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Performance of self compacted concrete under shear and torsion with fly ash and steel fibers

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ABSTRACT

The purpose of this research is to investigate the use of varied steel fibres with different aspect ratio in structural concrete to enhance the mechanical properties of self compacted concrete(SCC). The objective of the study is to determine and do the comparative study of the properties of concrete containing no fibres and concrete with fibres, as well as the comparison on the effects of different type and aspect ratio of fibres to the self compacted concrete. This investigation was carried out using several tests, which included workability tests of SCC, shear test, torsion test, moment etc

Introduction

Concrete is characterized by brittle failure, the nearly complete loss of loading capacity, once failure is initiated. This characteristic, which limits the application of the material, can be overcome by the inclusion of a small amount of short randomly distributed steel fibers and can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc. Steel fiber reinforced concrete （SFRC） has the ability of excellent tensile strength, flexural strength, shock resistance, fatigue resistance, ductility and crack arrest. In the hardened state, when fibers are properly bonded, they interact with the matrix at the level of micro-cracks and effectively bridge these cracks thereby providing stress transfer media that delays their coalescence and unstable growth. If the fiber volume fraction is sufficient, this may result in an increase in the tensile strength of the matrix.

Experimental confirmation has demonstrated that the mechanical properties of concrete improved by the presence of fibres in the matrix are such that in beams subjected to torsion the traditional steel reinforcement, i.e. longitudinal bars and stirrups are strictly necessary. The presence of fibres augments the torsion strength and ductility with respect to plain concrete, producing a crack pattern similar to the one observed in member reinforced with bars. However, the behavior of FRC beam under torsion shows marked differences if compared to the corresponding behavior of traditional reinforced concrete counterparts. The members of a reinforced concrete structures are subjected to shear forces, axial forces, bending moments and torsional moments. Many researchers carried out tests on reinforced concrete beams under bending-shear-torsion, bending-torsion and shear torsion and proposed modes of failure, empirical formulae and interaction curves. The investigations made in the field of the analysis of behaviour of SFRC rectangular beams in combined loading, available in the literature are fewer as compared with that in the field of pure torsion. In the present investigation Self compacted reinforced concrete beams with steel fibres were tested under combined torsion-bending-shear to correlate the test results.

Methodology

The present research work is experimental and requires preliminary investigations in a methodological manner.

A. Cement

The cement used in this experimental work is “Ultratech 53 grade Ordinary Portland Cement”. All properties of cement are tested by referring IS 12269 - 1987 Specification for 53 Grade Ordinary Portland cement. The specific gravity of the cement is 3.15. The initial and final setting times were found as 74minutes and 385 minutes respectively. Standard consistency of cement was 30%.

B. Fine aggregate

Locally available sand of Pravra river passed through 4.75mm IS sieve is used. The specific gravity of 2.75 and fineness modulus of 2.806 are used as fine aggregate. The loose and compacted bulk density values of sand are 1600 and 1688 kg/m3 respectively, the water absorption of 1.1%.

C. Coarse aggregate

Crushed granite aggregate available from local sources has been used. The coarse aggregates with a maximum size of 12mm having the specific gravity value of 2.70 and fineness modulus of 6.013 are used as coarse aggregate. The loose and compacted bulk density values of coarse aggregates are 1437 and 1526 kg/m3 respectively, the water absorption of 0.4%.

D. Fly ash

Fly Ash (FLA) is available in dry powder form and is procured from Dirk India Pvt. Ltd., Nasik. The light gray, fly ash under the product name “Pozzocrete 60” is available in 30kg bags. There are no standard performance tests and procedures specified for assessing the suitability of MAs to FAC. The Fly

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ash produced by the company satisfies all the requirements of the IS 3812: 1981, BS 3892: Part I: 1997.

E. Chemical admixtures

A polycarboxylic type superplasticizer (SP) is used in all concrete mixtures. In addition to the SP, a viscosity modifying admixture (VMA) is also used. The properties of both admixtures, as provided by their manufacturers, are shown in Table I.

Table I: Properties of chemical admixture

Chemical admixture	Dosage	Main component
SP	1%	Polycarboxylic ether
VMA	0.5%	Aqueous dispersion of microscopic silica

F. Fibres

The main variables used in the study are three different types of steel fibres i.e. hook ended steel fibre (HK), crimped type steel fibre(CR), straight type steel fibre(SF) with two values of aspect ratios (80 and 50). 2.5 % constant dosages of fibres are used by weight of cement.

