Steel Fibres as a Partial Shear Reinforcement in Self-compacting Concrete

K. Praveen and S. Venkateswara Rao

Abstract The present study investigates the possibility of replacement of shear reinforcement with steel fibres in Self-Compacting Concrete beams. A total of 12 beams were designed and tested for two grades of SCC, i.e. M30 and M70. The variable parameters in the study apart from grade of concrete are dosage of steel fibres and stirrup spacings. The size of the beam was 100 × 200 × 1200 mm. The clear span of beam, 1100 mm was maintained throughout the study. All the beams were tested under three- point loading with shear span-to-depth ratio a/d = 2. The investigation shows that shear strength decreased as spacing of stirrup increased. The test results indicates that the initial crack shear strength increased significantly in the presence of steel fibre and the improvement in ultimate shear strength was also achieved. The present study also proves that steel fibre can reduce the area of shear reinforcement (stirrups) required and that the combination of fibres and stirrups increase the shear strength properties.

Keywords Self compacting concrete · Shear strength · Steel fibers

1 Introduction

When principal tensile stresses within the shear region of a reinforced concrete beam exceed the tensile strength of concrete, diagonal cracks develop in the beam, finally causing failure. The brittle nature of concrete causes the collapse to occur shortly after the formation of the first crack. The addition of steel fibres to concrete mix can bridge the crack propagation and delays the failure of the beam, which can improve the brittle nature of concrete to a more ductile behaviour [1, 2]. Addition of

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steel fibres can also increase the flexural tensile strength of concrete, thereby enchasing the post-cracking behaviour of Reinforced Concrete (RC) member [3].

Of all the different types of failure in concrete, shear failure is a sudden and brittle failure. Addition of steel fibres in concrete, can modify the brittle shear failure mode into a ductile flexural-shear failure. Inclusions of steel fibres can also partially replace conventional shear reinforcement, i.e. stirrups without compromising the strength aspect, thereby significantly reducing the cost and duration of construction [4–6].

The principal parameters that influence shear behaviour of reinforced concrete beam are: shear span-to-effective depth ratio (a/d), concrete compressive strength (f_c), longitudinal tensile reinforcement (ρ_t) and spacing of stirrups (S_v). When fibres are also included, parameters like fibre volume fraction (V_f) or fibre type (material, dimensions shape, etc.), also affect the shear performance of concrete [7, 8].

The main purposes of the present study is (1) To study the mechanical behaviour of steel fibre reinforced self-compacting concrete beams under shear, (2) To study the potential use of steel fibres as partial replacement of stirrups in Self-Compacting Concrete, (3) To investigate the combined effect of stirrups and steel fibres for improvements in initial and ultimate shear strengths and also to check the ductility of Steel Fibre- Reinforced Concrete (SFRSCC).

2 Materials Used

2.1 Cement

Cement used in the present study was 53 grade ordinary Portland cement conforming to IS: 12269-2013 [9]. The specific gravity of cement was 3.14 and specific surface area of 225 m^2/g having initial and final setting time of 45 and 560 min respectively.

2.1.1 Fly Ash

The fly ash used in the experiments was obtained from Ramagundam Thermal Power Station (NTPC) and was sieved by 90 micron sieve and confirmed to IS 3812:1981 [10]. The specific gravity was 2.2 and specific surface area was 450 m^2/g. The fly ash had a silica content of 63.99%, silica + alumina + iron oxide content of 92.7%, pH value 10 and a loss on ignition 2.12.

2.1.2 Fine Aggregate (FA)

The fine aggregate used in the present study was conforming to Zone-2 according to IS: 383-2002 [11]. It was obtained from a nearby river source. The specific gravity was 2.65, while the bulk density of sand was 1.45 g/c.c.

2.1.3 Coarse Aggregate (CA)

Crushed granite was used as coarse aggregate. Coarse aggregates of 20 mm nominal size were obtained from a local crushing unit, which was a well-graded aggregate according to IS: 383-2002 [11]. The specific gravity was 2.8, while the bulk density was 1.5 g/c.c.

2.1.4 Water IS456-2000

Potable water was used in the experimental work for both mixing and curing of specimens.

