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An Experimental Study on Steel Fiber Reinforced Self Compacting Concrete

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***Abstract*:- Self Compacting Concrete (SCC) is a special type of concrete that can flow and compact under its own weight. Self Compacting Concrete (SCC) is suitable for placing in structures with congested reinforcement without vibration due to its excellent deformability and it also helps in achieving higher quality of surface finishes. SCC possesses enhanced qualities and improves productivity and working conditions due to elimination of compaction. Fibers are added to enhance its ductility, toughness and to reduce drying shrinkage. Due to addition of fibers, compressive strength may not be varies with respect to normal SCC Mix but there is a enormous increase in the split tensile strength of concrete with increase in fiber content. In this paper a simple mix design method named NAN SU method is followed to achieve self compacting concrete (SCC) of grade M30. To use this mix, it should satisfy the EFNORC guidelines for the workability in fresh state and strength requirement in hardened state. The volume and length of steel fibers combined with coarse aggregates in the mix influences the flow properties of wet mix. To identify this, fibers of 30mm length and diameter 0.5mm in varying dosages from 0.1% to 0.4% by volume of the mix were added to the plain SCC mix with Fly Ash as mineral admixture which is designed by using Nan Su method for the strength of 30Mpa using suitable parameters suggested, later modified it with adding extra cement to the obtained mix proportion. Due to the influence of maximum fiber factor and maximum size of aggregate, unacceptable results for workability of fresh mix due to a phenomenon such as blockage of spaces through the vertical bars of L-Box is predicted. In order to reduce this, the fibers of length and dosage not more than 25mm and 0.40% by volume of mix respectively are used. Then the fresh mix satisfies the EFNARC workability requirements.**

Keywords: - Self Compacting Concrete; NANSU method; Steel fibers; Fly Ash; maximum fiber factor; Blockage Problem.

1. INTRODUCTION:-

Concrete is one of the world's most widely used materials [11]. Concrete is a type of homogeneous mixture that plays a prominent role in the development of Infrastructure as well as in new Innovative Structures that used to help in creating historical monuments. For several years in 1900's the problem of the durable of concrete structures was a major topic of interest in the world. The creation of durable concrete structures requires adequate compaction by skilled workers. However, the gradual reduction in the number of skilled workers in construction industry has led to a similar reduction in the quality of construction work. Every day, research is going on how to improve the performance of concrete in various ways through various approaches for Durability criteria. One of such advancement in concrete led to the invention of Self Compacting Concrete by Hajime Okamura in the year 1986 to reduce the amount of skilled labour used in the field of construction.

Self Compacting Concrete is also known as Self Consolidating Concrete or Free Flow Concrete. Self Compacting Concrete is a new kind of High performance concrete with excellent deformability and segregation resistance. SCC is different from the HPC developed in North America and Europe, which emphasizes on high strength and durability of concrete. Self Compacting Concrete is different from normal concrete as it contains more powder and sand than the coarse aggregate compared to normal concrete. While designing it, several factors are taken into consideration such as limited aggregate content and increasing paste volume, low water powder ratio, use of super plasticizer and carefully controlling maximum size of coarse aggregates.

The utilization of Self Compacting Concrete started growing rapidly. EFNORC, making use of board practical experiences of all the members of European federation with SCC, has drawn up specification and guidelines to provide a framework for design and use of high quality SCC, during 2001. Most of the information particularly test methods are based on specification and guidelines of self-compacting concrete given by EFNORC.

Self Compacting Concrete has to satisfy the stage such as Self Compaction when it is fresh where as strength and durability as hardened state. SCC has more favorable properties such as excellent segregation resistance, high flow ability and distinctive Self-Compacting ability.

The compactness of the mix matrix due to higher amount of fine and extra fine particles of material such as Fly Ash improves interface zone properties and thereby fiber matrix bond, leading to enhanced post cracking toughness and energy absorption. Use of fibers in SCC enhances the tensile strength, delays tension cracks due to heat of hydration of more cement. Fibers impart the ductility property to the mix, which enables it to carry the loads even after the cracks are developed and thereby increasing the toughness of Self Compacting Concrete.

