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Comparative Study on the Mechanical Properties of Steel Fiber Reinforced Self-Compacting Concrete

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***Abstract*: Self-compacting concrete (SCC) is a flowable concrete which can consolidate under its own weight without the need of external vibration. The highly fluid nature of SCC makes it suitable for placing in difficult environments like congested reinforcement and thinner sections. Use of SCC can also help in decreasing noise pollution at worksites which is caused by vibration of concrete. SCC is used in bridges, buildings, and tunnel construction.**

The addition of small closely spaced and uniformly dispersed fibres to concrete would act as a crack resistor and would substantially improve its properties. This type of concrete is known as fibre reinforced concrete. In fact, the fibre reinforcement mechanisms can convert the brittle behaviour of this cement-based material into a pseudo-ductile behaviour up to a crack width that is acceptable under the structural design point-of-view. Fibre addition, however, increases the complexity of the mix design process, due to the strong perturbation effect that steel fibres cause on fresh concrete flow.

In the present study, the effect of steel fibres on fresh and hardened properties are studied by adding steel fibres of different percentages such as 0%, 1% and 2% for M70 grade of concrete. An experimental investigation has been carried out to determine different properties like workability and strength of Fiber Reinforced Self Compact Concrete and Self- Compacting Concrete (SCC). For testing the properties of SCC and Fiber Reinforced SCC (FRSCC) in fresh state slump-flow, T50 Test, L-box, U-box, and V-funnel tests were conducted. Whereas for testing the properties in hardened state compressive strength, split tensile strength and flexural strengths are carried out.

Detailed studies have revealed that the Steel Fiber Reinforced Self Compacting Concrete made with the Steel fibres displays a better performance. The investigations and results are presented from the study.

***Index Terms*: Self compacting concrete, Steel fibre reinforced concrete, Super plasticizer, Silica fume, Fly ash, Steel fibre.**

I. Introduction

Concrete is the predominant, most popular and widely used construction material. Self-Compacting Concrete (SCC) or Self-Consolidating Concrete is one of the most important innovations. When a large quantity of heavy reinforcement is to be placed in reinforced concrete, that is fully compacted without voids or honeycombing, compaction by manual or by mechanical vibration is extremely challenging in that situation [1-3]. Underwater concreting always required fresh concrete which should be placed without the need for compacting and in such circumstances, vibration is simply impossible [4]. This problem can now be solved with Self Compacting Concrete. This type of concrete flows easily around the reinforcement and into all concerns of formwork. Self-Compacting Concrete is described as concrete with the ability to compact itself only by its own weight without the reinforcement of vibration. Self-Compacting Concrete is also known as Self-Consolidating concrete. Self-Compacting Concrete is a concrete mix with a low yield stress, high deformability, good segregation resistance (prevents separation of particles in the mix), and moderate viscosity (necessary to ensure uniform suspension of solid particles during transportation, placement (without external compaction), and thereafter until the concrete sets [5-7]. In everyday terms, when poured, SCC is an extremely fluid mix with distinctive practical features - it flows very easily within and around the form work, can flow through obstructions and around corners measured using "passing ability", is close to self-compacting (although not actually self-levelling), does not require vibration or tamping after pouring, and follows the shape and surface texture of a mould very closely once set [4]. The typical method of compaction, vibration generates delays and is an additional cost to the project. In this project SCC is used along with steel fibre for increasing strength of the concrete [8-10]. Steel fibre has high elongation property i.e., tensile strength, by the addition of steel fibres in SCC an increase in the Compression Strength, Flexural Strength and Split Tensile Strength of Concrete was achieved.

II. Characteristic of Fresh SCC

SCC mixes must meet three key properties:

1. Ability to flow into and completely fill intricate and complex forms under its own weight.
2. Ability to pass through and bond to congested reinforcement under its own weight.
3. High resistance to aggregate segregation.