2.1.5 Silica Fume [12]

It is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high-performance concrete. The bulk density of silica fume varies from 130 to 600 kg/m^3. The specific gravity of silica fume is generally in the range of 2.2–2.3. Specific surface area of silica fume typically ranges from 15,000 to 30,000 m^2/kg.

2.1.6 Super Plasticizer (SP)

High-Range Water-Reducing (HRWR) admixture confirming to ASTM C494 [13] commonly called as super plasticizers was used for improving the flow or workability for decreased water–cement ratio without sacrifice in the compressive strength. These admixtures when they disperse in cement agglomerates significantly, decreases viscosity of the paste forming a thin film around the cement particles. In the present investigation, water-reducing admixture CHRYSO FLUID OPTIMA P-77 (poly carboxylic ether based) obtained from Chyrso Chemicals, India was used.

2.1.7 Steel Fibre [14]

Crimped Steel fibre (from Apex Encon Projects Pvt Ltd., New Delhi, India) with nominal diameter of the fibre 0.5 mm and cut length 30 mm with aspect ratio of 60 were used. Tensile strength and modulus of elasticity of this fibre is 850 MPa and 2.1×10^5 MPa.

2.1.8 Tension Reinforcement

TMT bars of 12 and 16 mm diameter of grade Fe 500 confirming to IS: 1786 [15] whose yield strength F_y = 500 N/mm^2 of length 1160 mm were used as tension reinforcement and 6 mm Ø mild steel bars whose yield strength F_y = 290 N/mm^2 was used as stirrups (shear reinforcement) and also for top compression reinforcement.

3 Experimental Programme

In the present study, a total of 12 shear deficient beams were designed and cast for two grades of SCC via M30 and M70. The dimensions of the beam were fixed as 100 × 200 × 1200 mm with a clear span of 1100 mm. All beams were tested under three-point loading. For compressive strength, standard cube moulds of 150 mm × 150 mm × 150 mm made of cast iron were used. For split tensile strength, standard cylinder moulds of 150 mm φ × 300 mm made of cast iron were used. For flexural strength, 100 × 100 × 500 mm of standard prism moulds were used. In the present study, dosage of steel fibres is taken as 0.5% by volume of concrete [16], from our preliminary research work it was found that 0.5% dosage of steel fibres is optimum based on fresh and hardened properties.

Table 1 shows the details of beams with spacing of stirrups and percentage of steel fibre per volume of concrete SCC30-0 beam indicates that Self-Compacting Concrete beam with M30 grade concrete without any shear reinforcement (Stirrups), Similarly, SFRSCC30-180 beam indicates that it is a steel fibrous concrete beam with spacing of stirrups as 180 mm.

Table 1 Details of beams cast

S. No.	Designation	Shear Span-to- depth ratio (a/d)	Spacing of stirrup's (mm)	Fibre volume fraction (kg/m^3)
1	SCC30-0	2	–	–
2	SFRSCC30-0	2	–	38
3	SCC30-180	2	180	–
4	SFRSCC-180	2	180	38
5	SCC30-360	2	360	–
6	SFRSCC-360	2	360	38
7	SCC70-0	2	–	–
8	SFRSCC70-0	2	–	38
9	SCC70-180	2	180	–
10	SFRSCC70-180	2	180	38
11	SCC70-360	2	360	–
12	SFRSCC-360	2	360	38

3.1 Reinforcement Details in Each Beam

The dimensions and typical reinforcement detail for both grades of SCC M30 and M70 with shear span to depth (*a*/*d*) ratio 2, are shown in Figs. 1, 2, 3 and 4. The stirrups spacing was varied in the shear span, i.e. 180–360. M30 grade SCC beams consisting of 2–12 mm Ø TMT bars as longitudinal reinforcement, 2–6 mm Ø mild steel bars as top compression reinforcement and two legged 6 mm Ø bar was used as stirrups. Similarly, M70 grade SCC beams consisting of 2–16 and 1–12 mm Ø bars as longitudinal reinforcement, 2–6 mm Ø mild steel bars as top compression reinforcement and two legged 6 mm Ø bar was used as stirrups.