2. LITERATURE REVIEW:-

Even though Self-Compacting Concrete has passed from research stage to field application, yet there are no systematic standards or specifications to be followed

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in its mixture proportions. In the absence of precise and codal procedures for SCC mix design, SCC is tried to evolve a workable and strong mix with and without fibers adopting the method suggested by Nan Su, Kung-Chung Hsu and His-Wen Chai[3] of mix design due to the advantages. However, the validity of this method should be verified to recommend it to the local construction industry through the experimental investigation.

Okamura [2] and Ozawa proposed an empirical method known as rational method. The guidelines given in EFNARC are based on this empirical method. The procedures defined in this method are too complicated for practical implementation. It yields in high paste content which results in higher strength than actually required and hence suitable for gravelly rounded aggregates.

Nan Su, et.al proposed a method based on packing theory. It starts with the packing of all aggregates and latter with filling of aggregate voids with paste. This method is quite easier to carry out the procedure and yields in less cement and filler material powder making the resultant concrete more economical.

Other popular methods are :- Sedran method, method suggested by Gomes and Ravindra Gettu, the absolute volume method, optimization of mix proportions using Taguchi's technique and Punkte test. Ferrara, et.al [13] proposed a mix design method for SCC with steel fibers. They developed a model considering fibers in the optimization of solid skeleton through the concept of equivalent specific surface diameter.

Prajapathi, et.al [5] carried out a mix design based on Japanese method. The use of fly ash in the mix improves its workability. Increase in the fly ash content in place of cement from 48kg/m^3 to 144kg/m^3 reduced the water requirement of the mix thereby reducing the 28days average cube strength of the mix from 52Mpa to 39Mpa.

Bhalachandra and Shirale [6] have adopted American Concrete Institute (ACI) method to design M25 grade replacing cement with Metakaolin by 12.5% by weight of cement. Optimum steel fiber dosage up to 3% to 4% by volume of mix increases the cube strength. Beyond 4%, balling problem of fibers is mainly responsible for decrease in all types of strengths.

Apparao and Raghuprasad [7] identified that with a small addition of fraction of steel fibers of 0.62% by volume in high strength concrete, the mode of failure changes from catastrophic to gradual. The fibers more than 2% by volume and aspect ratio more than 100 is difficult to mix. So in this study the steel fibers of aspect ratio equals to 60 and percentage by volume of fibers is not more than 0.5% is used.

3. MATERIALS USED:-

3.1. CEMENT:

Cement [11] is a grey color fine powder, which is a mixture of calcareous and argillaceous material used for binding between the materials of concrete. This paper presents the progress of research by using ordinary Portland cement (OPC) of 53 grade of specific gravity 3.15 and that confirms in accordance with IS 12269:1987 is used.

3.2. FINE AGGREGATE:-

Locally available sand of specific gravity 2.4 and fineness modulus of 3.38 is used. It confirms to Zone II of IS 383-1970. The bulk density of loosely packed aggregate is 1519.4 kg/m^3 and for tightly packed aggregates is 1595.37 kg/m^3. The maximum size of fine aggregate used is 2mm.

3.3. COARSE AGGREGATE:-

Crushed aggregates of maximum size passing from 12.5mm sieve and retained in 10mm sieve is of 50% of Total Coarse Aggregate, remaining 50% are passing from 10mm sieve and retained in 6mm sieve is used in the present paper. Specific Gravity of coarse aggregate is 2.875. The bulk density of loosely packed aggregates 1409.4 kg/m^3 and tightly packed aggregates are 1479.87 kg/m^3 respectively.

3.4. FLY ASH:-

Class F grade dry Fly Ash of specific gravity 2.15 confirming to IS 3812-2003 from Damodaram Sanjeevaiah thermal power plant is used. Fly Ash is used as the filler material to improve the rheological properties thereby reducing cracks because of reduced heat of hydration.

3.5. SUPERPLASTICIZER:-

MasterGlenium SKY 8233, which is also known as, Glenium B233 is an admixture of a new generation based on modified polycarboxylic ether. It is a High-performance super plasticiser based on PCE (polycarboxylic ether) for concrete. Its pH value is >= 6, specific gravity is 1.08 ±0.02 at 25^{0}C and dry material content is 40%.

3.6. WATER:-

Water suitable for drinking confirming to IS – 3025-1983 is used. Its pH value is 7.21.

