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Fracture Properties of Self Compacting Concrete with Steel Fibers using Notched Beam

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***Abstract*— Recent years, self-compacting concrete (SCC) has gained wide use for placement in reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness.**

Self-compacting concrete (SCC) is a highly-workable concrete that fills the formwork under its own weight without any vibration or impact. Fiber reinforced concrete (FRC) is a concrete in which small and discontinuous fibers are dispersed uniformly. The addition of fibers into concrete mass can dramatically change properties of concrete.

This work examines the effect fibers addition on rheological properties, mechanical properties and fracture energy of self compacting concrete. Rheological properties like J Ring, U Box, L Box were determined as per EFNARC standards. Mechanical characteristics like compressive strength and flexural strength obtained as per IS 516 on standard specimen size. Fracture energy (G_F) measured using the three-point bending test on pre-notched beams prescribed by RILEM recommendations.

The result shows that workability of SCC decrease with addition of fibers but ductility and fracture energy increase with addition of fibers in pain self compacting concrete.

***Keywords*— Self Compacting Concrete, Steel Fibers, Notched Beam, Fracture Properties, FRC**

I. INTRODUCTION

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding. So it was defined as a concrete that exhibits a high deformability and a good resistance to segregation. This kind of concrete is of great interest and has gained wide use especially in the case of difficult casting conditions such as heavily reinforced sections without undergoing any significant segregation or bleeding [1,2].

It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. SCC was developed in Japan in the late 1980s to be mainly used for highly congested reinforced structures in seismic regions. Recently, this concrete has gained wide use in many countries for different applications and structural configurations. SCC can also provide a better working environment by eliminating the vibration noise [3].

Using fibers in the concrete decreases brittle fracture of the concrete significantly, and under various loads, especially the compressive loads, tensile loads, and blast loads, the behavior of fiber- reinforced concrete will be ductile [4].

By bridging between sides of cracks, fibers tend to preserve the integration of concrete until high deformation and therefore prevent brittle failure. Nowadays, fiber-reinforced concrete is utilized in various areas including road pavements, sidewalks, bridges, lining of tunnel segments, and slabs [5,6].

Adding small amounts of fibers might not only reduce the problem of shrinkage cracking, but also increase mechanical properties such as tensile strength and toughness. The fibers added to the concrete paste while mixing are short elements with a reduced section and randomly distributed [7,8].

The increment in the mechanical properties of the concrete will depend mainly on the material of the fibers, their geometrical characteristics and the amount of fibers added. In some cases there is such an increment of the mechanical properties that the contribution of the fibers may be taken into account in the structural design [9].

Among the fibers used, the most common are made of steel due to their high modulus of elasticity and tensile strength. Concrete with steel fibers has been widely employed in the building industry for some time in applications such as industrial and airport pavements, reinforcement of projected concrete, and precast elements with reduced thickness, among others [10,11]. These uses have been based on extensive studies of the mechanical behavior of this type of concrete under tensile stresses, fatigue or even impact [12].

However, there are certain applications (such as tunnels and continuous slabs of high-speed railway) in which a concern about the effect of steel fibers on the magnetic and electric fields has led to the quantity of fibers used being reduced. Furthermore, the influence of the corrosion of steel fibers in the durability and performance of concrete remains a matter of study [13-15].

II. EXPERIMENTAL PROGRAM

2.1 Materials

- The cementitious materials used in all mixtures were commercially available Ordinary Portland Cement (OPC) of 53 grade confirming to IS: 12269. The specific gravity of the cement was 3.13.
- Locally available river sand passing through 4.75 mm IS sieve was used. The physical properties of the fine aggregates like specific gravity and bulk density were 2.67 and 1868 kg/m3 respectively.
- Coarse aggregates maximum sizes 40 mm were used for the investigation. The coarse aggregate, obtained from a local source, had a specific gravity and bulk density of 2.84 and 1652 kg/m3 respectively.
- The ***fly ash*** used in the investigation was procured from Kakatiya Thermal Power Station. This was collected from electrostatic precipitator. The specific gravity of fly ash was found to be 1.95.
- High range water reducing admixture called as ***super plasticizers*** were used for improving the flow or workability for decreased water cement ratio without sacrifice in the compressive strength. In the present work water-reducing admixture ***Glenium B233*** conforming to ASTM C494 types F was used.
- Three types of ***steel fibers*** trade name of Stewols India Pvt, Ltd, were used in this study. The steel fibers are relatively stiff and water-soluble, glued into bundles. The properties of fibers were as below:

Table 1 : Properties of Fibers

Property	Straight fiber	Hooked fiber	Round crimped fiber
Diameter (mm)	0.3-0.7	0.55	0.45-0.8
Length (mm)	25-35	65	25-40
Tensile strength (N/mm^2)	>650	1000-1100	750-1100

2.2 Mix Proportions

- To achieve, self capability, numbers of trail was done for different combination of materials.
- The aggregate combination of 50:20:30 (Fine aggregate: Coarse aggregate 10 mm maximum size: Coarse aggregate 20 mm maximum size) by volume was keep constant for all mixes.
- Dosage of super plasticiser was kept constant. i.e. 0.5% by weight of binder for providing the desired fluidity of the SCC.
- Fibers were added as 1% by volume.
- Mix Design for M40 was Carried out & then calculated the required materials for this Work considering total volume of 0.025 m^3.
- Constitute of final mixes are presented in Table 2.

Table 2 : Composition of Mix

Constituent	Mix Design	For this Work
Cement	344.64 kg/m^3	8.62 kg/m^3
Water	189.13lit/m^3	4.72 lit/m^3
Fine Aggregates	1015.59 kg/m^3	20.38 kg/m^3
Coarse Aggregate	744.12 kg/m^3	18.60 kg/m^3
Fly Ash	3.70 kg/m^3	0.092 kg/m^3
Super Plasticizer	3.48lit/m^3	0.087 lit/m^3

2.3 Mixing Procedure

- Mixing procedure and mixing time are more critical in SCC as compared to conventional concrete mixtures. In addition, previous experimental studies suggest that each mixture proportion has its own optimum mix procedure, including the sequence by which different materials are placed in the mixer, the percentage of water demand added with time, the total time of mixing, and the total time of casting, etc. [16].

- Not only a minor change in proportioning, but a minor change in the mix procedure itself may change significantly the properties of freshly mixed concrete, such as its rheological behavior. The sequence of mixing is very important as well.

1. Pre-mixing water, SP, and VMA (if needed), then pouring the resulting fluid in several steps in order to develop a homogenous matrix without paste lumps before adding the coarse aggregates and fibers.
2. Reducing the coarse-to-fine aggregate ratio to provide a well-developed paste layer which can fully surround individual coarse aggregate. Paste amount must be sufficient not only to fill the void between aggregates and fibers, but also fully cover the aggregate particles and the fibers. In this study the liquid (Water + SP) was added in several steps as described below. The following steps were used:
   1) Dry mix the aggregate and sand for 30 seconds. Then add cement and fly ash and rotate this dry mix for next 30 seconds.
   2) Pour 1/2 of water in the mixer. After mixing for about 2 minute, pour 1/4 of the remaining liquid (Water+SP).
   3) Rotate the concrete for next 2 minute, pour reaming 1/4 of liquid (Water+SP).
   4) After mixing for about 2 minutes, slowly add all steel fibers in the mixer.
   5) Continue mixing for about 1 minute after all the fibers have been added. The mixture is then ready for pouring.

Table 3 : Fresh Properties of Self Compactimng Concrete

Mix	Slump Flow (mm)	T_{50} cm slump flow (sec)	J Ring	J Ring flow (mm)	V Funnel flow (sec)	L box blocking ratio	U box filling height (mm)
EFNARC limit	*650 – 800*	*2-5*	*0-10*		*6-12*	*0.8-1*	*0-30*
SCC	760	4.2	6	730	8	0.93	20
SSFRSCC*	730	4.4	9	710	10	0.89	23
HSFRSCC*	755	4.9	10	650	12	0.80	27
RCSFRSCC*	745	4.6	9	690	11	0.86	26

SSFRSCC = Straight Steel Fiber Reinforced Self Compacting Concrete
HSFRSCC = Hooked Steel Fiber Reinforced Self Compacting Concrete
RCSFRSCC = Round Crimped Steel Fiber Reinforced Self Compacting Concrete

III. TEST PROGRAM & RESULTS

3.1 Assessment of Fresh State Concrete Properties

To evaluate workability of fresh self compacting concrete like filling ability, passing ability and segregation resistance, different test were carried out as per EFNARC standards. Filling ability of SCC was measured using slump flow and V – funnel test. Passing ability of SCC was measured using J- ring, L- box and U – box test. Test results shows that, addition fibers reduce the flow and filling ability. Additions of Hooked steel fibers resist flow of SCC compared to other steel fibers. Also, L Box and U Box test results shows that additions of fibers in concrete give negative result on workability of SCC. But all results are within limit of EFNARC[17]. Test results are shown in table 3.