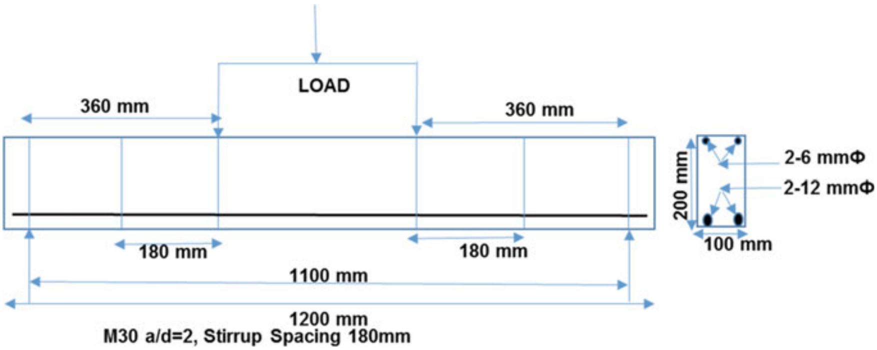

Fig. 1 Details of reinforcement for M30 SCC with *a*/*d* = 2

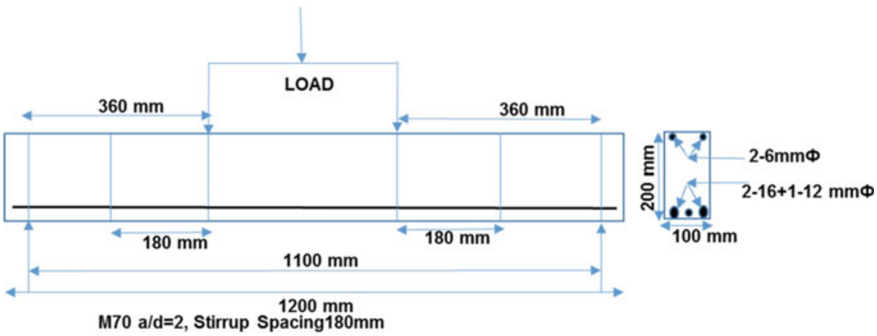

Fig. 2 Details of reinforcement for M70 SCC with *a*/*d* = 2

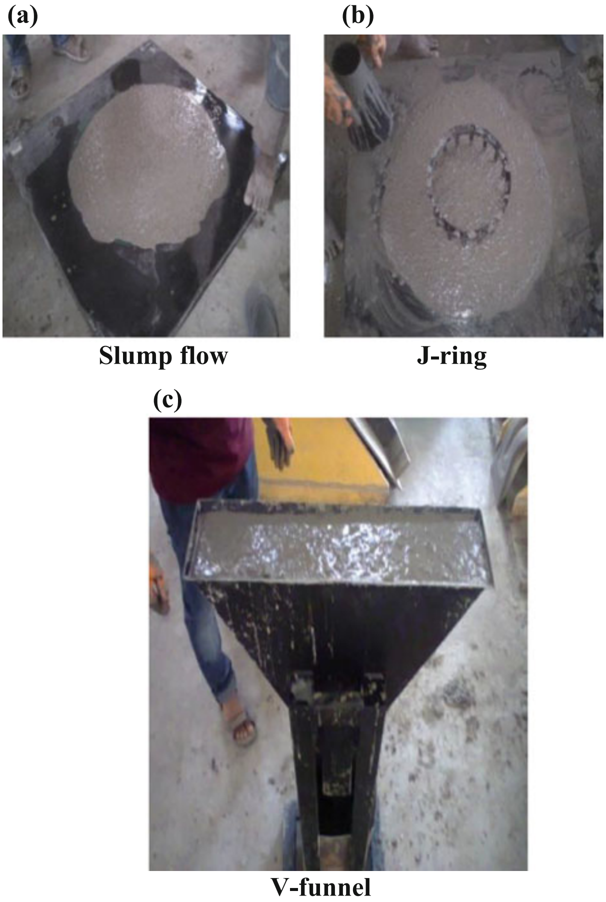

Fig. 3 Some tests on fresh properties of SCC

3.2 Mix Proportions

Self-Compacting Concrete (SCC) mixes were designed by using Rational Mix design method [17], details of mix proportions are presented in the Table 2. Trial mixes were carried out by varying Super Plasticizer dosage and binder content and evaluated the fresh properties as per EFNARC Specifications [18] via, Slump flow, T_{50}, L-Box, V-Funnel, T_5 and *J* ring tests.