3.7. STEEL FIBERS:-

Steel fibers of various forms has used in the present study. Crimped, Hook end and Straight Steel fibers of length 30mm and diameter of 0.5mm has used in the experimental investigation. The aspect ratio of the fibers used is of 60 (Ratio of length to its Diameter) and the MFF (maximum fiber factor is ratio of length of fibers to maximum size of coarse aggregates) is found to be 2.4.

4. EXPERIMENTAL INVESTIGATION:-

The present study aims to develop the Steel Fiber Reinforced Self Compacting Concrete (SFRSCC) of M30 grade and analyze the fresh and hardened properties of it. Nan Su mix design method has followed to develop the SCC of M30 grade. Steel fibers of different types (straight, hooked and crimped) in different percentages like 0.1%, 0.2%, 0.3% and 0.4% by volume of mix were added to SCC with fly ash as mineral admixture and then fresh and hardened properties of the resultant mixes have been studied.

According to EFNARC[10], to check the Workability criteria for the fresh SCC these requirements (Table: 1) are to be fulfilled at the time of placing. Likely changes in workability during transport should be taken into account in production.

S. No	Method	Units	Typical range of values	
			Minimum	Maximum
1	Slump Cone	mm	650	800
2	V - Funnel	sec	6	12
3	L - Box	No Units	0.80	1.0

Table 1: Acceptance criteria for Self-compacting Concrete

4.1. MIX DESIGN PROCEDRE BY NANSU METHOD[3]:-

The principal consideration of the NANSU method is to fill the paste of binders into voids of the aggregate framework piled loosely. The loose unit weight of the aggregate is according to the shoveling procedure of ASTM C29, except discharging the aggregate at a height of 30 cm above to the top of the measure. Usually, the volume ratio of aggregate is about 52–58%, in other words, the void in the loose aggregate is about 42–48% according to ASTM C29. When the aggregate binding with the paste at hardened state provides strength to SCC and binding paste at fresh state provides the workability of SCC. Therefore, the contents of coarse and fine aggregates, binders, mixing water and SP will be the main factors influencing the properties of SCC.

The procedure of NANSU mix design method is as following:

Step 1: calculation of coarse and fine aggregate contents
Step 2: calculation of cement content
Step 3: calculation of mixing water content required by cement
Step 4: calculation of fly ash (FA) contents
Step 5: calculation of mixing water content needed in SCC
Step 6: calculation of SP dosage
Step 7: adjustment of mixing water content needed in SCC
Step 8: trial mixes and tests on SCC properties
Step 9: adjustment of mix proportion

4.2. MIX PROPORTION:-

The following is the mix proportion obtained for M30 grade concrete by weight using NANSU Method.

MIX PROPORTION BY WEIGHT IN KG PER ONE CUBIC METER OF SELF COMPACTING CONCRETE (SCC)	
Packing Factor	1.06
S/a ratio	0.57
SP dosage (% of powder)	1.30%
Water powder ratio (W/P)	0.36
Cement	220
Fly Ash	190
Powder (Cement + Fly Ash)	410
Fine aggregate	909
12.5mm (50% of CA)	318.3
10mm (50% of CA)	318.3
Water after correction for SP	151.5
SP	5.35

Table 2: Mix Proportion for Self-compacting Concrete

This mix proportion satisfies the EFNARC guidelines such as the total powder content ranging from 400 to 600 kg/m^3.

4.3. MIXING:-

Measure the quantities of materials using weight machine and mix the materials for not less than 1 minute in dry condition. Mixing time for SCC is more than normal concrete due to more powder content. Water and Super Plasticizer should mix thoroughly and this mixture of water and super plasticizer is added to the mixed dry state materials and then mix total materials thoroughly for not less than 10 minutes. Then add the fibers in last 1-2 minutes before the sample is taken into casting moulds. Drum Mixer is preferable for FRSCC rather than hand Mix. Rahman et al identified that delay in mix or long time mixing will necessitates to add extra water periodically so as to compensate the loss of water will render the concrete with more pores making them to increase water absorption and chloride ion permeability.

4.4. CASTING AND CURING:-

The specimens of standard cubes (150mm x 150mm x 150mm), and standard cylinders (100mm diameter x200mm height) were casted to determine compressive strength and split tensile strength of the mix for 7,14 and 28 days respectively. After mixing, the Mixture is placed in these specimens of standard dimensions.

