Effect of Macro-Synthetic Fibers on the Flexural Strength of Self-Compacting Concrete Beams

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Research Article

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Abstract

The inclusion of fibers in Self-compacting concrete (SCC) is a prominent technique to attain concrete of superior mechanical properties. The effect of fibers on the flexural strength of SCC beams requires further supportive research. This study is carried out to comprehend the behaviour of the SCC flexural behaviour of beams. The beams were cast with SCC in which macro synthetic fibers (MSF) at doses of 0%, 0.5%, 1%, and 1.5% were included. Natural river sand has been supplemented with Manufactured sand (M-sand). Cement employed in the study was only 65% of the required cementitious material and 35% of cement content was replaced with pozzolanic materials such as fly ash (FA), silica fume (SF), and ground granulated blast furnace slag (GGBS). Various dosages of mineral admixtures were adopted; FA was invariably utilized in all the mixes.

Fibers are known to intervene in the flow properties of SCC. Only the mixes which exhibited satisfactory flow characteristics were adopted in the casting of the specimens. Six categories of mixes, with various combinations of mineral admixtures, were adopted. In each category, four varieties of specimens with different fiber contents (0%, 0.5%, 1% and 1.5%) were included. The flexural strengths of MSF-SCC beams with various dosages of fibers were compared with those of SCC with no fiber content. From the results, it has been concluded that the addition of MSF results in the enhancement of the flexural strength of SCC beam.

1. Introduction

Self-compacting concrete is a pioneering building material; owing to its exceptional properties, it offers several benefits in the construction process. The productivity as well as improved quality of the concrete elements can be achieved by adopting SCC. SCC finds its application in all the circumstances where the above mentioned attributes are mandatory. This is particular true in the case of heavily reinforced concrete members like bridge decks, abutments, tunnel linings and tubing segments, where vibrating the concrete is next to impossible. SCC is equally apt for normal engineering structures (Holschemacher, 2002).

The use of self-consolidating concrete (SCC) is gaining momentum so as to overcome possible defects arising from the use of normal concrete. Such defects can be in the form of honeycombs and voids formed due to congestions created by vertical and horizontal reinforcing bars, preventing concrete to fill the entire form work. The use of SCC, because of its high flowability will alleviate such potential problems (Kanellopoulos, 2020). SCC has its share of disadvantages and shortcomings.

SCC reaches lower values for E-modulus, compressive and flexural strengths but higher values for shrinkage creep and strain under restrained conditions. Besides the paste volume, the cement type plays a fundamental role regarding creep (Leemann, 2014). SCC mixtures show a greater plastic shrinkage as compared to conventional concrete mixtures. The main reason for this phenomenon is their lack of bleeding. Accordingly, SCC is more vulnerable to shrinkage cracking. The vulnerability is especially high during setting (Turcry, 2006). Studies were conducted to study the role of steel fibers in order to reduce such defects in SCC.

Steel fiber-reinforced self -compacting concrete (SFR-SCC) can be used to enhance shrinkage, serviceability aspects which arise due to a low aggregate-cement ratio. Durability, flexural strength and resistance to freezing and thawing are increased in SFR-SCC (Corinaldesi, V., and G. Moriconi, 2004). Self-compacting concrete (SCC) possesses great deformability and segregation resistance, adequate viscosity and lower value of yield stress. Inclusion of steel fibres in combination with mineral admixtures enhances the performance of SCC. Combination of hybrid fibres in SCC improves the flexural strength and durability (Ramkumar, 2020).

Iqbal (2015) conducted investigations to study the effect of change in micro steel fiber content on the properties of steel fiber reinforced high strength lightweight self-compacting concrete (SHLSCC). Alteration of nature of concrete from brittle to ductile is achieved by addition of steel fibers to SCC. Adoption of lightweight concrete leads to reduction in extra loads. Moreover, SCC evades the necessity of vibrators for concrete compaction. This is useful in case of renovation or strengthening of existing structures. They conclude that there is strong influence of steel fiber content at doses of 1% or more on the workability of SHLSCC. Compressive strength reduced by 12%; splitting tensile strength and flexural strength increased by 37% and 110% respectively, when steel fiber content from increased from 0–1.25%.

Pereira (2008) has also established that ductility of SCC can be greatly improved by addition of steel fibers. (Raju, 2020) carried out investigations on SCC beams and concluded that their flexural performance is enhanced with the addition of steel fibers. Similarly, numerous researches have been carried out to establish the effect of steel fibers on various properties of SCC. Only a few investigations have been done to understand the effect of MSF on the resistance of SCC beams against flexure. More studies of this kind are required and flexural strength of MSF-SCC beams need to be established further.