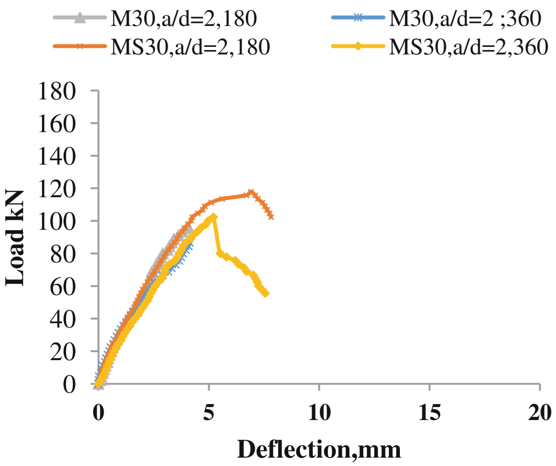

Fig. 4 Load versus deflection for SCC30

Table 2 Mix proportions of M30 and M70 grade SCC

Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Silica fume (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)
M30	350	324	0	746	945	203	5.73
M70	600	226	48	780	874	247	6.03

3.3 *Fresh Properties*

The details of Fresh Properties for M30 and M70 grades SCC without and with steel fibre were shown in Table 3. It can be seen from Table 3 that, addition of steel fibres has reduced the flow properties but are satisfying the EFNARC Specifications. Figure 3 shows the various testing methods on workability of SCC.

Table 3 Fresh properties of M30 and M70 grade SCC with and without fibre

	M30		M70	
Dosage of fibres (%)	0	0.5	0	0.5
Slump test (mm)	750	620	720	680
T_{50} slump flow (s)	3	5	2.5	4
V funnel (s)	6	6.58	10.5	11.8
V funnel @ T_5 (min s)	7.5	8.38	12	14
J-ring (s)	3	8	3	7

Table 4 Hardened properties of M30 and M70 grades of SCC at 28 days

	M30			M70		
Dosage of steel fibres (%)	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural strength (MPa)
0	39.67	4.17	3.98	78.25	5.04	5.34
0.5	48.76	4.34	4.87	86.66	6.85	7.41

3.4 Hardened Properties

The details of hardened properties of M30 and M70 grades of SCC without and with steel fibre at the end of 28 days of curing were shown in Table 4. All the tests were done as per IS: 516-2004 [19] specifications.

4 Results and Discussions

At the end of the required curing period, the beams were tested for three-point loading under the Tinius–Olsen Testing Machine (TOTM) of 2000 kN capacity. The linear variable differential transformers (LVDT) were used to measure the displacement at mid span. From the recorded data, the shear load versus deflection graphs were plotted, initial crack strength and ultimate shear strength were calculated. The toughness and stiffness were evaluated for both fibres and non-fibre concrete beams (Tables 5 and 6).

Table 5 Initial shear and ultimate shear strength values for SCC30

Designation	First crack shear strength (MPa)	Ultimate shear strength (v_u) (MPa)	Deflection (mm)	Toughness (kN/mm)	Stiffness (kN/mm)
SCC30-0	1.60	1.73	3.16	100.83	14.15
SFRSCC30-0	1.98	2.34	5.05	225.60	16.56
SCC30-180	2.03	2.66	4.18	234.27	18.23
SCC30-360	1.76	2.41	4.12	207.43	17.68
SFRSCC30-180	2.29	3.28	6.90	364.1	22.52
SFRSCC30-360	2.16	2.84	5.21	328	20.17

Table 6 Showing initial and ultimate shear strength values for SCC70

Designation	First crack shear strength (MPa)	Ultimate shear strength (v_u) (MPa)	Deflection (mm)	Toughness (kN/mm)	Stiffness (kN/mm)
SCC70-0	1.98	2.41	3.66	197.70	24.61
SFRSCC70-0	2.04	2.55	4.08	228.50	25.55
SCC70-180	2.16	3.21	4.92	365.7	29.17
SCC70-360	2.10	2.60	3.54	212.2	28.07
SFSCC70-180	3.52	4.44	5.90	525.03	36.47
SFSCC70-360	2.41	3.86	5.40	483.46	31.47