The test specimen cubes and cylinders were stored in a place, free from vibration, in most air at 90% relative humidity and at a temperature of 27 ±2c for 24 hours± ½ hour from the time of addition of water to the dry ingredients. Then the specimens are placed in curing tank for curing.

5. RESULTS AND DISCUSSIONS:-

A comparative study had done by comparing the hardened properties such as compressive strength and split tensile strength of SCC and SFRSCC of grade M30.

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S. No	Method	Units	Typical range of values		Results
			Minimum	Maximum	
1	Slump Cone	mm	650	800	750
2	V - Funnel	sec	6	12	7
3	L - Box	No Units	0.80	1.0	0.9

Table 3: Properties of fresh Self-Compacting Concrete with no fibers

S. No	Mix	Compressive Strength (MPa)			Split Tensile Strength (MPa)		
		7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
1.	Plain SCC	19.18	27.45	30.5	2.42	3.35	3.7

Table 4: Properties of Hardened Self-Compacting Concrete with no fibers

The steel fibers of different forms (Hook end, crimped and straight fibers) at appropriate dosages are used. Fibers of length 30mm, 0.5mm diameter are added to the SCC mix. The resulting mix is nothing but Steel Fiber Reinforced Self Compacting Concrete. At 0.4% dosage, when straight, hook-end and crimped steel fibers are added then the slump flow reduces from 750 mm to 693 mm, 687 mm and 680 mm respectively and V- funnel time increases from 7 sec to 10.6 sec, 11.1 sec and 11.4 sec respectively which indicates the decrease in workability of mix.

From the results, it is clear that the workability of steel fiber reinforced self compacting concrete made with crimped steel fibers is observed to be less than that of the SCC made with other steel fibers. For all dosages of fibers except 0.1%, the fresh mix yields unsatisfactory results of L-box by blocking the bar openings.

S.NO	TYPE OF STEEL FIBER	% OF FIBER BY VOLUME OF MIX	SLUMP CONE (mm)	V – FUNNEL (sec)	L-BOX
1.	CRIMPED FIBERS	0.1	742	7.4	0.82
		0.2	725	8.3	0.73
		0.3	711	9	0.7
		0.4	693	10.6	0.62
2.	HOOK – END FIBERS	0.1	738	7.6	0.84
		0.2	720	8.5	0.74
		0.3	706	9.2	0.7
		0.4	687	11.1	0.64
3.	STRAIGHT FIBERS	0.1	730	8.1	0.84
		0.2	715	9.2	0.75
		0.3	700	10.1	0.71
		0.4	680	11.4	0.66

Table 5: Properties of fresh fiber reinforced Self –Compacting Concrete

S.NO	TYPE OF STEEL FIBER	% OF FIBER BY VOLUME OF MIX	COMPRESSIVE STRENGTH (MPa)			SPPLIT – TENSILE STRENGTH (MPa)		
			7 DAYS	14 DAYS	28 DAYS	7 DAYS	14 DAYS	28 DAYS
1.	CRIMPED FIBERS	0.1	20.4	27.84	30.74	2.64	3.66	4.02
		0.2	20.55	28.05	30.92	2.72	3.76	4.14
		0.3	20.79	28.32	31.2	2.85	3.95	4.35
		0.4	21.10	29.6	31.48	2.96	4.1	4.51
2.	HOOK – END FIBERS	0.1	19.96	27.65	30.69	2.59	3.56	3.94
		0.2	20.16	28.03	30.74	2.67	3.69	4.06
		0.3	20.42	28.28	31.13	2.81	3.84	4.23
		0.4	20.77	29.4	31.27	2.87	3.93	4.32
3.	STRAIGHT FIBERS	0.1	19.37	27.5	30.57	2.48	3.4	3.9
		0.2	19.87	28.01	30.63	2.57	3.61	4.0
		0.3	20.03	28.17	30.92	2.73	3.7	4.09
		0.4	20.51	29.3	31.06	2.79	3.8	4.24

Table 6: Properties of Hardened Fiber Reinforced Self-Compacting Concrete

From Table 6, for different fibers of increasing percentage of dosages, there is increase in Compressive Strength and Split Tensile Strength, but increase in Split Tensile strength is more than the increase in Compressive strength. The compressive and Split Tensile strength may be further increases by the addition of fibers of high dosages but it will decreases the workability of SCC which is the main purpose of SCC.

