect ratio of 50.
- The improvement in Split Tensile strength if Steel fiber SCC for M_{60} @ 28 days in comparison with ordinary SCC was found to be 6.26% for 0.25% Steel fiber, 17.40% for 0.50% Steel fiber, 25% for 0.75% Steel fiber, 43.75% for 1.00% Steel fiber, 68.50% for 1.25% Steel fiber, 43.50% for 1.50% Steel fiber with aspect ratio of 50.
- The improvement in Flexural strength of Steel fiber SCC for M_{60} @ 28 days in comparison with ordinary SCC was found to be 39.60% for 0.25% Steel fiber, 41% for 0.50% Steel fiber, 42.80% for 0.75% Steel fiber, 57.50% for 1.00% Steel fiber, 71.70% for 1.25% Steel fiber, 40% for 1.50% Steel fiber content with aspect ratio of 50.

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