2. Objective Of The Experimental Study

The objective of this study is to understand the flexural behaviour of MSF-SCC beams. The beams were cast with SCC in which macro synthetic fibers (MSF) of 0%, 0.5%, 1% and 1.5% doses were mixed. Complete replacement of natural river sand with Manufactured sand (M-sand) was adhered to; fine aggregate used in the experimental study was M-sand. Cement constituted only 65% of the required cementitious material and 35% of cement content was substituted with mineral admixtures such as fly ash (FA), silica fume (SF), and ground-granulated blast furnace slag (GGBS), at varying doses. Fiber content of mixes with flow properties suitable for SCC was arrived at.

Six categories of mixes, with various combinations of mineral admixtures were endorsed. In each category, four varieties of specimens with different fiber contents (0%, 0.5%, 1% and 1.5%) were adopted. Beams of dimensions 600 mm * 100 mm*100 mm were cast. The specimens were cured for duration of 28 days. In total, 72 MSF-SCC beams samples were cast. Flexure tests were performed on the MSF-SCC beams. The influence of dosage of fibers on the flexural strength was studied. The results of MSF-SCC beams with various fiber contents were compared with those with zero fiber content. Maximum improvement of flexural strength was exhibited by beams with two or more mineral admixtures and 1.5% fiber dose.

3. Materials And Mixing Proportions

3.1. Materials

Cement, Fly ash (FA), Silica Fume (SF), GGBS (GGBS), Coarse Aggregate (CA), Manufactured Sand (M Sand), Chemical Admixture, Water, and MSF are the constituent elements used in the concrete mixes used in the experiment.DCP super plasticizer DCP Supaflo PC360M was used as chemical admixture. Reduction of water content without adverse effect on workability can be achieved with this admixture.MSF of length ranging from to 36mm to 47mm and diameter less than 0.8mm was used. Physical properties of all the materials are stated in Table 1.

Table 1
Physical Properties of SCC Materials

S. No	Name of the Material	Physical Properties of SCC Materials	
1	Ordinary Portland Cement - 53 grade	Final setting time	240 minutes
		Initial setting time	29 minutes
		Specific gravity	3.10
		Fineness	5.4%
		Normal consistency	29%
2	Coarse aggregate of 10 mm to 12.5 mm size	Specific gravity	2.62
		Water absorption	0.35%
		Moisture content	0.25%
		Bulk density	1600kg/m^3
3	Fine aggregate (M Sand) passing through 4.75mm IS sieve	Specific gravity	2.58
		Fineness modulus	2.60
		Water absorption	2.31%
4	GGBS	Specific gravity	2.80
5	Silica Fume	Specific gravity	2.31
6	Class F Fly ash	Specific gravity	2.5
7	Chemical Admixture - Super plasticizer DCP Supaflo PC360M	Colour	Light brown liquid
		Specific gravity	1.7
		Chemical	DCP Supaflo PC360
		pH value	≥ 6
8	Appearance	Appearance	Clear
	Turbidity(NT units)	Turbidity(NT units)	1.75
	Taste	Taste	Agreeable
	pH	pH	7.1
9	Macro-synthetic fibers	Surface texture	Continuously embossed
		Base resin	Polyolefin
		Diameter	< 0.8 mm
		Length	37–47 mm

3.2. Mixing Proportions

Several trial mixes were made, out of which only a few MSF-SCC mixes were finalised. Table 2 depicts the mix proportions of SCC.

Table 2
Mix Proportions of SCC Mixes

Mix	Cement (kg/m³)	Fly ash (kg/m³)	M-Sand (kg/m³)	CA (kg/m³)	Fibers (%)	SF (kg/m³)	GGBS (kg/m³)
SZ_1	345	186	891	810	0	0	0
SZ_2	345	160	891	810	0	26.55	0
SZ_3	345	133	891	810	0	53.1	0
SZ_4	345	160	891	810	0	0	26.55
SZ_5	345	133	891	810	0	0	53.1
SZ_6	345	133	891	810	0	26.55	26.55

The mixes were categorized into groups as shown in Table 3.