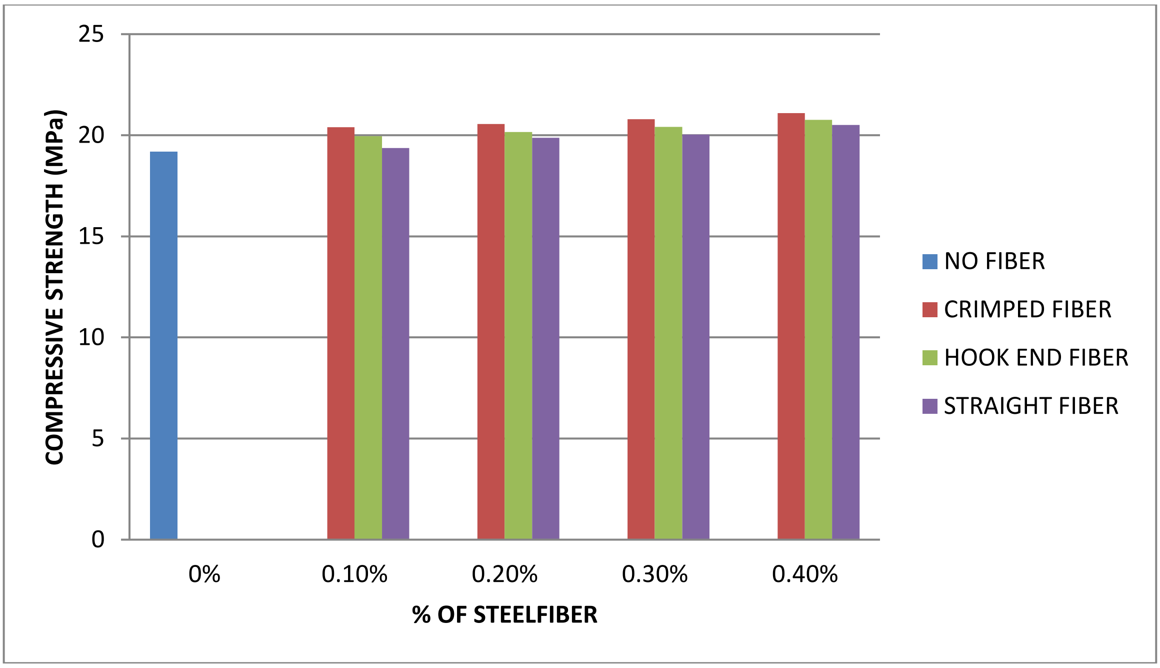

Fig 1: 7 Days Compressive Strength of FRSCC

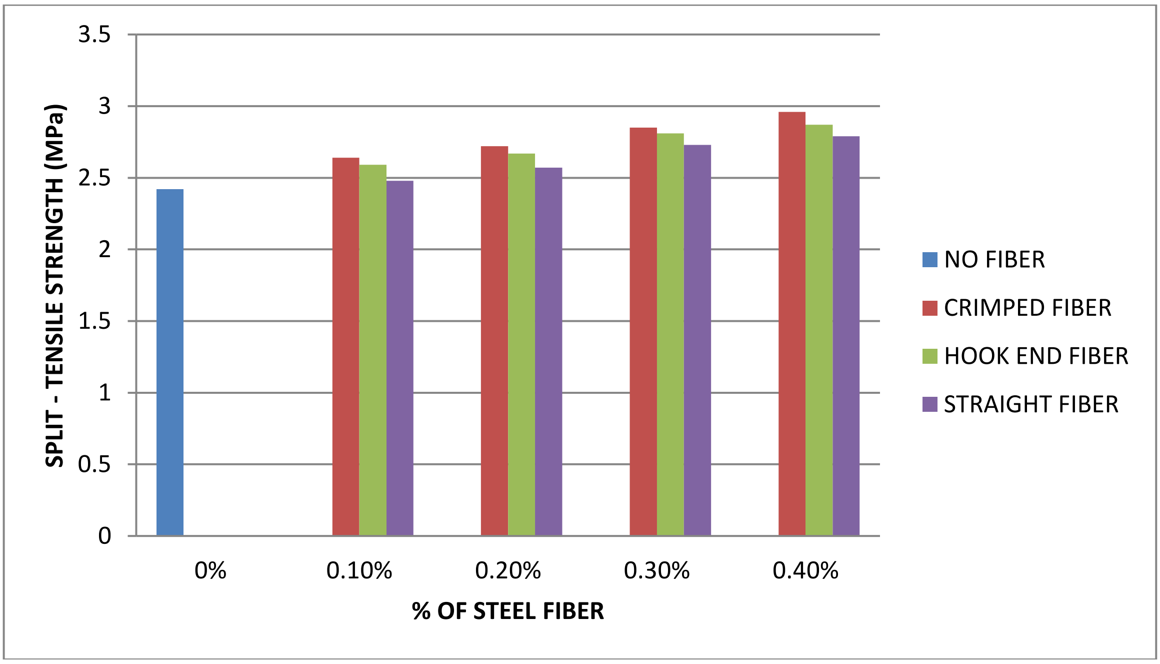