3.2 Assessment of Mechanical Properties

After casting cubes, cylinders and flexural beams, specimens are tested as per IS 516 [18]. Results of compression, split tensile and flexural strength test are presented in Table 4.

Fiber addition increased indirect tensile strength in concretes. The best performance was obtained with the steel fibers that showed the best results, which was probably due to the anchorage of the fibers and the higher modulus of elasticity of the material itself. Moreover, the addition of glass fiber also increased tensile strength.

Table 4 : Mechanical Properties

Mix	After 28 days (N/mm^2)	
	Compressive Strength	Split tensile strength
SCC	54.19	3.00
SSFRSCC	55.23	3.12
HSFRSCC	56.78	3.45
RCSFRSCC	55.90	3.30

3.2 Fracture Test

Test Setup

In accordance with the RILEM Technical Committee 89- FMT on fracture mechanics of concrete, specimens are prepared and three-point bending tests were carried out in three prismatic specimens of each concrete type with dimensions 431 ×152 × 100 mm3 to understand effect of fibers addition on fracture energy. The details of the geometry and its dimension are shown in Figure 1.

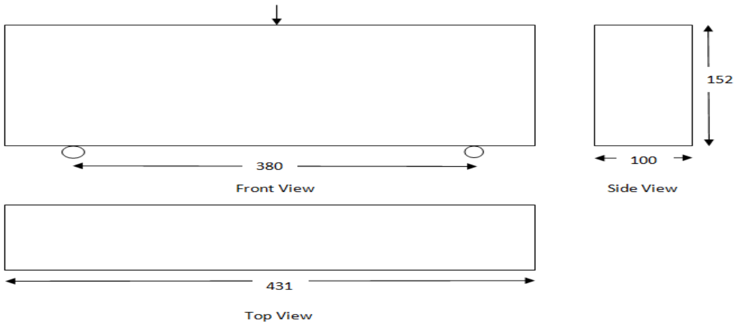

Figure 1: Geometry of the Specimen

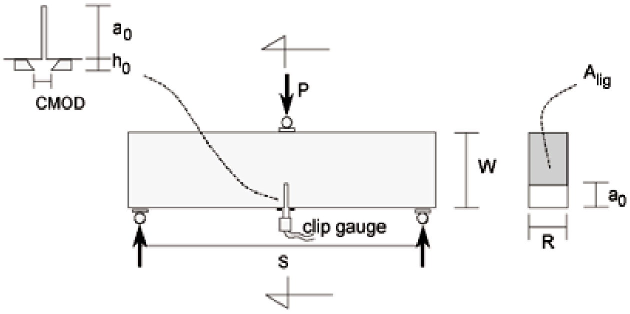

Figure 2: Fracture Toughness Test

Figure 3: Fracture Test Setup

Table 5: Peak Load, Displacement & CMOD

Detail	SCC	SSFRSCC	HSFRSCC	RCSFRSCC
Peak load (kN)	6.68	6.78	6.97	6.85
Displacement at peak (mm)	0.43	0.45	0.47	0.46
Displacement (mm)	1.21	3.32	4.00	3.87
CMOD (mm)	1.72	5.89	6.40	6.20
Minimum load (kN)	0.36	0.79	1.13	0.97
Area under load displacement curve (kN.mm)	1.71	8.45	12.03	10.67

All the specimens are tested in a closed loop servo-controlled testing machine having a capacity of 100 kN as shown in Figure 3. The load-point displacement is measured using a linear variable displacement transformer (LVDT). The crack mouth opening displacement (CMOD) is measured using a clip gage. All the tests are performed in CMOD control. All results stored in data acquisition system.

Test Results and Discussion

In order to obtain the fracture energy of each concrete, load– deflection curves and load–CMOD curves were assembled. Fracture tests were performed for each concrete specimen. The results of load, displacement, CMOD and time are simultaneously acquired through a data acquisition system. Peak load, displacement at peak, total displacement and clip gauge opening and area under load displacement curve for plain and different types of steel fiber reinforced specimens are measured and presented in Table 5.

