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A Study on the Mechanical Properties and Flexural Behaviour of Standard Grade Glass Fibre Reinforced Self Compacting Concrete

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Abstract

Self compacting concrete(SCC) is a recently developed concept in which the ingredients of the concrete mix are proportioned in such a way that it can flow under its own weight to completely fill the formwork and passes through the congested reinforcement without segregation and self consolidate without any mechanical vibration. When the benefits of SCC are added to those resulting from the addition of discrete glass fibres, develops a high performance material designated as Glass Fibre Reinforced Self Compacting Concrete (GFRSCC). In this investigation anti-crack high dispersion glass fibres were added to five SCC mixes of strength 30MPa and Glass Fibre Reinforced Self Compacting Concrete was developed. An attempt has been made to study properties and behaviour of SCC and GFRSCC in both fresh and hardened states. A considerable improvement in the flexural strengths was observed due to the addition of glass fibres to SCC mixes. An improvement in the Ultimate load and ultimate moment capacity was also observed by testing under reinforced SCC and GFRSCC beams in flexure. The paper also compares the structural behaviour such as load-deflection characteristics, crack widths and deflections at service loads for both SCC and GfRSCC beams. First crack load and post cracking behaviour were found to have improved due to the addition of glass fibres.

Keywords: Self compacting concrete, fibres, Glass fibre, fiber reinforced SCC, admixtures.

Introduction

Current scenario in the building industry shows increased construction of large and complex structures, which often leads to difficult concreting conditions. When large quantity of heavy reinforcement is to be placed in reinforced concrete members it is difficult to ensure that the form work gets completely filled with concrete, that is fully compacted without voids or honeycombs. Vibrating concrete in congested locations may cause some risk to labour and there are always doubts about the strength and durability of concrete placed in such locations. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of Self Compacting Concrete (SCC). SCC is that concrete which is able to flow under its own weight and completely fill the formwork without segregation, even in the presence of dense reinforcement, without the need of any vibration whilst maintaining homogeneity [1,2].

SCC was developed in Japan by Okamura in the late 1980's to be mainly used for highly congested reinforced concrete structures in seismic regions. Since then SCC has generated tremendous interest among the research scholars, engineers and concrete technologists.

Though concrete possesses high compressive strength, stiffness, low thermal and electrical conductivity , low combustibility and toxicity, two characteristics, have limited its use: it is brittle and weak in tension. However the development of fibre-reinforced composites(FRC) have provided a technical basis for improving these deficiencies. Fibres are small pieces of reinforcing material added to a concrete mix which normally contains cement, water and fine and coarse aggregate. Among the more common fibres used are steel, glass, asbestos and polypropylene .When the loads imposed on concrete approach that for failure, cracks will propagate, sometimes rapidly; fibres in concrete provide a means of arresting the crack growth. If the modulus of elasticity of the fibre is high with respect to the modulus of elasticity of the concrete or mortar binder, the fibres help to carry the load, thereby increasing the tensile strength of the material. Fibres improve the toughness, the flexural strength, reduces creep strain and Shrinkage of concrete[3,4].

Glass Fiber Reinforced Concrete(GFRC) is composed of concrete, reinforced with glass fibers to produce a thin, lightweight, yet strong material. Though concrete has been used throughout the ages, Glass Fiber Reinforced Concrete (GFRC) is still a relatively new invention. High Compressive and flexural strengths, ability to reproduce fine surface details, low maintenance requirements, low coefficients of thermal expansion, high Fire resistance, and environmentally friendly made GFRC the ideal choice for civil engineers. The strength of GFRC is determined by glass content, fiber size, fiber compaction, distribution and orientation[5-7, 11-14].

Considering the advantages of SCC and GFRC an attempt has been made to combine these two and to produce Glass Fibre Reinforced Self Compacting Concrete (GFRSCC) and to investigate the properties of both SCC and GFRSCC in fresh and hardened states.

Experimental Programme

Five SCC Mixes with different types of admixtures were developed in the laboratory and Cem-FIL anti-crack high dispersion glass fibres of 600 grams/m^3 of concrete were added to these SCC mixes and glass fibre reinforced self compacting concrete was developed. The experimental programme consisted of casting and testing of SCC and GFRSCC elements in compression , tension and in flexure. Cubes of 100mm size and Cylinders of 150 mm diameter and 300 mm long were cast for testing in compression and in tension. Prisms of 100 X 100 X 500mm were cast for testing in flexure. Also under reinforced beams of 120 X 200 X 2000 mm were cast for testing in flexure under two point loading.

