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Experimental Study on Self-Compacting Concrete using Glass Fibre

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Abstract—

Self-compacting concrete (SCC) flows under its own weight and fills the formwork without vibration. This paper reports an experimental study on M20 SCC designed by IS 10262:2009, with glass fibre added at 0, 0.25, 0.5, 0.75, 1.0 and 1.25%. Fresh properties were measured by the slump flow, T50cm, V-funnel and L-box tests, and the compressive, split tensile and flexural strengths were measured at 3, 7 and 28 days. As the fibre content rises, the slump flow falls from 650 to 520 mm and the T50cm time rises from 6.82 to 14 s. The 0.5% mix gave the highest strengths at 28 days: 38.29 N/mm² in compression (28.2% above the plain SCC), 4.54 N/mm² in split tension (35.5% above) and 12.00 N/mm² in flexure (38.1% above). At 1.0% and 1.25% the compressive strength falls to 21.30 and 16.53 N/mm², below the plain SCC. The stiffness measured in the modulus test differs by no more than 2.5% between mixes. The optimum glass fibre content is therefore 0.5%, although the flexural values are unusually high and should be re-checked.

Index Terms—self-compacting concrete, glass fibre, workability, compressive strength, split tensile strength, flexural strength, modulus of elasticity

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I. Introduction

Concrete technology has advanced greatly over the last three to four decades in durability, strength and other properties. Self-compacting concrete (SCC), also called self-consolidating concrete, is a concrete that flows under its own weight, fills the formwork completely and compacts itself without vibration. The concept was proposed by Professor Okamura in Japan in 1986, and the first prototype was completed in 1988. SCC is now used worldwide in tall and heavy structures and in tunnels, but its use in India is still limited because awareness of the technology is low.

SCC can fill formwork of any size and shape, including congested and narrow sections, and it gives a homogeneous mass without bleeding, segregation or honeycombing. It lowers noise because no vibrators are used, reduces manpower, and gives a smooth surface finish. Its low tensile and flexural strength can be improved by fibre reinforcement.

A. Glass fibre

Glass fibre is made of extremely fine glass filaments. It is light, strong and robust, and its raw material is less expensive and less brittle than that of many other fibres. Its large surface area in relation to its weight makes it effective in a concrete matrix, and its elastic modulus is slightly higher than that of other common fibres. This study adds glass fibre to SCC to improve the strength, and compares the fresh and hardened properties of six mixes with fibre contents from 0 to 1.25%.

II. Objectives of the Project

The objectives of the project are: (i) to compare the fresh and hardened properties of SCC with glass fibre against those of normal self-compacting concrete (NSCC); (ii) to determine the fresh properties of both; (iii) to determine the hardened properties of both; and (iv) to compare the elastic modulus of NSCC and SCC with glass fibre.

III. Literature Review

Ahmad *et al.* [1] compared normal concrete (NC), SCC and glass-fibre SCC at a water–cement ratio of 0.35, using three fibre mixes. The fibre slightly reduced the workability of SCC and raised the compressive and tensile strengths compared with NC, while the elastic modulus and modulus of rupture were higher in NC than in SCC. Persson [2] studied eight mixes with water–binder ratios from 0.24 to 0.8 and found that the elastic modulus, creep and shrinkage of SCC did not differ drastically from those of NC. Dinakar *et al.* [3] used fly ash at 0–85% in SCC. Their strength was lower at 28 days and improved over 90–180 days, with high tensile strength and low elastic modulus compared with NC.

Shahanasheril *et al.* [4] added 0.05%, 0.1%, 0.15% and 0.2% glass fibre to M20 SCC and raised the compressive strength by 8.2%, 9.2%, 7.02% and 3.5%. For M30 the gains were 5.1%, 7.1%, 5% and 2.3%. The gain therefore peaked at 0.1% and fell at higher dosages. Srinivasa Rao *et al.* [5] found that glass fibre in SCC reduces bleeding and the chance of cracking and improves surface integrity, but did not improve the flexural strength of beams. Deepak Raj *et al.* [6] compared SCC and fibre-reinforced SCC, noting that fibre improves the tensile and ductile behaviour. Kasturi *et al.* [7] used 0.05–0.2% glass fibre in M30 SCC and tested fresh and hardened properties. Balachandra [8] found 25.5% higher compressive strength and higher split tensile strength with 1.75% steel fibre in SCC. Dehn *et al.* [9] studied the time development of the properties and the bond behaviour of SCC.

Most of these studies used fibre contents below about 0.2%. The present work covers a wider range, 0.25–1.25%, to find the optimum and the point where the benefit is lost.