Load– deflection and load-CMOD curves for plain, and steel fiber reinforced self compacting concrete specimens are prepared. To understand effect of fibers on behaviour concrete, curves are assembled and presented in Figure 4 & 5.

It was observed that there was slightly increased in peak load due to addition of steel fibers in to concrete but energy absorption capacity (are under load displacement curve) increased tremendously.

As the micro- cracks connected with each other and formed larger cracks, in addition to increasing the peak load, the fibers bridged more effectively both faces of the fracture surface which meant an improvement in the post-peak load bearing capacity and flexural toughness. When compared with the reference concrete specimens, addition of fibers in concrete leads to the better in post-cracking response.

Fibers improve residual load-bearing capacity in the small displacement range. Therefore, a material with a remarkable performance at low strains, which correlates with the serviceability limit state, was obtained.

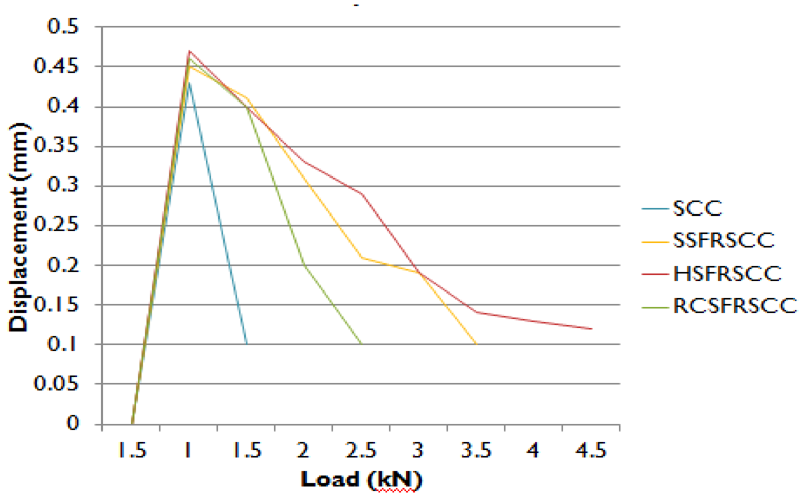

Figure 4: Load vs. Displacement

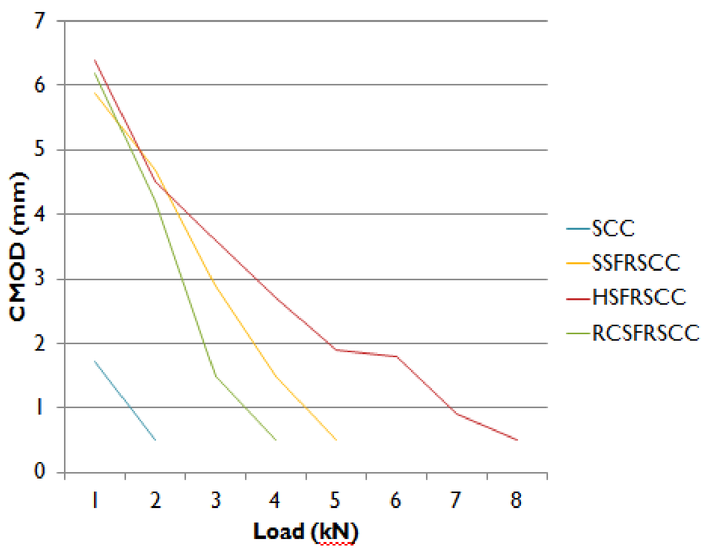

Figure 5: Load vs. CMOD

IV. CONCLUSIONS

This paper presented a study on the three-point bending behavior of notched SFRC beams. The following observations emerged by analyzing the experimental results:

- The inclusion of fibers has a direct effect on the flow characteristics of SCC. Addition of fibers decreases the workability of the SCC.
- Concrete with hooked steel fibers has less workability compared to straight and crimped steel fiber reinforced concrete.
- The results revealed that the addition of fiber reduces the passing ability and increase the possibility of blockage.
- Addition of fibers in concrete improved mechanical properties, allow production of high-performance concretes with good ductility and flexural toughness.
- Fibers lead nominal increase in compressive strength but marginal increase in spilt tensile strength of self compacting concrete.
- It was observed that there is slightly increased in peak load but total displacement, crack opening at failure and area under load displacement curve increased tremendously.

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