The main characteristics of SCC are.

i) Passing ability
ii) Filling ability
iii) Resistance to Segregation

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III. Objective of the Work

In the present study, it is proposed to study the following on M70 grade concrete using steel fibres of different percentages by weight of cementitious material, silica fume and fly ash:

- Comparison of different properties like workability and strength of Self-Compacting Concrete (SCC) with Steel Fiber Reinforced Self Compacting Concrete (SFRSCC).
- Tests involving various fibre proportions for a particular mix of SFRSCC.
- Test methods used to study the properties of fresh concrete were Slump test, V – funnel, T50, and L – Box.
- To determine Hardening properties like Compressive Strength, Flexural Strength, Split tensile strength for cubes, prisms and cylinders.
- To determine the load vs deflection curves of beams by varying percentage of steel fibres.

IV. Materials & Methodology

Cement: Ordinary Portland Cement OPC 53 Grade available in the local market was used. The below test properties according to IS: 4031-1988 and found confirming to IS: 12269-1987 was used. Normal Consistency 32%, Specific Gravity 3.10, Initial and Final Setting time of 45 min and 580 min respectively, Fineness 2.37% and Soundness of 4 mm was measured on Le-Chatelier's apparatus.

Fine aggregate: Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size being finer than gravel and coarser than silt. Fine aggregate (sand) used for this investigation is river sand conforming to zone-II of IS 383-1970 and it was well graded, passing through 4.75mm sieve.

Coarse Aggregate: Crushed angular granite material available from the local market was used as coarse aggregate in this investigation. The coarse aggregate (passing through IS Sieve 12mm and retained on IS Sieve 10mm was tested for its characteristics as per IS: 2386-1963 and found to be confirming to the specifications.

Fly Ash: Fly ash is one of the most widely used by- product materials in the construction field resembling Portland cement. The physical and chemical properties of the fly ash as used in the investigation confirm to grade, I fly ash of IS: 3812-2003. Specific Gravity 2.20 and Specific Surface area 420m^2/kg. The chemical composition was SiO_2 68%, Al_2O_3 23%, Fe_2O_3 4%, CaO 1.1% and MgO 0.5%.

Silica Fume: Silica Fume is a byproduct of producing silicon metal or ferrosilicon alloys. The quality of silica fume used was as specified by ASTM C 1240 and AASHTO M 307. Powdered Silica Fume with a Specific Gravity of 2.2 and bulk density of 220 Kg/m^3 was used.

Steel Fibres: Hooked end steel fibres of 0.4mm diameter and Aspect ratio of 30 and 12-mm length were used. Here in the present study, steel fibres hooked at both ends were used.

Water: Ordinary portable water of normal PH 7 was used for mixing and curing the concrete specimen.

Admixtures: CONPLAST SP430 confirming the requirement of IS: 9103-1979 as a high range water reducing admixture was used.

V. Mix Design

Mix design is the process of selecting suitable ingredients of concrete and determining their relative proportion for producing concrete of certain minimum strength and durability as economically as possible for Grade M70 using the Code IS 10262:2019[11]. The proportions of the mix are listed in Table I.

VI. Tests on Fresh Concrete

Different test methods were used to characterize the properties of SCC.

1. Slump flow & T50 test,
2. V- funnel test & V-funnel at T5 minutes
3. L- box test

The acceptance criteria as per EFNARC is mentioned Table II.

TABLE I.
Mix Proportion for SCC

W/C	Cement	Fly Ash	SF	CA	FA	WC	Super plasticizer (1.8% by weight of Cement)
0.31	421*	78.9	26.3	945.23	720	148	7.58

*All quantities in kg/m3. SF-Steel Fibers, WC-Water Content

TABLE II.
Acceptance Criteria for SCC

Sl. No	Method	Unit	Typical rangeof values Minimum	Maximum
1	Slump flowby Abram's cone	mm	650	800
2	Time increase, V-funnel at T5minutes	Sec	2	5
3	V-funnel	Sec	6	12
4	L-box	mm	0.8	1

VII. Tests on Hardened Concrete

Testing of hardened concrete plays an important role in controlling and confirming the quality of concrete work. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable parts of any quality control programmed for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete with regards to both strength and durability [12-13]. The hardened property test such as compression test by using compression testing machine, split tensile test by using compression testing machine and flexural test by using ultimate testing machine were conducted using the specimen cast as shown in Fig. 1 and Fig. 2. The results obtained for the various mixes of SCC, SCC with 0%, 1%, and 2% Steel Fibres is listed in the results section.