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IV. Materials and Mix Design

A. Materials

Ordinary Portland cement of 43 grade conforming to IS 8112 [10] was used. The coarse aggregate was crushed, cubical aggregate of 10 mm and 12 mm size, and the fine aggregate was natural sand, both obtained from a local supplier. The super-plasticizer was Super Plast 200 (specific gravity 1.15). Potable water meeting IS 456 [11] was used for mixing. Glass fibre was added at 0.25%, 0.5%, 0.75%, 1.0% and 1.25%. The properties found in the college laboratory are given in Table I (Fig. 1).



Fig. 1. Materials: (a) coarse aggregate, (b) fine aggregate, (c) cement, (d) glass fibre.

TABLE I
PROPERTIES OF MATERIALS

Material	Property	Value
Cement (OPC 43)	Specific gravity	2.53
Coarse aggregate	Specific gravity	2.89
	Fineness modulus	2.96
Fine aggregate	Specific gravity	2.44
	Fineness modulus	3.5
Super-plasticizer	Specific gravity	1.15

B. Mix design

An M20 SCC mix was designed according to IS 10262:2009 [12]. With a standard deviation s of 4 N/mm², the target mean strength is

$$f_{ck}' = f_{ck} + 1.65\, s = 20 + 1.65 \times 4 = 26.6 \text{ N/mm}^2 \quad (1)$$

A water–cement ratio of 0.5 was taken from IS 456 [11]. For 10 mm aggregate the maximum water content is 208 L/m³, and 30% more was allowed for a 650 mm flow, giving 270.4 L. The super-plasticizer permits a 20% reduction, so the water content is 216.32 L/m³ and the cement content is 216.32 / 0.5 = 432.64 kg/m³, above the 320 kg/m³ minimum for severe exposure. The volume fractions of coarse and fine aggregate are 0.46 and 0.54 for zone II sand. After subtracting the volumes of cement (0.17 m³), water (0.216 m³) and admixture (0.0056 m³), the aggregate volume is 0.61 m³. The resulting quantities are given in Table II, in the ratio 1 : 1.86 : 1.87 (cement : fine : coarse) by mass.

TABLE II
MIX PROPORTIONS PER M³ OF SCC (M20)

Ingredient	Quantity
Cement	432.64 kg
Fine aggregate	803.73 kg
Coarse aggregate	810.93 kg
Water	216.32 L
Super-plasticizer	5.6 kg
Water–cement ratio	0.50

V. Testing of Specimens

The work followed the steps in Fig. 2. Fresh SCC was tested for filling ability by the slump flow, T50cm and V-funnel tests, and for passing ability by the L-box test (Fig. 3). The report's acceptance criteria were a slump flow of at least 650 mm, a T50cm time of 2–5 s, and a V-funnel time of 8–12 s. In the L-box test the ratio H2/H1 should be close to 1, and a ratio of at least 0.8 is commonly adopted [14].

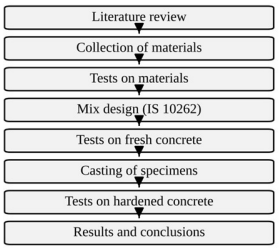


Fig. 2. Methodology of the study.

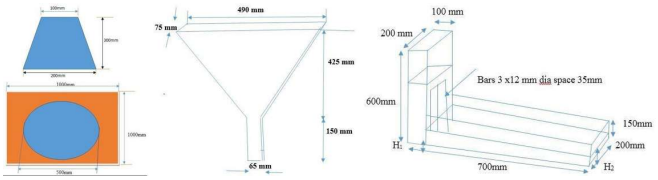


Fig. 3. Fresh-state test apparatus: slump cone and base plate, V-funnel and L-box.

Cubes of 150 mm, cylinders of 150 mm × 300 mm and beams of 100 × 100 × 500 mm were cast without any compaction. The moulds were removed after 24 hours, and the specimens were cured and tested at 3, 7 and 28 days following IS 516 [13]. Each result is the average of three specimens. The strengths were calculated as

$$f_c = P / A \quad (2)$$

$$f_{sp} = 2P / (\pi\, L\, D) \quad (3)$$

$$f_b = P\, l / (b\, d^2) \quad (4)$$

where fc, fsp and fb are the compressive, split tensile and flexural strengths, P is the failure load, A the loaded area, L and D the length and diameter of the cylinder, l the span, and b and d the width and depth of the beam. For the modulus test, loads were applied in steps of 10 kN and the deformation was read on a dial gauge of 150 mm gauge length (least count 0.001 mm). The strain is ΔL / L.