Materials Used

Cement	Ordinary port land cement of 53 grade confirming to IS-12269 having specific gravity of 3.15
Fine Aggregate	Natural river sand confirming to IS-383 zone II having specific gravity 2.63
Coarse Aggregate	Crushed granite angular aggregate of size 12.5 mm passing confirming to IS-383 having specific gravity 2.67
Mineral admixtures	Fly Ash Confirming to IS 3812-1981 Ground granulated blast furnace slag (GGBS) confirming to BS 12089-1987 Rice Husk Ash
Chemical admixtures	Super plasticizer Conplast SP430 Viscosity modifying agent (VMA) Glenium stream 2
Water	Confirming to IS 456 .
Glass Fibres	Cem-FIL anti-crack high dispersion glass fibres

Mix Proportion

To start with a M 30 grade SCC mix was designed based on Nan Su method of mix design, and was further modified by fine tuning the relative proportions of fine and coarse aggregate, filler material like fly ash, GGBS and RHA along with super plasticizers and viscosity modifying agents. The guide lines given by Professor Okamura&Ozawa1995, Takada1998, Gibbs1999, Boral2001, Nan. Su 2001, Subramanian2002 and EFNARC 2002 & 2005 were taken as references and the final SCC mix proportion was arrived [8-10].

Development of SCC and GFRSCC

Number of attempts were made in the laboratory to get optimum dosages of mineral and chemical admixtures to produce M 30 grade SCC without segregation and bleeding with satisfying the properties both in fresh and hardened states. From these trials five SCC Mixes shown in Table 3 with different types of admixtures like fly ash, GGBS and RHA with different dosages which had given relatively high compressive strengths were selected for the investigation and to these mixes Cem-FIL anti-crack high dispersion glass fibres of 600 grams/m^3 of concrete were added to get GFRSCC shown in Table 4

Table 2 : Properties of Glass Fibre

1	Trade name	Cem-FIL anti-crack high dispersion glass fibres
2	Number of fibres	212 million/kg
3	Aspect ratio	857:1
4	Specific surface area	105 m^2/kg
5	Typical addition rate	0.6 kg/m^3 of concrete
6	Tensile strength	1700 Mpa
7	Modulus of elasticity	73 Gpa
8	Corrosion resistance	Excellent
9	Specific gravity	2.6
10	Density	26 KN/m^3
11	Filament diameter	14 µ
12	Filament length	12 mm

Table 3 : Mix proportions of SCC

S No	Design -ation	Cemnt Kg	C.A Kg	F.A Kg	Fly -Ash % Kg	GGBS % Kg	RHA % Kg	Water Kg	S.P % bwc	VMA % bwc
1	SCC 1	240	700	900	----	260	----	199.5	2.5	--
2	SCC 2	240	700	900	-----	100% =260	Addition 1% =2.6	199.5	2.5	--
3	SCC 3	240	700	900	-----	97% = 252.2	Replacement 3% =7.8	199.5	2.5	--
4	SCC 4	240	700	900	49.5%= 128.7	49.5% =128.7	Replacement 1% =2.6	199.5	2.5	--
5	SCC 5	240	700	900	60% =144	40% =96.0	Addition 1% =2.4	198.5	2.5	0.35

Table 4 : Mix proportions of GFRSCC

Sl.no.	Designation	Mix proportion
1	SCC 1 F	SCC 1 + 600 grams/m^3 of Cem-FIL HD Glass Fibre
2	SCC 2 F	SCC 2 + 600 grams/m^3 of Cem-FIL HD Glass Fibre
3	SCC 3 F	SCC 3+ 600 grams/m^3 of Cem-FIL HD Glass Fibre
4	SCC 4 F	SCC 4 + 600 grams/m^3 of Cem-FIL HD Glass Fibre
5	SCC 5F	SCC 5 + 600 grams/m^3 of Cem-FIL HD Glass Fibre

Testing of SCC in Fresh State

Slump flow, V- Funnel and L- Box tests were performed in the laboratory on fresh SCC and GFRSCC to find Filling ability, Passing ability and Segregation resistance. The prescribed limits of the tests as per the EFNARC specifications are as shown in table 1

