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A STUDY ON STEEL FIBER REINFORCED SELF COMPACTING CONCRETE

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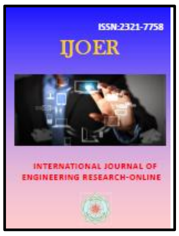

ABSTRACT
Self compacting concrete (SCC) is a special type of concrete that can flow and compact under its own weight. Due to its excellent deformable and segregation resistance property, full compaction can be achieved without vibration in form works with heavy and congested reinforcement. Fibers are added to enhance its ductility, toughness, tensile strength and to reduce drying shrinkage. In the present study a simple mix design method viz NAN SU method is followed to proportionate the mix design of self compacting concrete (SCC) of grade M30. At the same time, it should satisfy the EFNORC guidelines for the workability at fresh state and strength requirement at hardened state. The volume and length of steel fibers combined with coarse aggregates in the mix influences the flow properties of wet mix. To indentify this, crimped, hooked end and straight steel fibers of 30mm length and 0.5mm diameter in dosages varying from 0.1% to 0.4% by volume of the mix were added in plain SCC mix with Fly Ash as mineral admixture designed by Nan-Su method for the strength of 30MPa. Due to the influence of maximum fiber factor and maximum size of aggregate used, 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. So, to reduce this, the fibers of length and dosage not more than 25mm and 0.40% by volume of mix respectively may be used to satisfy the EFNARC workability requirements of fresh concrete. The compressive strength of SCC is found to be more or less constant whereas, the split tensile strength increases with increase in fiber content.

Key words: self compacting concrete; nan-su method; steel fiber; maximum fiber factor; blocking problem.

1.INTRODUCTION

Concrete is one of the world's most widely used materials. Every day, research is carried out such as to improve the performance of concrete in various ways through various approaches for different applications. One such advancement in concrete led to the development of Self Compacting Concrete (SCC) by Okamura in the 1986 due to the unavailability of skilled workers for proper compaction and vibration of concrete in Japan. As per ACI 237R-07 (2007)[1], self compacting concrete (SCC) is defined as a highly flowable and has resistance against segregating concrete that can fill the formwork and encloses the reinforcement with less compaction effort and sometimes without any external compaction.

SCC has to satisfy the stages such as self compaction when it is in fresh state where as strength and durability as in hardened state. SCC has got more favorable properties such as excellent segregation resistance, high flow ability and distinctive self-compacting ability. Self compaction is achieved by using super plasticizer, limited aggregate content where as strength and durability is achieved by using low w/c ratio, limiting the coarse aggregates content. Then energy consumption of coarse aggregate to cause flow which is particularly high is bought to a level lower than the normal and SCC is effective in avoiding the blockage of aggregates in U-box, L-box due to increased internal stresses.

EFNARC[14] recommends the use of fibers in self compacting concrete. 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 also fiber matrix bond, leading to enhanced post cracking toughness and energy absorption.

Fibers with hooked ends[15] achieved minimum anchorage with concrete and good cement paste bond along the length of fiber. Use of fibers[16] in SCC enhances the tensile strength, delays tension cracks due to heat of hydration of more cement. Fibers[17] 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:

Hajime Okamura[2] of Tokyo University first introduced the SCC in the year 1986. The main aim behind the concept of Self-Compacting Concrete is to overcome the difficulty of non availability of skilled labour. Non availability of skilled workers led to sub-standard construction of structures, in turn causing serious durability related problems. Khayat et al[3] had proposed the application of SCC in the members with congested reinforcement. Good flowability, valuable characteristic of Self Compacting Concrete encourages its use in heavily reinforced members which are popularly used today.

The feasibility of the usage of quarry rock dust as 100% substitutes for natural sand in concrete was studied by Ilangovana et al[4]. In their investigation the cube strength and flexural strength of concrete made of quarry rock dust was indentified to be nrarer to Normal Concrete. Rajamane et al[5] studied the properties of HPC in which cement was replaced partially with GGBS. They identified that the 28 days cube strength increased by 10.2MPa in comparison with the Conventional Concrete showing the increased strength efficiency of GGBS.

2.1Mix Design Methods

Okamura and Ozawa[6] 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[7] 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[8], method suggested by Gomes and Ravindra Gettu[8], the absolute volume method[9], optimization of mix proportions using Taguchi's technique[10] and Punkte test[11].

Ferrara, et.al[12] 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. Fibers were considered in the particle size distribution of the solid skeleton through the concept of an equivalent diameter. It was indentified that as w/b ratio and dosage of super plasticizer in a mix increases, viscosity of fresh mix decreases and hence slump flow increases.