Fig 2: 7 Days Split - Tensile Strength of FRSCC

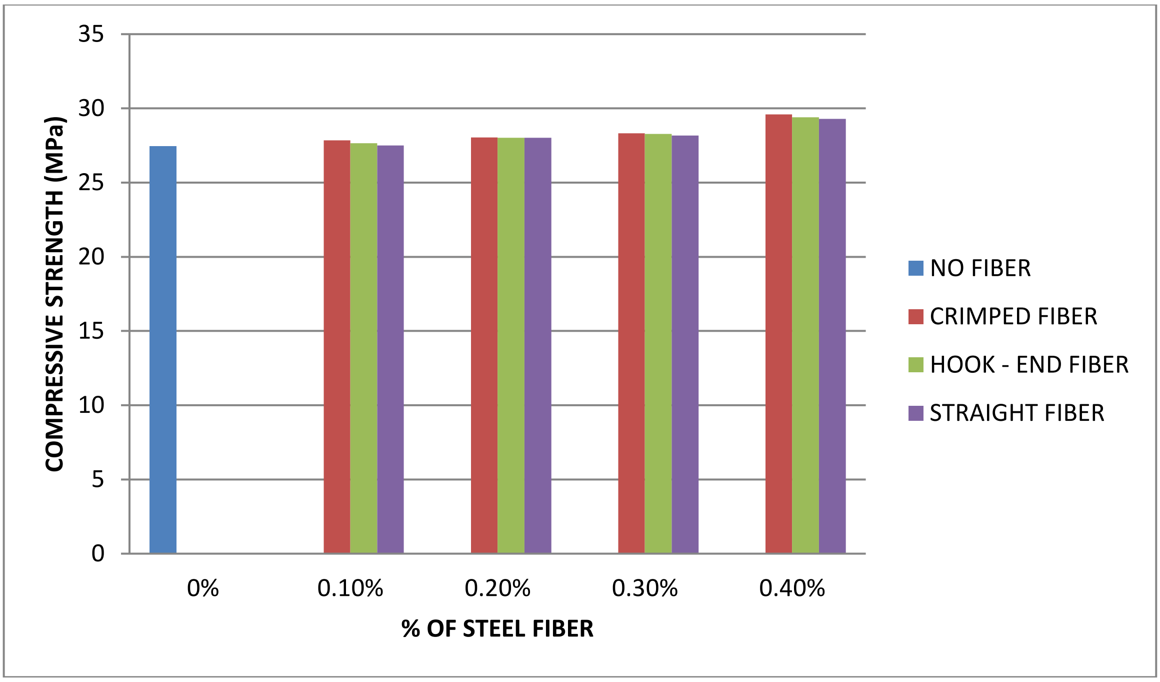

Fig 3: 14 Days Compressive Strength of FRSCC

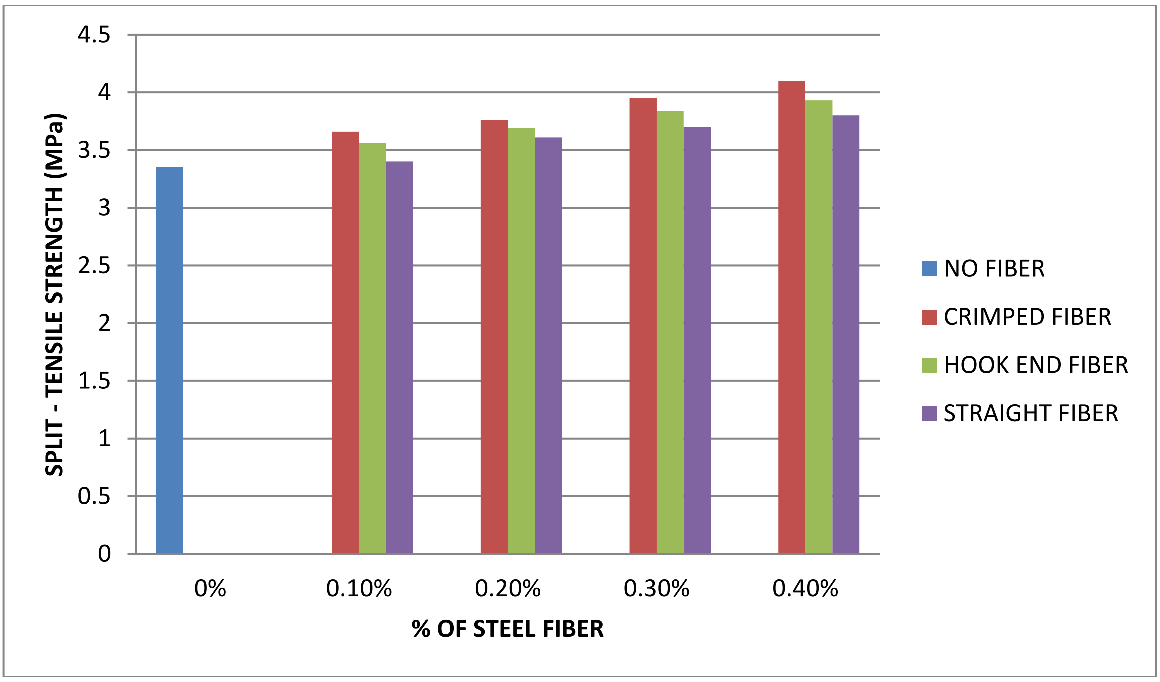