Table 3
Description of Groups of Test Specimens

Group	Cementitious materials	Mix	Fiber (%)
A	65% cement, 35%FA, 0%SF, 0%GGBS	SZ_1	0
		SH_1	0.5
		S1_1	1
		S1H_1	1.5
B	65% cement, 30%FA, 5%SF, 0%GGBS	SZ_2	0
		SH_2	0.5
		S1_2	1
		S1H_2	1.5
C	65% cement, 25%FA, 10%SF, 0%GGBS	SZ_3	0
		SH_3	0.5
		S1_3	1
		S1H_3	1.5
D	65% cement, 30%FA, 0%SF, 5%GGBS	SZ_4	0
		SH_4	0.5
		S1_4	1
		S1H_4	1.5
E	65% cement, 25%FA, 0%SF, 10%GGBS	SZ_5	0
		SH_5	0.5
		S1_5	1
		S1H_5	1.5
F	65% cement, 25%FA, 5%SF, 5%GGBS	SZ_6	0
		SH_6	0.5
		S1_6	1
		S1H_6	1.5

4. Fresh Properties Of Various Mixtures Scc Mix

Filling, passage, and resistance to segregation are vital attributes of fresh SCC. According to EFNARC, filling ability is defined as its capacity to flow into every space of the form work while bearing its own weight. Passing capacity is defined as its ability to move freely through narrow apertures, such as those between steel reinforcing bars. Segregation-resistance is the ability of SCC to remain homogeneous in composition during transport and placing. All these essential qualities were measured by suitable tests. Table 4 shows V-Funnel, L-Box and U-Box Test results and Table 5 depicts the slump test results of various SCC mixtures used in the experimental study.

Table 4
Workability Test Results of MSF-SCC Mixes

Fiber Percentage	Test	A	B	C	D	E	F
0	V-Funnel values in mm (Range: 6–12 sec)	6.47	9.13	8.6	7.97	7.39	6.9
0.5		7.1	9.59	9.01	8.61	8.03	7.59
1		7.5	10.21	9.5	8.99	8.27	7.97
1.5		8.03	10.91	9.9	9.31	8.77	8.53
0	L-Box values (Range:0.8-1.0)	3.9	4.2	4.24	3.91	4	4.26
0.5		4.21	4.45	4.5	4.25	4.33	4.8
1		4.33	4.7	4.8	4.38	4.6	5.1
1.5		4.4	5	5.1	4.8	4.9	5.18
0	U-Box values in mm (Range: 0–30)	5.71	17.41	19.71	14.61	12.51	9.21
0.5		8.61	20.31	22.41	16.91	14.71	11.61
1		12.51	23.61	25.81	20.21	17.61	14.71
1.5		14.61	25.71	27.91	21.51	18.61	16.31

Table 5
Slump Flow Test Results of MSF-SCC Mixes

Fiber Percentage	Test	A	B	C	D	E	F
0	Slump in mm (Range: 650–800 mm)	745	714	702	726	732	738
0.5		724	692	681	704	714	720
1		703	674	669	681	687	692
1.5		675	659	651	660	669	672
0	T-50 Flow- seconds (Range: 3–6 s)	2.92	3.51	3.61	3.34	3.24	3.07
0.5		3.03	3.84	3.96	3.62	3.44	3.29
1		3.17	3.94	4.1	3.73	3.56	3.46
1.5		3.34	4.08	4.31	4.26	3.76	3.6

It was observed that all the mixes with MSF dosages of 0, 0.5, 1, and 1.5 percent have satisfied the workability values stipulated by EFNARC. The fluidity of mixes at a dosage of 1.5% has reduced substantially.

5. Casting Of Beam Specimens

MSF-SCC beams were cast without the use of compaction equipment, adopting the mix proportions listed in Table 2. A total of 72beams, three specimens for each type of mix were cast. The size of the beam was 600 mm × 100 mm * 100 mm. No additional tension steel reinforcement was provided. Figure 1 shows casting of beams in the moulds. The curing period of the beams was 28 days.

6. Experimental Program

When the load is applied to the beam member through two points of contact it is known as Two-Point Load test. Figure 2 depicts the loading positions adopted in the experiment.

Before conducting the experiment, the beam samples were dried completely and cleaned. The positions of the supports and loading positions were indicated. The beam member was placed horizontally over the two steel rollers of 38 mm diameter and these rollers were placed at centre to centre distance of 600mm and the load was applied equally through two points of contacts to the beam specimens up to the failure. The load was applied gradually with the help of the hydraulic frame machine. The setup for the flexure test of the beam has been shown in Fig. 3. The loading arrangement in the loading frame is such that concentrated loads were applied at the one-third points of the beam specimen. Seventy two beams were tested in similar way.

7. Results And Discussion Of Results

The maximum load which the beam can resist before the complete failure of member takes place is the flexural strength of that member. Flexural strength, f_{cr} can be obtained by substituting the values of applied load (P), effective span (L), width (b) and depth (d) in the formula shown below. Flexural strength or bending strength is calculated in N/mm^2.

$f_{cr} = (P * L) / (b * d^2)$

The values of flexural strength of the MSF-SCC beams are shown Fig. 4.