4.1 Load Versus Deflection Curves

From the recorded data, load versus deflection curves were plotted, Figs. 4 and 5 show the comparison of load deflection curves of M30 and M70 grade concrete among SCC and SFSCC beams. The SCC30-0 beam without stirrups failed very early after first diagonal crack occurred. SCC30-180 beam with stirrups spacing at 180 mm shows load carrying capacity and brittle failure pattern compared to the SFRSCC30-180, addition of steel fibres has increased the load bearing capacity by 23.25% and also maximum deflection corresponding to ultimate load increased by 65.07%. Similarly, the SCC30-360 beam also shows lower load carrying capacity and brittle failure pattern compared to the beam with steel fibres (SFSCC30-360). With increase in the stirrup spacing from 180 to 360 mm, the ultimate shear strength decreased by 10.37% without fibres and by addition of steel fibres the ultimate shear strength was reduced by 6.7%. This shows that steel fibres will bridge the cracks and increase the shear strength. Similarly, for higher grade

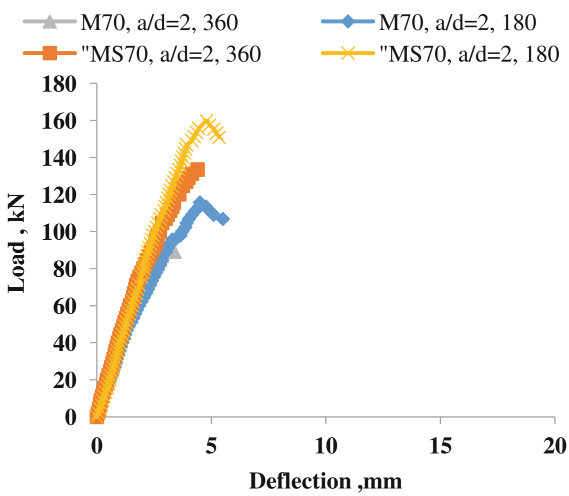

Fig. 5 Load versus deflection for SCC70

concrete (SCC 70), addition of steel fibres has increased the ultimate shear strength by 38.07% and also maximum deflection corresponding to ultimate load increased by 19.91%. From the above observations, it can be concluded that the addition of steel fibres can increase the load carrying capacity and can greatly enhance the ductility and also change the failure pattern of the beam from brittle shear failure to ductile flexural-shear failure. It can be proven that steel fibres can only replace stirrups partially by increasing the stirrup spacing, but not completely replacing the stirrups as shear reinforcement.

5 Details of Tested Beams

A total of 12 beams including 6 Plain and 6 fibre SCC beams have been cast and tested. Figures 6 and 7 show the typical failure pattern of plane and fibrous SCC M30 grade concrete.

Similarly, Figs. 8 and 9 show the failure pattern for plain SCC and fibrous SCC for M70 grade concrete. It was noticed that plain specimen's failed in sudden brittle failure, where as in case of fibrous SCC mode of failure was ductile.

Fig. 6 Failure pattern of SCC30

Fig. 7 Failure pattern of SFRSCC30

Fig. 8 Failure pattern of SCC70

Fig. 9 Failure pattern of SFRSCC70

6 Conclusions from Experimental Study

1. Addition of fibre has modified the failure pattern from brittle shear failure to a ductile flexural-shear failure. There is also an increase in the ultimate shear strength. This shows that steel fibres play a very important role before and after cracking.
2. For an increase of stirrups spacing from 180 to 360 mm for a/d = 2, the ultimate shear strength decreased by 15.49% without fibres.
3. In case of M30 grade SCC, addition of fibres enhanced cracking and ultimate shear strength by 19.2 and 23.2%, respectively, and also toughness and stiffness increased by 56.8 and 18.8% respectively.
4. In case of M70 grade SCC, addition of fibres enhanced the cracking and ultimate shear strength by 25.71 and 30.77% respectively.
5. Steel fibres can be used as partial shear reinforcement by increasing the spacing of stirrups thereby reducing the area of shear reinforcement.

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