Prajapathi, et.al[19] adopted Japanese method for their investigation and found that the use of fly ash in the mix improves its workability. Increase in the fly ash content from 48kg/m^3 to 144kg/m^3 reduced the water requirement of the mix. In the absence of precise and codified procedures for SCC mix design, it was tried by Vijay Kumar and Sakey Sharma[13] to evolve a workable and strong mix with and without fibers adopting the method suggested by Nan Su, Hsu and Chai[7] of mix design. In the present work, an attempt was made to make SCC using both Fly Ash and Steel Fibers of different forms.

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3.MATERIALS USED

Cement: Ordinary Portland Cement (OPC) of 53 grade of specific gravity 3.13 and that confirming to IS12269: 1987 is used in this study.

Fly Ash: Class F dry Fly Ash of specific gravity 2.15 confirming to IS 3812-2003 is used.

Fine Aggregate: Locally available river sand of specific gravity 2.4 and fineness module 3.38 is used. It is confirming to Zone II of I.S.383-1970. The bulk density of loosely packed aggregates is 1519.4 kg/m^3 and for tightly packed it is 1595.37 kg/m^3.

Coarse Aggregates: Crushed granite stones of size not greater than 12.5 mm are used as coarse aggregate. Coarse aggregate(CA) used in the present work, 50% of CA which were passed from 12.5mm sieve and retained on 10mm sieve and the remaining 50% of CA passed from 10mm sieve and retained on 6mm sieve has been used. The specific gravity of combined aggregates is 2.875. The bulk density of loosely packed aggregates is 1409.4 kg/m^3 and for tightly packed it is 1479.87 kg/m^3.

Water: water suitable for drinking confirming to IS-3025-1983 (water for construction perpose) of IS 456-2000 is used. Its pH value is 7.21.

Super Plasticizer: Glenium B 233, poly carboxylated ether (PCE) based super plasticizer confirming to IS 9103-1999 is used. Its pH value is 6.82, specific gravity is 1.08 and dry material content is 40%.

Steel Fibers: Steel fibers of various forms have been used in the present study. Crimped, Hook end and Straight Steel fibers of length 30mm and diameter of 0.5mm have been used in the experimental investigation. The aspect ratio of the fibers used is of 60 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 at developing the Steel Fiber Reinforced Self Compacting Concrete (SFRSCC) of grade M30 and analyzed the fresh and hardened properties of it. Nan Su mix design method[7] has been followed to develop the SCC of M30 grade. Steel fibers of different types (straight, hooked and crimped) were added to SCC mix with fly ash as mineral admixture in different percentages like 0.1%, 0.2%, 0.3% and 0.4% by volume of mix and then fresh and hardened properties of the resultant mixes have been studied. For each mix, fresh properties of SCC such as filling and passing abilities have been studied by conducting the tests namely slump flow test, "V" Funnel test and "L" Box test and the values were tabulated. For each mix, three cubes of size 150 mm and three cylinders of diameter 100mm and height 200mm were casted to determine cube strength and split tensile strength of the mix for 14 and 28 days and their average values were reported. A comparative study has been done by comparing the hardened properties such as compressive strength and split tensile strength of SCC and SFRSCC of grade M30. All the results obtained from the experimental work have been furnished and also graphically represented for better understanding.

5.RESULTS AND DISCUSSIONS

5.1Mix design and mix proportions

A mix using Nan Su method with packing factor of 1.06 and S/a ratio (ratio of sand to total aggregates by weight) of 0.57 is designed for the characteristic strength of 30MPa as it yields more powder material and tends to improve the workability of fresh mix. The proportions of mix designed by weight are given in Table 1.

Table 1: Showing SCC Mix Proportions

SCC MIX PROPORTIONS BY WEIGHT IN KG PER ONE CUBIC METER OF CONCRETE	
Packing factor	1.06
S/a ratio	0.57
Cement	214.3
FLY Ash	391
Powder	605.3
Fine aggregate	909
12.5mm (50% of CA)	318.3
10mm (50% of CA)	318.3
Water after correction for SP	217.8
SP dosage (% of powder)	1.30%
Water powder ratio (W/P)	0.36

This mix proportion satisfies the EFNARC guidelines such as the total powder content ranging from 400 to 600 kg/m^3. The IS 456-2000 restricts it up to 450 kg/m^3 due to the problems such as drying shrinkage in fresh mix. Self compacting concrete requires 160-200 liters/m^3 of water, to wet not only the powder material but also the aggregate present in the mix.