Fig 4: 14 Days Split - Tensile Strength of FRSCC

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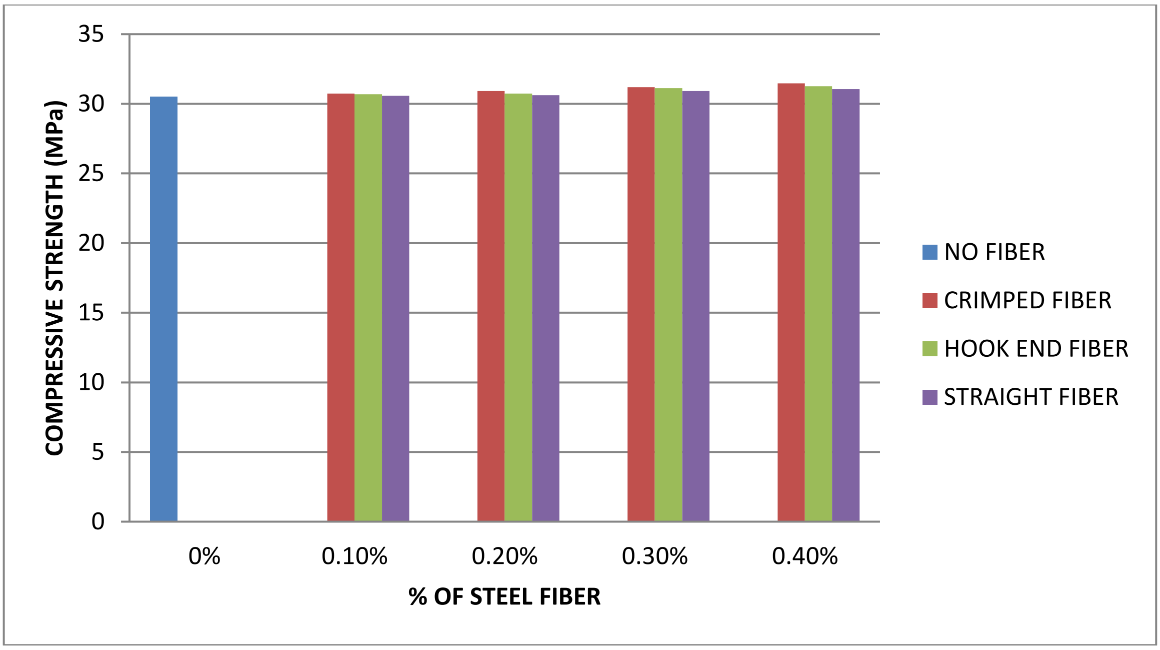