VI. Results and Discussion

A. Fresh properties

Table III and Fig. 4 give the fresh properties. The filling ability falls steadily as the fibre content rises. The slump flow drops from 650 mm for plain SCC to 520 mm at 1.25% (20% less), and the T50cm time doubles from 6.82 to 14 s. By the stated criteria, only the plain SCC meets the 650 mm slump flow limit, and the 0.25% mix (640 mm) just misses it. All T50cm times are longer than the 2–5 s range, so every mix is more viscous than the target. The V-funnel times of 8.31–11.6 s are all within 8–12 s. The L-box ratios of 0.81–0.92 are all above 0.8, so passing ability is acceptable, although no ratio reaches 1. The fibre therefore affects the filling ability more than the passing ability and segregation resistance.

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TABLE III
FRESH PROPERTIES OF SCC WITH GLASS FIBRE

Glass fibre	Slump flow (mm)	T50cm (s)	V-funnel (s)	L-box H2/H1
0% (SCC)	650	6.82	8.31	0.826
0.25%	640	7.8	8.7	0.920
0.5%	610	9.2	9.9	0.836
0.75%	550	11.6	10.2	0.810
1.0%	530	12.4	11	0.920
1.25%	520	14	11.6	0.904

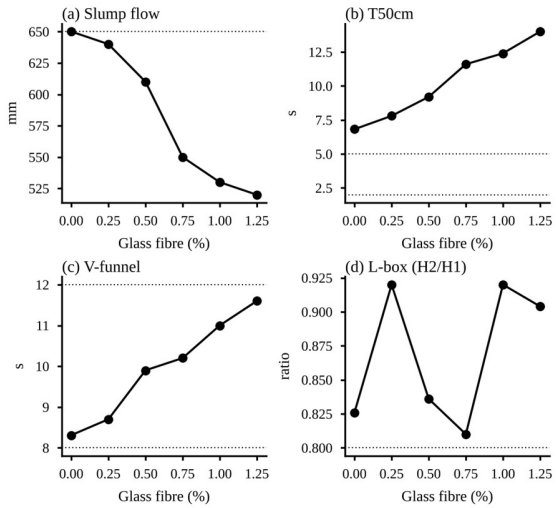


Fig. 4. Fresh properties against glass fibre content. Dotted lines mark the acceptance limits.

B. Compressive strength

Table IV and Fig. 5 give the strengths. The 28-day compressive strength of the plain SCC is 29.87 N/mm², above the target of 26.6 N/mm². With glass fibre it rises to 31.32 N/mm² at 0.25% (+4.9%), peaks at 38.29 N/mm² at 0.5% (+28.2%), and is 30.53 N/mm² at 0.75% (+2.2%). Beyond that it falls sharply, to 21.30 N/mm² at 1.0% (−28.7%) and 16.53 N/mm² at 1.25% (−44.7%), and the 1.25% mix does not reach the 20 N/mm² characteristic strength. The 3-day and 7-day results show the same pattern, with 0.5% highest (15.15 and 21.53 N/mm²). The strength loss at high dosage coincides with the loss of workability in Table III.

TABLE IV
COMPRESSIVE AND SPLIT TENSILE STRENGTH (N/MM²)

Glass fibre	fc 3 d	fc 7 d	fc 28 d	fsp 3 d	fsp 7 d	fsp 28 d
0%	10.70	18.78	29.87	0.89	2.30	3.35
0.25%	12.00	19.70	31.32	1.40	2.56	3.80
0.5%	15.15	21.53	38.29	1.69	2.88	4.54
0.75%	12.38	17.80	30.53	1.53	2.25	4.11
1.0%	10.36	17.80	21.30	1.19	1.77	3.57
1.25%	9.86	15.19	16.53	1.12	1.43	2.82

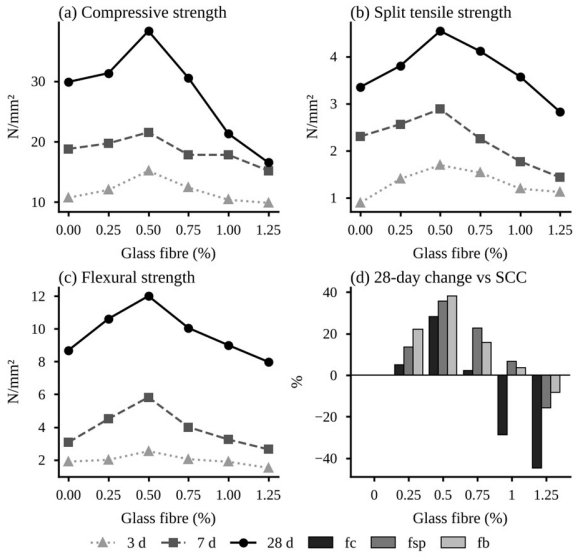


Fig. 5. Hardened properties: (a)–(c) strength at 3, 7 and 28 days against glass fibre content; (d) change at 28 days relative to plain SCC.