Table 1 : EFNARC Specifications

Name of the test	Property	Unit	Min.	Max.
Slump flow	Filling Ability	mm	650	800
T 50cm Slump Flow	Filling Ability	sec	2	5
V-Funnel	Filling Ability	sec	6	12
V-Funnel 5sec	Seg. Resistance	sec	6	15
L-Box	Passing Ability	H2/H1	0.8	1.0

Specimen Preparation

After testing the SCC and GFRSCC in fresh state the concrete was poured into moulds of cubes, cylinders and prisms. After 24 hours of casting the specimens were de-moulded and placed in water for curing. After 28 days of curing the specimens were taken out from water and allowed the surfaces for drying . For each SCC and GFRSCC mixes 3 cubes, 6 cylinders and 3 prisms were cast. Also ten under reinforced SCC and GFRSCC beams of 120 X 200 X 2000 mm were cast and cured for 28 days.

Tests on SCC and GFRSCC in Hardened State

i. compressive strength tests were carried out on Cubes of 100 mm size using a compression testing machine of 1000 KN capacity as per IS 516:1959

ii split tensile strength tests were carried out on cylinders of 150 mm diameter and 300 mm height using a compression testing machine of 1000 KN capacity as per IS 516:1959

iii Flexural strength tests were carried out on prisms of size 100 X 100 X 500 mm on flexure testing machine of capacity 100 KN as per IS 516:1959 iv A two point flexural bending tests were carried out on under reinforced beams of size 120 X 200 X 2000 mm on 1000 KN capacity Universal Testing Machine.

Experimental Arrangement And Testing Procedure For Beams

The test set up used for carrying out the static flexural test on the beams is shown in figures 1&7. The effective span of the beam was 1700 mm. The beams were simply supported and subjected to two point loading and tested on 1000 KN capacity universal testing machine(UTM). Dial gauges were fixed at centre of the beam, under the load positions, and midway between the load and supports to record the deflection of the beam during testing. Curvature meters were also fixed to the frames connected to the beams to measure curvature of the beams during testing. Load was measured at every 1 mm raise of the base of the UTM till the occurrence of the first crack and later at every 2 mm raise. The beam was loaded up to ultimate failure and cracks were measured at ultimate load and the crack pattern was also marked.