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5.2 Properties of Fresh and Hardened Self Compacting Concrete Mix

Workability properties i.e., the average values of slump flow, V- funnel and L- box tests of SCC of grade M30 are furnished in the Table 2. The fresh mix will yield satisfactory results due to sufficient amount of paste content.

Drum mixer is used to make plasticizer properly and intimately mixed in concrete to bring about proper distribution with cement particles. Mixing time need to be longer than normal concrete due to more powder content in it. The dry materials mixed for one minute and later, solution containing water and super plasticizer is added and mixed for 10 minutes only. Rahman et al[18] 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.

FIG. 1 TESTS ON SCC FOR WORKABILITY REQUIREMENTS AS PER EFNARC

Table 2:showing properties of fesh self compacting concrete

PROPERTIES OF FESH SELF COMPACTING CONCRETE			
S.NO	**TESTS**	**RECOMMENDED**	**RESULTS**
1	SLUMP	650mm – 800mm	750mm
2	V-FUNNEL	6 sec – 12 sec	7 sec
3	L-BOX	0.8 – 1.0	0.9

Table 3:showing hardened properties of self compacting concrete

HARDENED PROPERTIES OF SELF COMPACTING CONCRETE				
MIX	**Compressive strength**		**Split tensile strength**	
	14 days	**28 days**	**14 days**	**28 days**
SCC	27.45	35.49	3.35	3.7

During testing, it is noted that the slump flow and L-box tests are good qualitative measures of acceptability of mixes. This will make the concrete maker to identify whether the mix is acceptable or not. All the tests on fresh mix are completed within a short and stipulated period soon after the water is added to mix to identify the true measurements of the performance of fresh mix.

5.3 Steel Fiber Reinforced Self Compacting Concrete (SFRSCC)

The steel fibers of different forms (Hook end, crimped and straight steel fibers) at appropriate dosages are used. While mixing fibers are added in the drum of mixer before water is added to ensure even distribution of fibers in the mix. Fibers of length 30mm, 0.5mm diameter and maximum fiber factor = 2.4 is added to the SCC mix.The resulting mix is nothing but Steel Fiber Reinforced Self Compacting Concrete and test results of SFRSCC are given in Table 4.

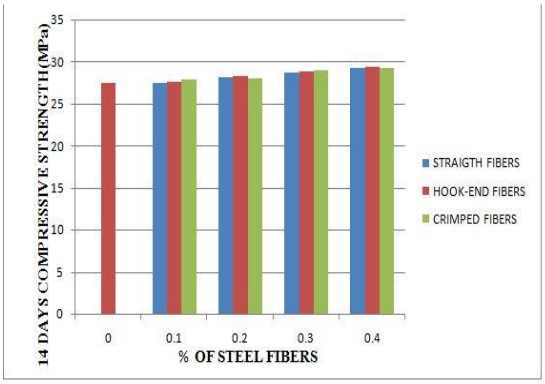
At 0.4% dosage, when straight, hook-end and crimped steel fibers are added, the slump flow reduces from 750 mm to 693 mm, 687 mm and 680 mm respectively and V- funnel time increases from 7 sec to 10.6 sec, 11.1 sec and 11.4 sec respectively which indicates the decrease in workability of mix. From the 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.

Table 3:showing hardened properties of steel fiber reinforced self compacting concrete

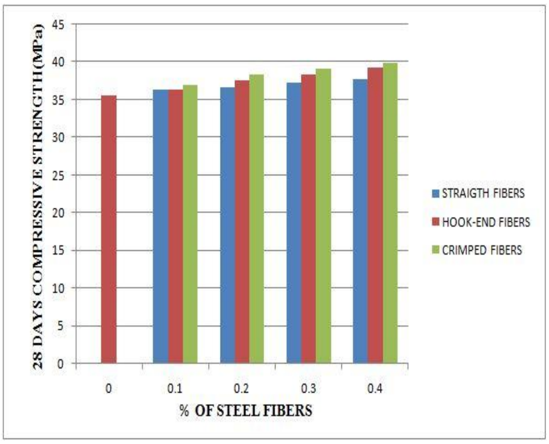
HARDENED PROPERTIES OF STEEL FIBER REINFORCED SELF COMPACTING CONCRETE						
S.NO	FIBER TYPE	% OF FIBERS BY VOLUME OF MIX	COMPRESSIVE STRENGTH(MPa)		SPLIT TENSILE STREGTH(MPa)	
			14 DAYS	28 DAYS	14 DAYS	28 DAYS
1	Straight	0.1	27.5	36.3	3.4	3.9
		0.2	28.1	36.6	3.61	4.5
		0.3	28.7	37.2	3.7	4.9
		0.4	29.3	37.6	3.8	5.5
2	Hook-end	0.1	27.65	36.25	3.54	4.05
		0.2	28.3	37.43	3.69	4.76
		0.3	28.8	38.17	3.84	5.12
		0.4	29.4	39.1	3.93	5.84
3	Crimped	0.1	27.84	36.83	3.66	4.18
		0.2	28.O	38.19	3.76	5.02
		0.3	28.9	39	3.95	5.62
		0.4	29.3	39.74	4.1	5.95