Fig 5: 28 Days Compressive Strength of FRSCC

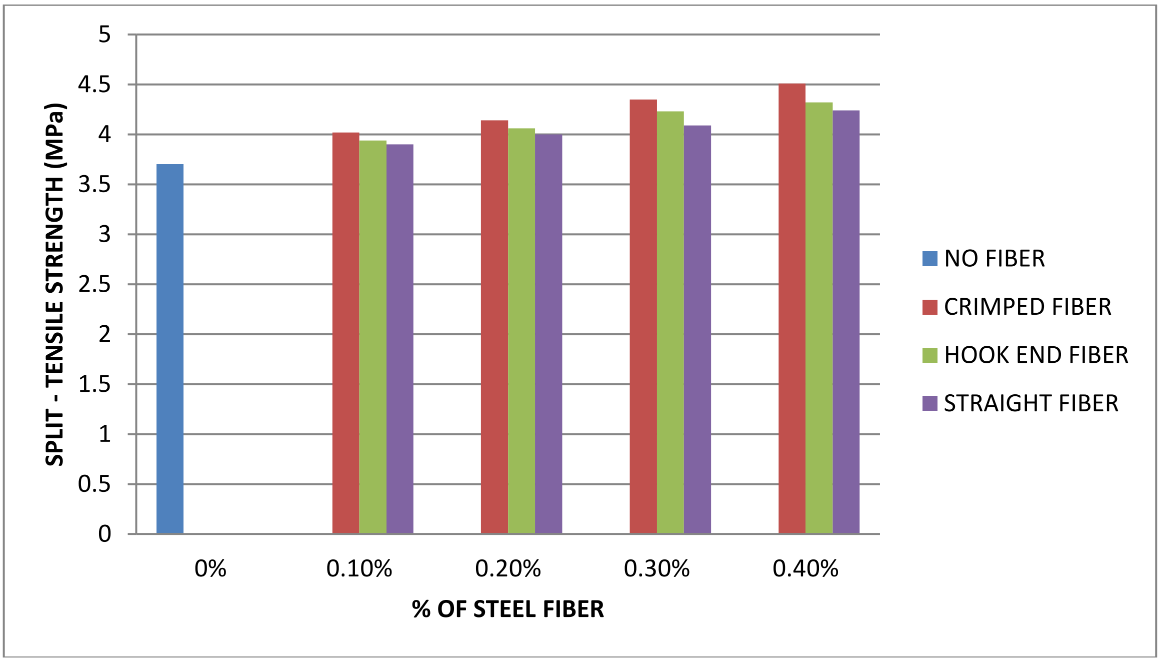

Fig 6: 28 Days Split - Tensile Strength of FRSCC

6. CONCLUSION:-

1. The workability of steel fiber reinforced SCC such as slump flow diameter, L-box ratio and v-funnel time has been decreased considerably for fibers of 30mm length at 0.4% dosage by volume of mix. And it is due to increase in resistance to flow by combined action of large fiber length and 12.5mm size aggregate. These properties can be improved by using fibers of reduced length.
2. Fibers of length not more than 25mm are recommended to yield a mix that is free from blockage of L-box opening. And also, the maximum fiber factor should not be more than 2 as the maximum size of coarse aggregate used in this experimental investigation is 12.5 mm.
3. The workability of steel fiber reinforced self compacting concrete made with crimped steel fibers was observed to be less than that of the SCC made with other steel fibers.
4. The tensile strength of steel fiber reinforced SCC made with crimped steel fibers is observed to be more than that of the SCC made with other steel fibers at the same dosage.
5. When the Steel Fibers of 0.5% in volume of concrete were added to the mix, the fresh concrete lost its flow properties and hence the concrete cannot be referred to as Self Compacting Concrete.

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