C. Split tensile and flexural strength

The split tensile strength follows the same trend (Table IV). At 28 days it is 3.35 N/mm² for plain SCC and rises to 4.54 N/mm² at 0.5% (+35.5%). It stays above the plain SCC up to 1.0% (+6.6%) and falls to 2.82 N/mm² at 1.25% (−15.8%). Tensile strength is therefore more tolerant of high fibre content than compressive strength, which is consistent with the crack-bridging action of fibres. The flexural strength (Table V) is 8.69 N/mm² for plain SCC and peaks at 12.00 N/mm² at 0.5% (+38.1%). It is +3.6% at 1.0% and −8.2% at 1.25%. At 7 days the 0.5% mix is 89.6% stronger in flexure than the plain SCC, so the benefit is largest at early age.

TABLE V
FLEXURAL STRENGTH, 28-DAY CHANGES AND RELATIVE STIFFNESS

Glass fibre	fb 3 d	fb 7 d	fb 28 d	Δfc 28 d (%)	Δfsp 28 d (%)	Δfb 28 d (%)	E rel.
0%	1.89	3.07	8.69	—	—	—	1.000
0.25%	2.00	4.50	10.61	+4.9	+13.4	+22.1	1.007
0.5%	2.53	5.82	12.00	+28.2	+35.5	+38.1	1.013
0.75%	2.04	4.00	10.05	+2.2	+22.7	+15.7	1.017
1.0%	1.88	3.24	9.00	−28.7	+6.6	+3.6	1.019
1.25%	1.51	2.64	7.98	−44.7	−15.8	−8.2	1.025

D. Modulus of elasticity

Fig. 6 shows the load–strain curves of the six mixes. The slope of the stress–strain line, found by linear regression of the report's data (R^2 of 0.976–0.995), is almost the same for all mixes. Relative to plain SCC it is 1.007, 1.013, 1.017, 1.019 and 1.025 for 0.25–1.25% glass fibre (Table V). The stiffness is therefore only up to 2.5% higher with fibre, which is within the scatter of dial-gauge readings, and the elastic modulus should be called comparable to that of plain SCC rather than superior. This agrees with Persson [2], who found no drastic difference in the modulus of SCC and NC.

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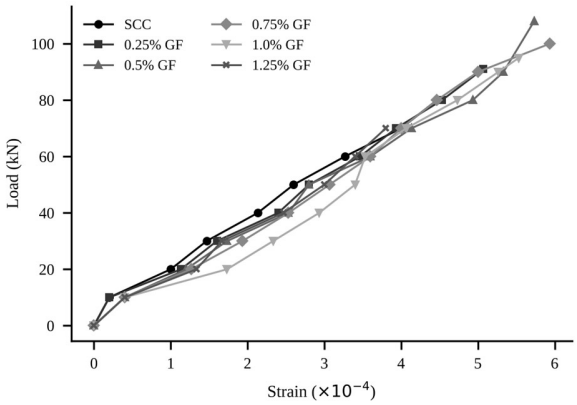


Fig. 6. Load–strain curves in the modulus test.

E. Limitations

The flexural strengths of 7.98–12.00 N/mm² are two to four times the value of about 3.1 N/mm² given by 0.7√fck for M20 concrete in IS 456 [11], and the 28-day values are 2.8 times the 7-day values. These results should be checked against the span, loading arrangement and test records. The absolute elastic modulus is not reported because the area of 70,650 mm² used in the report's stress column is four times the cross-section of a 150 mm cylinder, and the slopes it gives (about 2.4 kN/mm²) are far below the usual values for concrete. Only the relative stiffness is therefore reported. The specific gravity of the cement (2.53) is also lower than the usual value for OPC and should be re-checked. A single grade (M20) and one fibre type were tested, durability was not studied, and the fibre details are to be added.

VII. Conclusion

Glass fibre at 0–1.25% was added to M20 SCC designed by IS 10262:2009. Workability falls steadily with fibre content: the slump flow drops from 650 to 520 mm and the T50cm time rises from 6.82 to 14 s, while the V-funnel and L-box results stay within limits. At 28 days the 0.5% mix gave the highest compressive (38.29 N/mm², +28.2%), split tensile (4.54 N/mm², +35.5%) and flexural (12.00 N/mm², +38.1%) strengths. Above 0.75% the compressive strength falls, and at 1.0% and 1.25% it is below that of plain SCC. The stiffness is comparable for all mixes, within 2.5%. The optimum glass fibre content is therefore 0.5%. Future work should include a re-test of the flexural strength, the true elastic modulus on standard cylinders, other fibre lengths and aspect ratios, a mix with a higher super-plasticizer dose to restore workability at high fibre content, and durability tests.

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