Behaviour In Flexure of Beams: Experimental investigation is carried out on beams to determine its flexural behaviour. The beams are tested using a 1000kN capacity Load Frame under midpoint load setup to get the flexural behaviour.

Beams casted were tested by placing them on the load frame to draw the load versus deflection curves.

VIII. Results & Discussion

The results were obtained by experimentally testing the specimen in the Fresh state and Hardened state and are detailed and discussed in the subsequent text below.

A. Fresh Properties

Fresh properties of various mixes of M70 grade plain self-compacting concrete (SCC) based on various combinations of steel fibre contents using various workability test methods are presented below in Table III. The filling ability, passing ability and segregation resistance values, which are the basic requirements for SCC in fresh state, were found to be satisfying as per EFNARC.

Figure 1. Casting of Cube, Cylinder & Prism Specimen

Figure 2. Casting of Beams

B. Hardened Properties

Compressive Strength

From the compressive strength results of cubes shown in Table IV, the 90 days compressive strength of SCC mixes when Steel fibres are added from 0%, 1% and 2 % the strength observed was 71.23 MPa, 75.14 MPa, and 58.53 MPa that is an increase of 5.49%, from adding 1% steel fibres to 0% steel fibres and a decrease of 18.25% by adding 2% steel fibres to 0% steel fibres as shown in the Fig. 3 and Fig. 4.

TABLE III.
FRESH PROPERTY RESULTS FOR SCC

Grade	Fresh Properties			Remarks	Designat-ion (% of SP)
	Slump flow T50 cm Test Sec	V-Funnel Test Sec	L-Box Test H2/H1		
M70	8(600)	12	0.6	Not withinlimits	SCC (0.5%)
	6 (600)	12	0.7	Not withinlimits	SCC (1%)
	5(620)	11	0.90	Within limits	SCC (1.5%)
M70	4(650)	7	0.9	Within limits	SCC (1.8%)

TABLE IV.
COMPRESSION TEST RESULTS AFTER 90 DAYS FOR M70

Mix	0% SF	1% SF	2% SF
Compressive Strength(N/mm2)	71.23	75.14	58.53

Figure 3. Failure of Cube

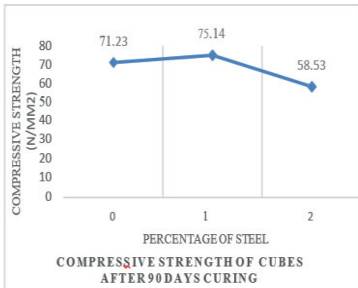

Figure 4. Graph representing Compressive Strength of Cubes

Split Tensile Strength

From the Split Tensile strength results of cylinders shown in Table V, the 90 days Split Tensile strength of SCC mixes when Steel fibres are added as 0%, 1% and 2 % the strength observed was 10.86 MPa, 11.30 MPa, and 11.86 MPa that is an increase of 4.05% and 9.20% by adding 1% to 0% and adding 2% to 0% steel fibres as shown in Fig. 5 and Fig. 6.

TABLE V.
SPLIT TENSILE TEST RESULTS AFTER 90 DAYS FOR M70

Mix	0% SF	1% SF	2% SF
Split Tensile Strength (N/mm2)	10.86	11.30	11.86

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Figure 5. Failure of Cylinder

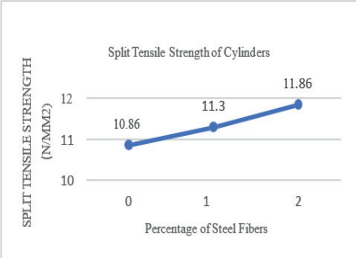

Figure 6. Graph representing Split Tensile Strength of Cylinders

Flexural Strength

From the Flexural strength results of prisms shown in Table VI, the 90 days Flexural strength of SCC mixes when Steel fibres are added from 0%, 1% and 2 % the strength observed was 5.86 MPa, 6.69 MPa, and 7.5 MPa that is an increase of 14.16% and 27.98% from adding 1% to 0% and adding 2% to 0% steel fibres as shown in Fig. 7 and Fig. 8.