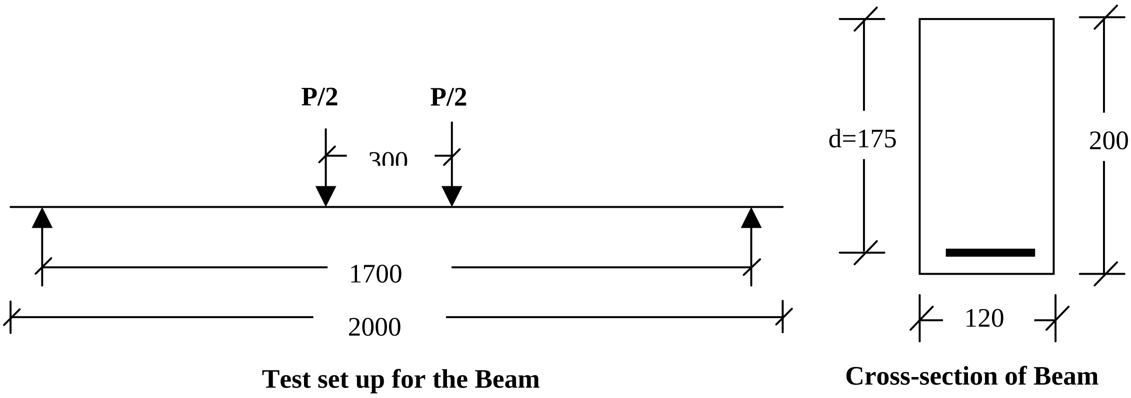

Figure 1 : Test set up and cross section of the beam

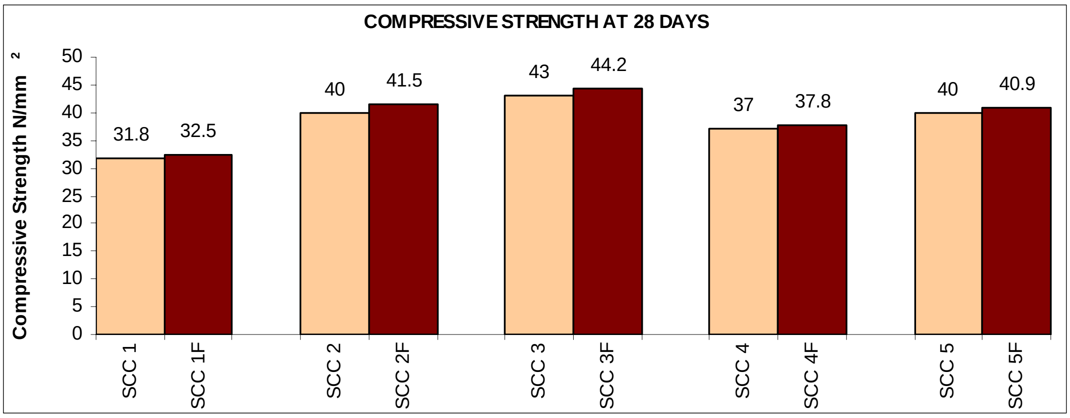

Figure 2 : Compressive Strength at 28 days for SCC and GFRSCC Elements

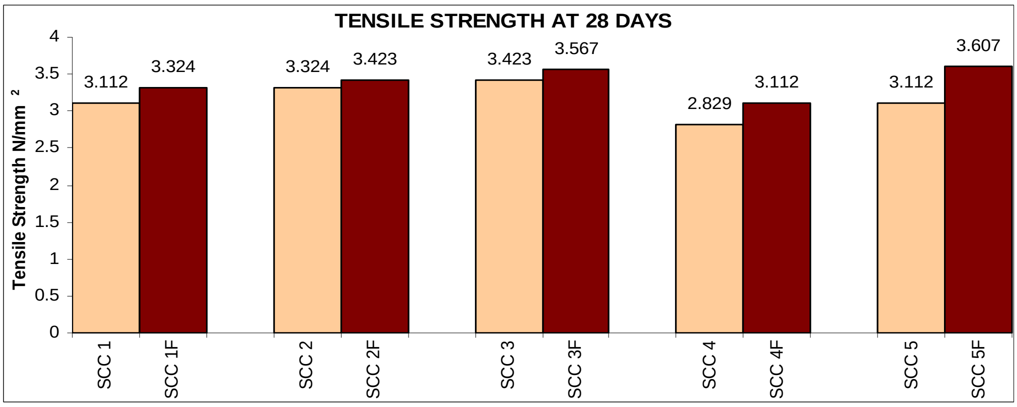

Figure 3 : Tensile Strength at 28 days for SCC and GFRSCC Elements

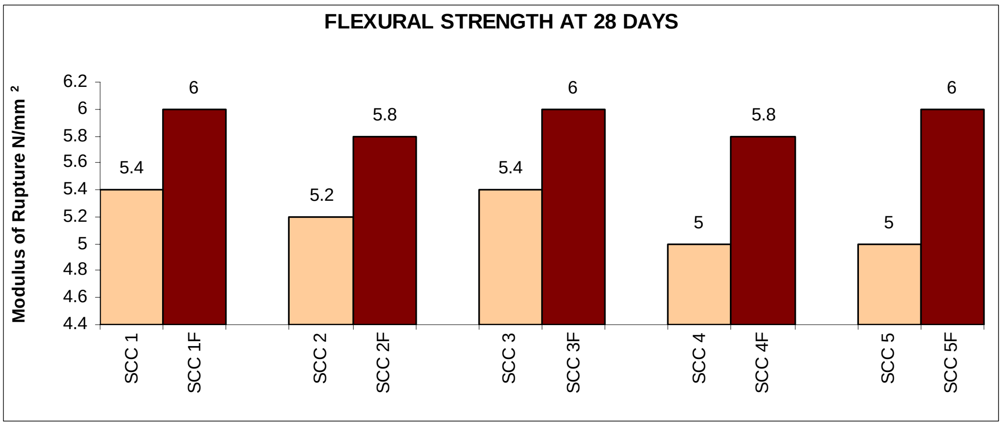

Figure 4 : Flexural strength at 28 days for SCC and GFRSCC Elements

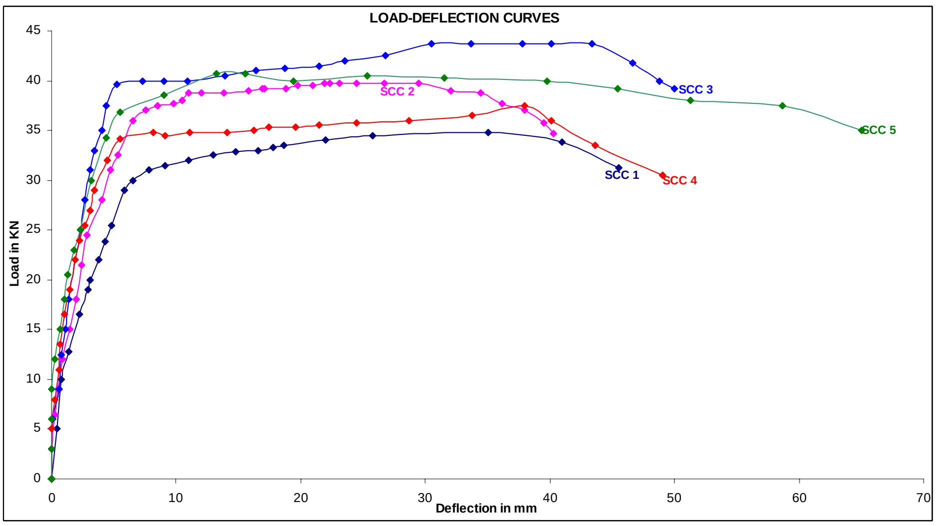

Figure 5 : Load-Deflection curves for SCC beams

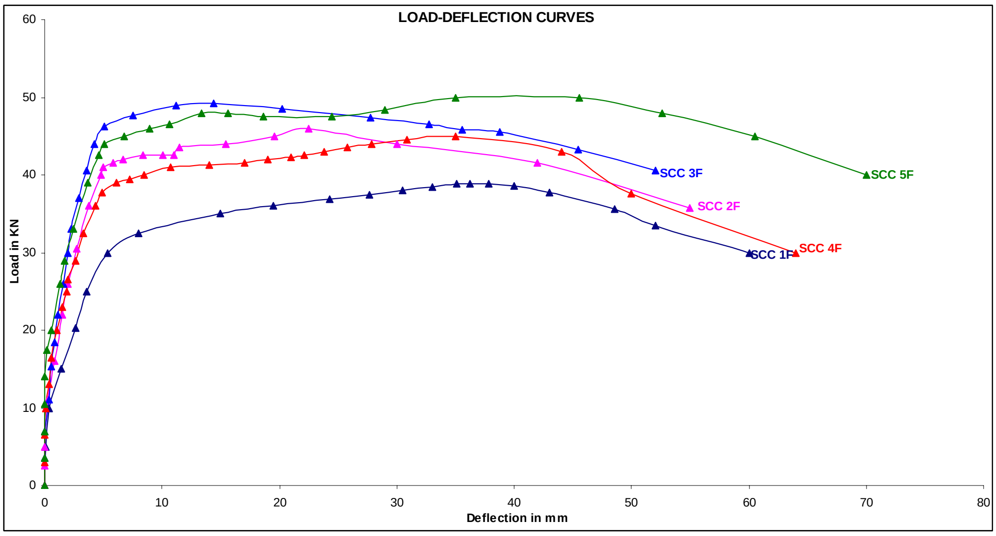

Figure 6 : Load-Deflection curves for GFRSCC beams

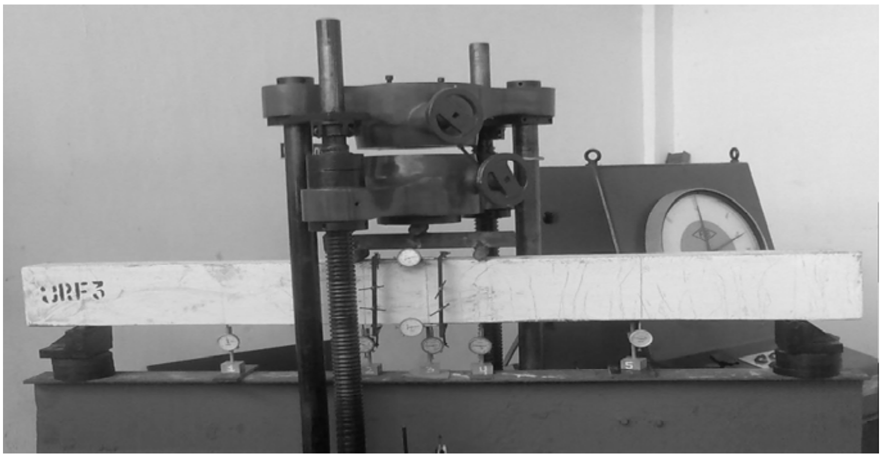

Figure 7 : Test set up for the beam

Behaviour of Beams under Load

In all the beams as the load was increased , cracks appeared in flexure span and further increase in load resulted in additional cracks and widening of some of the earlier cracks. Most of the cracks transversed up the beam and spalling of compression concrete took place at later stages under increased load. In the case of specimens additionally reinforced with glass fibres, a large number of finer cracks developed in the flexure span when the load was increased. At higher loads some of the cracks propagated up the beam and tension steel started yielding at this stage. All the cracks traversed towards the top and some portion of compression concrete was found to have crushed. First crack load, ultimate load and deflection at ultimate load were increased considerably by the addition of glass fibres. Figs. 8,9 shows tested specimens of SCC and GFRSCC beams . Glass fibres acted as crack arresters , that intern restricted the propagation of cracks during loading.

