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Fracture Properties of Fiber Reinforced Self Compacting Concrete Notched Beams

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Abstract— In recent years, self-compacting concrete (SCC) has gained wide use for placement in congested 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 paper examines the effect fibers addition on rheological properties, mechanical properties and fracture energy of self compacting concrete. Rheological properties were determined as per EFNARC standards. Mechanical characteristics like compressive strength, splitting tensile 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; Fibers, Fracture Properties; Notch

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 [3] 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.

Plain concrete is brittle, thus it seems essential to use materials that can fix this problem. 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. 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].

El-Dieb [6,7] studied mechanical and durability properties of ultra-high strength fiber-reinforced concrete (UHS-FRC) with self-compacting characteristics and the influence of fibers on rheological properties.

Siddique [8] investigated the properties of SCC made with different amounts of fly ash. According to Fava et al. [9], in SCC with ground-granulated blast furnace slag (GGBFS), the strength can be increased. Flexural performances of reinforced, pre-stressed and composite self-compacting concrete beams were also studied by Cattaneo et al. [10]. Soutsos et al. [11] also scrutinized the flexural performance of fiber-reinforced concrete made with steel and synthetic fiber.

Once SCC has hardened, there are few differences between this and a standard concrete, with two being that they are quasi-brittle materials with low tensile strength and good compressive strength. Adding small amounts of fibers might not only reduce the previously mentioned problem of shrinkage cracking [12], but also increase mechanical properties such as tensile strength and toughness [13]. The fibers added to the concrete paste while mixing are short elements with a reduced section and randomly distributed. Fibers may be manufactured through using many materials such as steel, palm, glass, carbon, or polypropylene, among others [14, 15].

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 [16].

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 [17]. These uses have been based on extensive studies of the mechanical behavior of this type of concrete under tensile stresses, fatigue or even impact [18–20].

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 [21–23].

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 [24]. The specific gravity of the cement was 3.12.

Pozzocrete 60 confirming IS 3812 part 1 [25] fly ash manufactured by dark was used. Pozzocrete is a high efficiency pozzolanic material, obtained by selection and processing of power station fly ashes resulting from the combustion of pulverized bituminous coal. Specific gravity of fly ash was 2.0.

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 are 2.62 and 1868 kg/m^3 respectively.

Two different sizes of coarse aggregates maximum sizes 10 mm and 20 mm were used for the investigation. The coarse aggregates, obtained from a local source, had a specific gravity and bulk density are of 2.8 and 1652 kg/m^3 respectively for 10 mm down, and 2.78 and 1632 kg/m^3 respectively for 20 mm down aggregates.

Master Glenium SKY 8276 manufactured by BASF confirming ASTM C 494 [26] was used to increase the flow capability of the concrete and improve the viscosity.

Two types of fibers, steel and glass, used in this study. Hooked end steel fibers trade name of “Dramix” from Bekaert Corporation manufacturer, Belgium, are used. It has a diameter of 0.55 mm, a length of 65 mm, and a tensile strength of 1000-1100 N/mm^2. The steel fibers are relatively stiff and water-soluble, glued into bundles.

The glass fibres used are of Cem-FIL AntiCrack HD, high dispersion, alkali resistance with modulus of elasticity 72 GPa, Filament diameter 14 microns, specific gravity 2.68, length 12 mm and having the aspect ratio of 857, the number of fibres per kg is 212 million fibres.

2.2 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. [27].

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. According to the previous research of various mixing procedures for SCC, the sequence of placing the various materials in the mixer plays an important role, especially when higher volume fraction of fibers are added. The advantages of two procedures found in prior studies have been incorporated in this study.

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 minutes after all the fibers have been added. The mixture is then ready for pouring.

Note that if glass fibers are use, than add glass fibers directly in water before adding water in mixture. It is also important to note that the quality of fresh SCC, such as flowability and segregation resistance, will be achieved only if the mix procedure is strictly followed.

2.3 Mix Proportions

To achieve, self capability, numbers of trail was done for different combination of materials. Binder contents varies between 450–700 kg/m^3 and W/B ratios varies between 0.29 to 0.34 (by weight) with corresponding variation in the paste volume to investigate the influence of binder quantity and water binder ratio on the fresh properties of SCC. The paste volume was varied from 350 liter to 450 liter. 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. A polycarboxylate-based high range water reducing admixture (HRWRA) was also used in the mixtures; dosage of superplasticiser was kept constant. i.e. 0.5% by weight of binder for providing the desired fluidity of the SCC. For all test ratio of cement to fly ash was kept constant. (Cement: Fly ash=70:30). Constitute of final mixes are presented in Table 1.