TABLE VI.
FLEXURAL TEST RESULTS AFTER 90 DAYS FOR M70

Mix	0% SF	1% SF	2% SF
Flexural Strength (N/mm2)	5.86	6.69	7.5

Figure 7. Failure of Prism

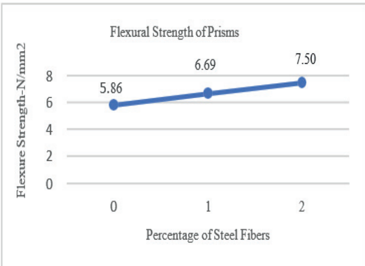

Figure 8. Graph representing Flexural Strength of Cylinders

Flexure of Beams (Load vs Deflection)

The load-deflection results from the Loading Frame using two LVDTs for different SCC mixes after 28 days of curing are listed in Table VII and the Load vs Deflection for the three specimen PSCC, PSCC+1%SF and PSCC+2%SF are shown in Fig. 9 and Fig. 10.

TABLE VII.
LOAD & DEFLECTION VALUES

Sl. No	Method	Ultimate load (KN)	Ultimate Deflection mm
1	Plain SCC	112.50	9.95
2	PSCC+1%SF	195.50	5.58
3	PSCC+2%SF	165.13	6.33

Figure 9. Failure of Beam

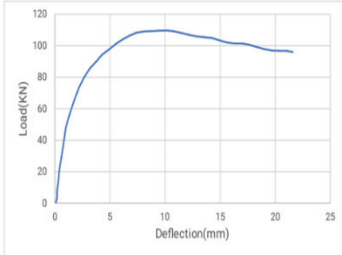

Figure 10. Load vs Deflection PSCC

From overall results of the testing, the ultimate load for self- compacting concrete beams with 1% and 2% steel fibres has increased by 71% and 46% when compared with the plain self-compacting concrete beams. Whereas deflection for self-compacting concrete beams with 1% and 2% steel fibres has decreased by 43.9% and 50% when compared with the plain self-compacting concrete beams.

IX. CONCLUSIONS

Based on the experimental work conducted on SCC mixes and SFRSCC mixes of different grades are the following specific conclusions are drawn from this experimental study:

1. Fibre reinforced self-compacting concrete can be produced by incorporating Steel fibres to improve its performance. However, the use of appropriate dosage of super plasticizer is essential to maintain the fresh properties of self-compacting concrete.
2. Addition of steel fibres has decreased fresh properties for M70 grade SCC but are within the EFNARC specifications.
3. With increase of fibre dosage, the workability decreases. This problem of workability and flow properties of concrete can be overcome by adding superplasticizers.
4. Overall slump flow diameter (flow ability) decreases with the increase in steel fibre content of concrete mixtures with respect to plain mixtures.
5. V-funnel flow time increased with the increase in steel fibre content of the concrete mixtures with respect to plain mixtures.
6. To retain high level workability or fluidity with fibre reinforcement, the amount of paste in the mix should be increased to provide better dispersion of fibres. It can be done by increasing cement content or increasing fine aggregate content or using pozzolanic and chemical admixtures (High range water reducing admixture).
7. By the number of trials mixed, the dosage of the super plasticizer at 1.8% by weight of cementitious material was concluded as optimal.
8. In M70 grade concrete the compressive strength of the Steel Fiber Reinforced Self-compacting concrete was found to have increased in its strength by 5.49% with a dosage of 1% steel fibres by weight of cementitious material and has decreased by 18.25% by an addition of 2% steel fibres when compared to plain self- compacting concrete.

9. Addition of fibres has a marginal increase in the split tensile and flexural strengths as dosage of fibres increased. The split tensile strength increased by 4.05%, 9.20% and flexural strength by 14.16% and 27.98%, when compared to plain SCC with 1% and 2% dosage of steel fibre .
10. In beams, the ultimate load value is maximum for SCC with 1% steel fibres and the deflection decreases when compared with the plain SCC and SCC with 2% steel fibres .
11. From the above experimental investigation, it is observed that Ultimate load will increase with increase in fibre content.
12. With increasing fibre content, mode of failure is observed changing from brittle to ductile failure when subjected to compression and bending.
13. From the overall investigation 1% steel fibres give an enhanced compression strength, split tensile, flexure strength and for load vs deflection.

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