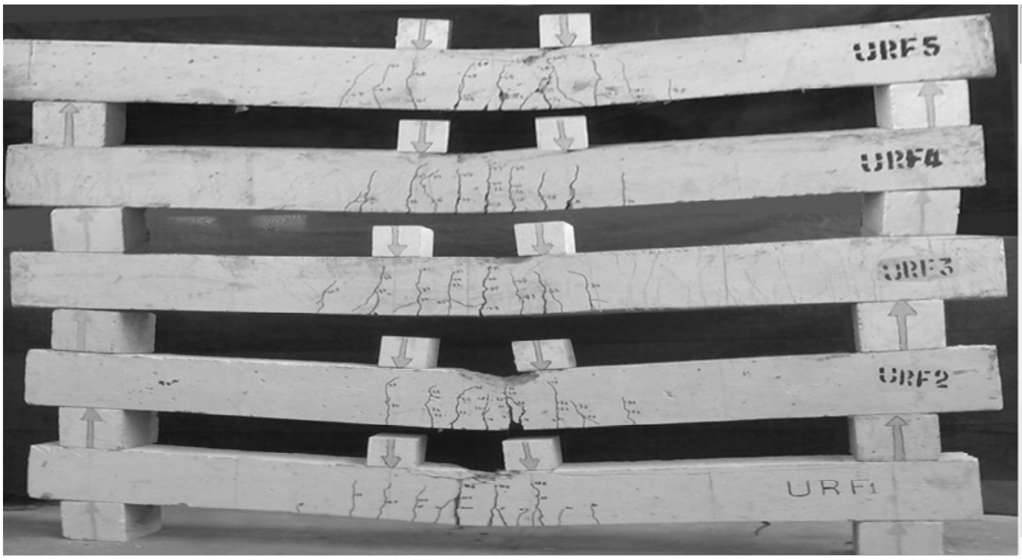

Figure 8 : GFRSCC beams showing crack pattern

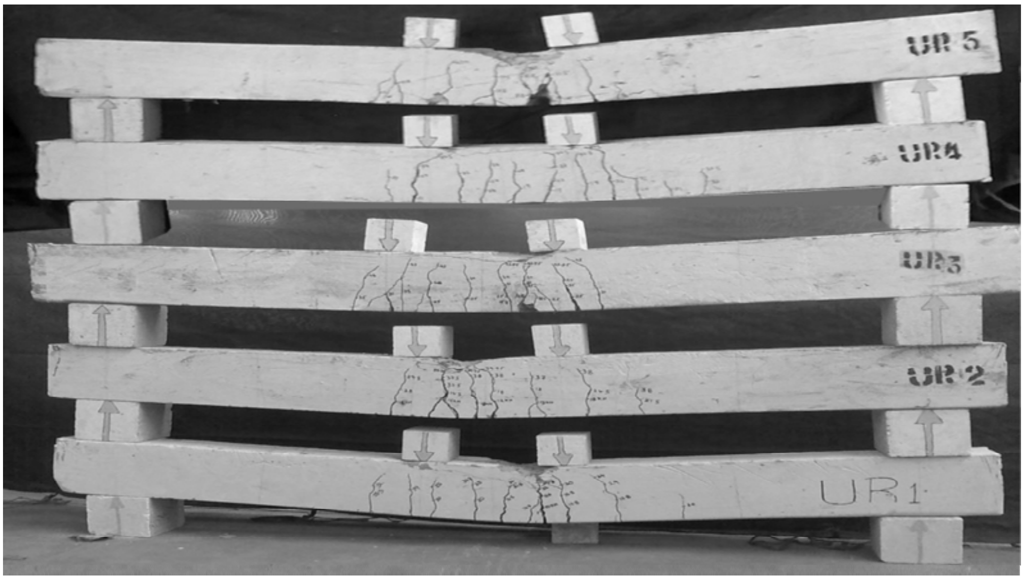

Figure 9 : SCC beams showing crack pattern

Results

Fresh properties of SCC and GFRSCC are shown in Tables 3.1

Table:3.1 : Fresh Concrete properties of SCC and GFRSCC

Sl. No.	Designation	Slump Cone Test		V Funnel Test		L Box Test
		Horizontal Slump (mm)	T 50 (time in Sec)	Time for complete discharge	T 5 min in Sec	H_2/H_1
1	SCC 1	690	3.0	7.0	9.5	0.81
2	SCC 2	680	4.0	8.0	10.5	0.81
3	SCC 3	690	3.5	7.5	9.0	0.80
4	SCC 4	685	3.0	7.0	9.0	0.82
5	SCC 5	690	3.5	7.5	10	0.83
6	SCC 1 F	680	4.0	9.0	10.5	0.81
7	SCC 2 F	675	4.0	9.5	11.5	0.80
8	SCC 3 F	680	4.5	8.0	10.0	0.80
9	SCC 4 F	680	4.0	8.0	10.0	0.82
10	SCC 5F	690	4.0	7.0	9.5	0.82

Ultimate moments, ultimate loads, load at first crack for SCC and GFRSCC beams are shown in table 5

Load-Deflection plots for SCC and GFRSCC are shown in figures 5 & 6

Table 5 : Results of Beam Test

Sl.No	Designation	Ultimate load P_u KN	Max. Deflection δ_{max}.at mid span mm	Ultimate Moment M_u KN-m	Load at first Crack KN	Max. Crack width at P_u mm	Deflection at service load mm
1	SCC 1 (UR1)	34.8	45	12.03	10	4	4
2	SCC 2 (UR2)	39.75	40.25	13.9125	12	2.1	3.8
3	SCC 3 (UR3)	43.75	42	15.3125	12.5	1.9	2.8
4	SCC 4 (UR4)	37.5	45	12.8	11	3.3	2.6
5	SCC 5 (UR5)	40.7	55	14.245	11.8	2.2	2.8
6	SCC 1F(URF1)	38.8	52	13.58	12	2.1	3.6
7	SCC 2F (URF2)	46	50	16.04	14	0.5	2.8
8	SCC 3F (URF3)	51	50.45	17.85	14.3	1.5	2.5
9	SCC 4F (URF4)	45	54	15.75	13	2.1	2.4
10	SCC 5F (URF5)	50	64.8	17.5	14	2.1	2.5

Table 6 : Reinforcement details of beams

Slno	Designation	Tensile reinforcement	Hanger bars	Shear reinforcement
1	All SCC & GFRSCC Beams	2-10 mm Φ TMT	2-6mmΦ MS	MS 6 mm Φ 2-legged vertical stirrups at 65 mm c/c

Results and Discussions

Results of experimental investigations are discussed in the following sections with respect to the characteristics of Self compacting concrete mixes in the fresh and hardened states.