Table 1 Composition of Reference Mix

Constituent	Quantity (Kg/m3)
Cement	354
Fly ash	96
Fine aggregate	634
Coarse aggregates (<10 mm)	224
Coarse aggregates (<20mm)	332
Water	160*
Superplasticiser	2.225*

*is in liter

Table 2 Fresh Properties of Self Compacting Concrete

Mix	Slump Flow in mm	T_{50} cm Slump Flow in Sec	J Ring	J Ring Flow in mm	V-Funnel Flow in Sec	L Box Blocking Ratio	U Box Filling Height
EFNARC Limit	*(650-800 mm)*	*(2-5 Sec)*	*(H_1-H_2=0-10 mm)*		*(6-12 Sec)*	*(H_2/H_1=0.8 -1.0)*	*(H_1-H_2=0-30 mm)*
SCC	760	4.2	6	730	8	0.93	20
GFRSCC	725	4.3	7	700	9	0.89	22
SFRSCC	655	4.8	10	610	12	0.82	28

After finalizing the reference mix proportions, various trial mixes were conducted with different quantity of steel fibers (Dramix RCBN 35/65 hooked end) and glass fibers in a similar way and finalize the quantity of fibers. The final dosage of steel and glass fibers in SCC about 32 kg/m^3 and 50 gm per beg of cement respectively.

The SCC with steel fibers (SFRSCC) and glass fibers (GFRSCC) is prepared and fresh and mechanical properties was tested and presented in Table 2 and Table 3

III. TESTS PROGRAM AND 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 [28]. 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. Similarly resistance to segregation of self compacting concrete was measured with the help of GTM Screen stability test. Test photograph are shown in Figure 2. Test results shows that, addition fibers reduce the flow and filling ability. Additions of steel fibers resist flow of SCC compared to recron fibers. Slump flow was observed 655 mm by addition steel fibers while it was 725 mm in case of addition of glass fibers. Similarly, V-funnel flow 12 sec and 9 sec was observed in case of addition of steel fibers and glass 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[28].

3.2 Assessment of mechanical properties

After casting cubes, cylinders and flexural beams, specimens are tested as per IS 516 [29]. Results of compression, split tensile and flexural strength test are presented in Table 3

Addition of 32 kg/m^3 hooked end steel fibers in SCC enhance compressive strength by 6.30%, on other hand 2.33% increased in compressive strength was observed due to addition of glass fibers. Fibers lead nominal increase in compressive strength but marginal increase in spilt tensile strength and flexural strength of self compacting concrete. Spilt tensile strength was increased by 31.36% while flexural strength was increased by 34.47% by addition of steel fibers in SCC. Similarly, 11.18% and 12.10% increased in split tensile strength and flexural strength respectively in case of addition of glass fibers. Fiber addition increased indirect tensile strength in concretes.

Table 3 Hardened Properties

Mix	Compressive Strength (MPa)	Spilt Tensile Strength (MPa)	Flexural Strength (MPa)
SCC	62.64	4.56	4.38
GFRSCC	64.10	5.07	4.91
SFRSCC	66.59	5.99	5.89

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.

3.3 Fracture tests

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 mm^3 to understand effect of fibers addition on fracture energy. The details of the geometry and its dimension are shown in Figure 2