The ultimate flexural strength is the greatest in the beams cast with triple blended admixtures among all the MSF-SCC beams. Fiber-content increase in each group has resulted in increase in flexural resistance. The change in the flexural capacity with increase in fiber content for all the MSF-SCC beams was analysed. To express the rise in flexural capacity with fibers quantitatively, it is depicted in the form of a graph as given in Fig. 5

As it is evident from the graph, with a raise in fiber dose, improvement in flexural capacity of MSF-SCC beams was exhibited in all the mixes with varying mineral admixtures. For each category of mix, maximum strength was achieved at fiber dosage of 1.5%. The percent increase was in the range of 8–22%. This indicates that fibers as well as mineral admixture contribute to the enhancement of flexural strength of MSF-SCC beams. Least growth was recorded in mixes made with single admixture, fly-ash. Fibers demonstrate a greater influence on the flexural strength in triple blended mixes.

8. Conclusions

After the experimental procedure of tests to evaluate the fresh properties and flexural strength of MSF-SCC beams, the following conclusions are arrived at.

1. The workability guidelines laid down by EFNARC were fulfilled by all the SCC mixes with and without fibers, for V-funnel, Slump flow, and T50, L-box and U-box tests. Decrement of flow properties with an increment in fiber percentage was observed. This applies to SCC mixes with FA-only, double-blended and triple-blended mixes, as well.
2. Flexural capacity of MSF-SCC beams is upgraded with a rise in fiber content of MSF-SCC beams; higher the fiber dosage higher is the bending strength. The increase in strength was registered up to fiber content of 1.5%. Higher fiber dosages beyond 1.5% were not examined since their workability requirements did not meet the EFNARC guidelines.
3. Addition of macro-synthetic fibers to SCC beams results in improvement of flexural strength. This tentatively leads to enhancement of ductility, thereby reducing the risk of brittle failure. Optimum fiber content in terms of workability should be established prior to usage in the flexural members.
4. Betterment of flexural capacity is the greatest in beams cast with MSF-SCC mixes of triple-blended admixtures. MSF-SCC beams made with triple blends of admixtures in addition to cement achieve superior flexural resistance.

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Figures

Figure 1

Casing of Beams

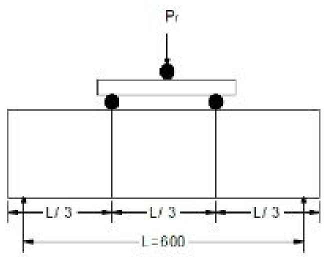

Figure 2

Two point loading setup for flexure test

Figure 3

Two-point loading setup for flexure test

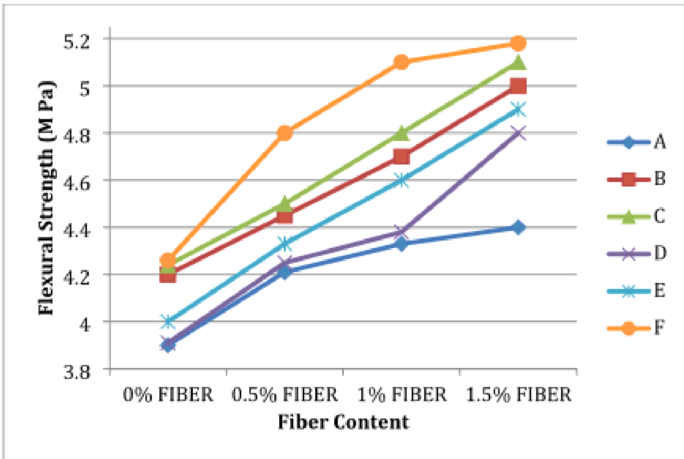

Figure 4

Flexural Capacity in MSF-SCC beams with Fibers

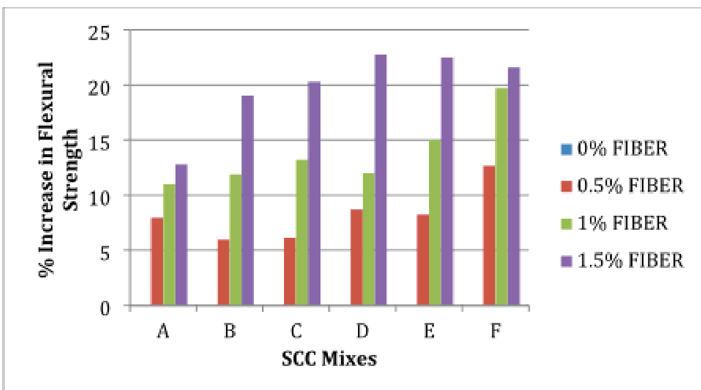

Figure 5

Increase in Flexural Capacity in MSF-SCC beams with Fibers