Characteristics of SCC Mixes in Fresh State

Properties such as filling ability, passing ability etc. of the SCC and GFRSCC mixes in the fresh state are given in table3.1. These values on comparison with EFNARC Specifications indicate that the mixes possess the self compacting characteristics.

The filling ability and passing ability values of GFRSCC mixes compared to SCC mixes given in tables 3.1 indicate that the presence of glass fibres did not have any pronounced effect. This may be due to the low dosage of fibre addition (0.03%) and also may be due to the high dispersing nature of the fibres.

Characteristics of SCC Mixes in Hardened State

Affect on Compressive Strength:

The compressive strength values obtained by testing standard cubes made with different SCC and GFRSCC mixes are shown in Fig.2.All the mixes have shown strength above 30 MPa, which is the required strength. The GFRSCC mixes compared to normal SCC mixes have shown an improvement in compressive strength by 2.0 to 5.5%.

Tensile Strength:

The tensile strength of mixes is obtained (i) by conducting split tensile test on standard cylindrical specimens and also by (ii) by conducting three point bend test on standard prisms. The results are tabulated in Figs.3 & 4 . The results indicated that the incorporation of glass fibres in to the SCC mixes, increased the Split tensile strength and Flexural strengths by 3.0 to 7.0 % and 11.0 to 20.0 % respectively. The increase is significant and it may be due to high tensile strength (1700Mpa) of glass fibres. Also the observations were in conformity with the observations made by Building Research Establishment ,England and BS 1881

First crack load and ultimate load:

First crack load was determined from load-deflection plot shown in figs. 5& 6 corresponding to that point on the curve at which the curve deviated from linearity. Load at first crack was also observed during the experiment given in table 5 and these values coincide with the values obtained from graphs.