Slump test

V- Funnel test

L- Box test

U- Box test

Figure 1. Workability test as per EFNARC

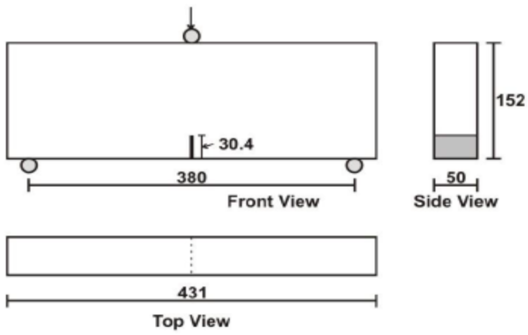

Figure 2. Details of geometry of the specimens

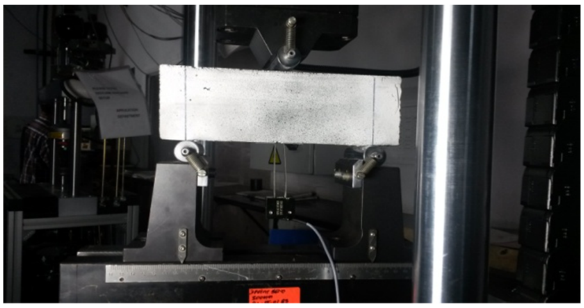

Figure 3. Fracture test set up

All the specimens are tested in a closed loop servo-controlled testing machine having a capacity of 100 kN as shown in Figure 3. A specially calibrated 50 kN load cell is used for measuring the load. 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 with a rate of opening of 0.0005 mm/sec. 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, glass fiber reinforced and steel fiber reinforced specimens are measured and presented in Table 4

Table 4 Peak load, displacement, CMOD

Sr No	Details	Plain	Glass fiber	Steel fiber
1	Peak load (kN)	6.68	6.70	6.91
2	Displacement at peak (mm)	0.43	0.43	0.46
3	Displacement (mm)	1.21	2.02	3.90
4	CMOD (mm)	1.72	3.19	6.62
5	Minimum load (kN)	0.36	0.59	1.02
6	Area under load displacement curve (kN.mm)	1.71	4.86	12.21

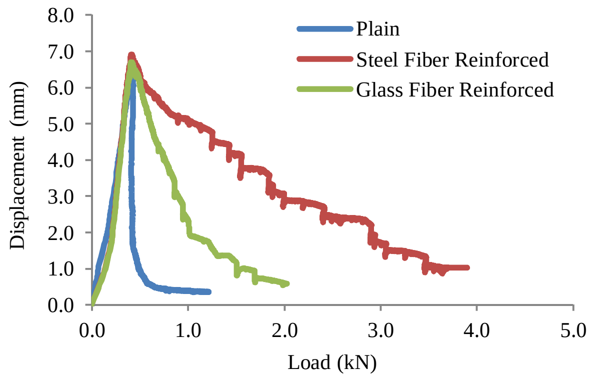

Figure 4.Load Vs Displacement curves

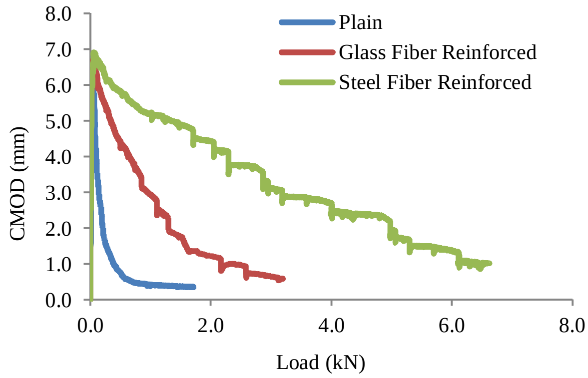

Figure 5.Load Vs CMOD curves

Load– deflection and load-CMOD curves plain, glass fiber 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 glass fibers and steel fibers in to concrete but energy absorption capacity (are under load displacement curve) increased tremendously. Energy absorption capacity increased by 184% and 614% due to addition of glass fibers and steel fibers respectively. Addition of fibers in concrete increase ductility of concrete.

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.

The addition of fibers in plain SCC, significant increase energy absorption ability. Glass fibers give good energy absorption within the large displacement range, while the steel 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.

IV. CONCLUSIONS

This paper presented a study on the three-point bending behavior of notched SCFRC beams. Particularly, the present experimental focused on investigating the possible influence of glass fiber and hooked-end steel fibers on fresh and harden properties of self compacting concrete. 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 steel fibers has less workability compared to glass 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, in addition to surface treatments which enhance adhesion with matrix, both 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 and flexural strength of self compacting concrete.
- The glass fibers are light and show a significant deformation capacity. The addition of a low amount of fibers enables a stable and reliable post-cracking behavior, maintaining fresh properties and with a lower weight of fibers.
- Addition of steel fibers to concrete significantly improves the tensile and flexural strength of concrete and produces strain hardening material.
- 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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