Table 4:showing flow properties of fresh steel fiber reinforced self compacting concrete

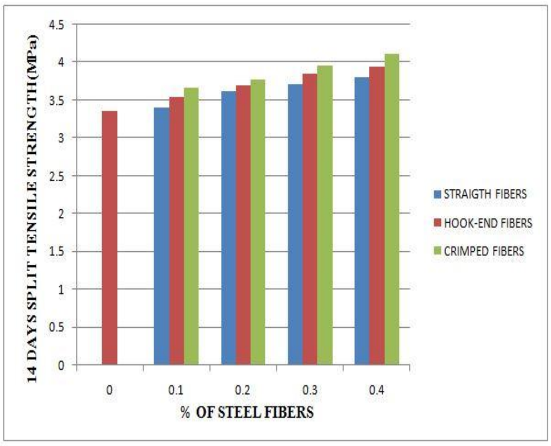
FLOW PROPERTIES OF FRESH STEEL FIBER REINFORCED SELF COMPACTING CONCRETE					
S.NO	FIBER TYPE	% OF FIBERS BY VOLUME OF MIX	SLUMP FLOW (mm)	V-FUNNEL (Sec)	L-BOX
			RANGE : (650-800mm)	RANGE : (6-12Sec)	RANGE: (0.8-1.0)
1	Straight	0.1	742	7.4	0.84
		0.2	725	8.3	0.75
		0.3	711	9	0.71
		0.4	693	10.6	0.65
2	Hook-end	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	Crimped	0.1	730	8.1	0.82
		0.2	715	9.2	0.73
		0.3	700	10.1	0.7
		0.4	680	11.4	0.62



Graph 1: 14 days compressive strength of SFRSCC for different percentages of fibers



Graph 2: 28 days compressive strength of SFRSCC for different percentages of fibers.



Graph 3: 14 days split tensile strength of SFRSCC for different percentages of fibers.

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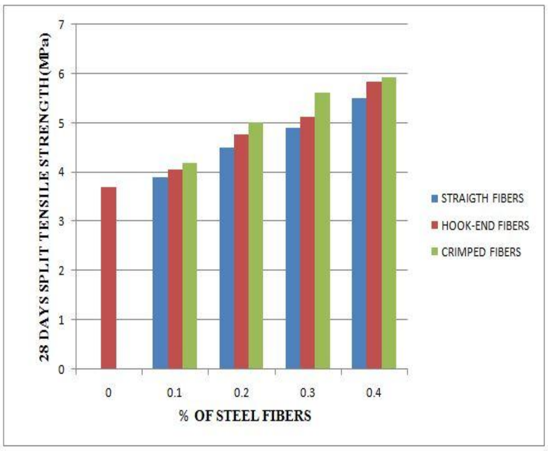

Graph 4: 28 days split tensile strength of sfrscc-f for different percentages of fibers.

From Table 5, for fibers at the dosage of 0.4%, the 14 and 28 days average compressive strength of SCC mix increases from 27.45 MPa to 29.3 MPa, 29.4 MPa and 29.3 MPa and from 35.49 MPa to 37.6 MPa, 39.1 MPa and 39.74 MPa for straight, hook-end and crimped steel fibers respectively. The 14 and 28 days average split tensile strength of the mix at the dosage of 0.4% of fibers, increases from 3.35 MPa to 3.8 MPa, 3.93 MPa and 4.1 MPa and 3.7 MPa to 5.5 MPa, 5.84 MPa and 5.95 MPa for straight, hook-end and crimped steel fibers respectively. These strengths further increases as dosage of these fibers increases but the increase in the dosage of fibers beyond 0.4% reduces the workability of the mix and the mix cannot be referred to as self compacting concrete.

6. CONCLUSIONS

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 compressive strength of SCC increases marginally, where as the tensile strength increases considerably with addition of steel fibers. The percentage increase in tensile strength of SFRSCC with 0.4% of straight, hook-end and crimped fibers are 48%, 57.8% and 60.8% respectively for 28 days over normal SCC.
5. 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.
6. 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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