Load at first crack increased with the addition of glass fibre, which is due to increase in strain carrying capacity of the concrete in neighbourhood of fibres. Also fibres arrest the micro cracks developed in the matrix which results in requirement of more energy. This lead to an improvement in load at first crack. There is a significant increase in the load at first crack by 14% to 20 % due to the addition of glass fibres to the SCC mixes.

As and when micro cracks develop in the matrix, the fibres in the vicinity of such micro cracks will try to arrest these cracks and prevent further propagation. Hence the cracks that appearing inside the matrix has to take meandering path , resulting in the demand for more energy for future propagation, which in turn will increase the ultimate load. Results show a marginal increase of up to 11.5 % to 22.8% in ultimate load for specimens with glass fibre.

A reduction in crack width was observed at ultimate load when glass fibres were added to SCC mixes. The lower values of crack width may be due to higher flexural strength of concrete due to the addition of glass fibres to SCC mixes and due to the effect of fibre bridging

Crack Pattern and Deflections at service loads:

Crack pattern observed for all SCC beams shown in fig. 9 is appeared to be same. Similarly the Cracks observed for all GFRSCC beams shown in fig. 8 also appeared to follow the same pattern except the spacing of the cracks.

Deflections observed from the load-deflection curves at service loads calculated at $P_u/1.5$ for all the specimens are less than the maximum permissible deflection of 6.8 mm i.e Span/250 specified by IS 456-2000. Also marginal reduction in deflections at service loads were observed due to the addition of glass fibres to SCC beams..

Load-deflection behaviour:

Load-deflection plots for SCC and GFRSCC are drawn and are shown in figs. 5&6. The load-deflection curve is linear up to first crack load. Further application of load, caused multiple cracks and curve deviated from linearity into a non-linear region. Beyond the multiple cracking stage steel was found to yield and the P-δ curve become more or less flat till the ultimate load reached with slight increase in load. Finally all the beams failed by compression of concrete and the load deformation curves are plotted up to failure stage.

Same behaviour was noticed in all the SCC and GFRSCC beams. The differences noticed between SCC and GFRSCC elements were the increase in the horizontal plateau of the load-deflection curve and increase in load at first crack and ultimate load of GFRSCC elements.

Conclusions

All the SCC and GFRSCC mixes developed satisfied the requirements of self compacting concrete specified by EFNARC

Addition of 0.03% high dispersion glass fibres to SCC mixes did not have any pronounced effect on the filling and passing ability when compared to SCC mixes.

Incorporation of glass fibres by 0.03% ie 600 grams / m^3 of concrete has increased the compressive strengths at 28 days by 2.0 to 5.5 %.

Addition of 0.03% high dispersion glass fibres to SCC mixes have increased the tensile strength by 3.0 to 7.0 %.

Though the percentage increase in the compressive and tensile strengths is marginal due to the addition of steel fibres , there is a considerable increase in the flexural strength by 11.0 to 20.0 % . This shows the flexural strength of SCC can be increased by the addition of small quantity of high dispersion glass fibres.

The compressive, tensile and the flexural strengths of SCC can be increased further by adding higher dosages of high dispersion glass fibres without loosing the self compacting characteristics.

The fibres are effective in resisting deformation at all stages of loading from first crack to failure

Comparing SCC beams with GFRSCC beams additionally reinforced with 600 grams/m^3 volume fraction of glass fibres , it is seen that the first crack load was found to increased by 14% to 20% and ultimate load was found to increase by about 11.5% to 22.8% .

Addition of glass fibres control the initiation of micro cracks , improve the first crack load, the ultimate load and ductility of SCC specimens under flexure. The improvement was considerable in case of first crack load and ultimate load.

In view of the assured self compactability property and improved energy absorption capacity of GFRSCC this concrete can be adopted for any structural applications, especially when there is heavy congestion of reinforcement and for seismic force resisting structures.

The strength and ductility of SCC can be improved by the addition of a short, discrete, randomly oriented glass fibres to the SCC mixes retaining self compactability of the mix.

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