G. Mixture proportion

Cement: Fly Ash : Sand : C.A. : Water

1 : 0.3 :1.814 : 1.48 : 0.408

H. Testing on Fresh Concrete

Test conducted for verifying the flow characteristics of fresh concrete are

1. Slump flow
2. V-Funnel
3. L Box
4. U Box.
5. J Ring

Deformability and viscosity of fresh concrete is evaluated through the measurement of slump flow time and diameter, J-Ring test, L-Box ratio test, U-Box test and V-funnel flow time. The slump flow is used to assess the horizontal free flow (deformability) of SCC in the absence of obstructions. The procedure for the slump flow test and the commonly used slump test are almost identical. In the slump test, the change in height between the cone and the spread concrete is

measured, whereas in the slump flow test the diameter of the spread is determined as the slump flow diameter (D). According to Specification and Guidelines for SCC prepared by EFNARC (European Federation of National Trade Associations), a slump flow diameter ranging from 650 to 800 mm can be accepted for SCC. In the slump flow test ability of concrete to flow and its segregation resistance can also be measured. To measure these properties, the time it takes for the concrete to reach a 50-cm spread circle and any segregation border between the aggregates and mortar around the edge of spread are recorded. EFNARC suggests a slump flow time (t50cm) of 2-5s for a satisfactory SCC. In addition to the slump flow test, J-Ring test, L-Box test, U-Box test and V-funnel test, are also performed to assess the flow ability, passing ability and stability of the SCC. The L-box ratio is in the range of 0.80-1.0, the J-ring test values are in the range of 0-10mm. The V-funnel is filled completely with concrete and the bottom outlet is opened, allowing the concrete to flow. The V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top. Good flow able and stable concrete would consume short time to flow out. According to EFNARC, time ranging from 6 to 12 sec is considered adequate for a SCC.

The experimental investigation consisted of casting and testing steel fibre reinforced self compacted concrete beams under combined effect of shear and torsional loading. The size of each beam is 100 mm x 150 mm x 1000 mm. The volume fraction of the fibre content is constant of 2.5 % weight of cement. The proportioning of concrete is maintained constant throughout the investigation. A concrete mix targeting a compressive strength of 30 MPa is used.

The cured beams are white washed a day before testing to facilitate the crack identification. One end of the beam is supported on rollers, while the other end is supported on rigid support. This type of test setup Facilitates free rotation of roller end and provides stability to the test specimen during testing. Specially made twist arms or twist angles are placed at both supports of the beam having an arm length of 0.60 m. Load on the twist arm is applied through a hydraulic jack and the loading is monitored through a proving ring attached to the jack. Absolute care has taken, such that, the plane of loading and twisting arm are perpendicular to the longitudinal axis of the beam. This avoids any possibility of bending of the beam instead of twisting and as a result the beam between the two supports is subjected to pure torsion. The complete test setup is schematically presented in Fig 1. It shows the actual test set up in 3D view. Load is applied at an eccentricity of 0.66 m from the center of the beam. For every applied load, the corresponding dial gauge readings are noted. Which were placed at L/3 distance from both end and considering average of two readings. For 10 divisions of proving ring that is 0.01 readings the multiplying factor is 73.69 Kg and Weight of jack is 41.58 Kg. Hence the shear strength, experimental moment and torsional moment of beam are calculated by the following formulas,

Shear force in kN = (Proving ring reading ×73.69+41.58) ÷100 [1]

Experimental moment= liver arm of triangle × shear force [2]

Torque (T) = GϴJ/L [3]

Where,

G = Modulus of rigidity in N/mm^2

ϴ = Angle of twist in radian

J = Polar moment of inertia in mm^4

L = Span of beam in mm

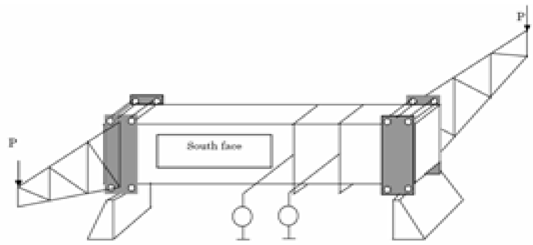

Fig.1: 3D- View of Test Setup

Result and Discussions

The very first step to satisfy flow requirement of SCC is to determine the optimum dose of superplastisizer.

A. Trials for Optimum Dose of Superplastisizer:

Table II: Trials for Optimum Dose of Superplastisizer

Dose of Super plastisizer	Slump Cone Test		V Funnel Test
	Horizontal Slump (mm)	T50 -Time (Sec.)	Flow Time (Sec.)
1%	715	2.5	8.2
2%	790	2.1	7.8
3%	815	1.9	7.3
4%	860	1.7	6.9
5%	890	1.2	6.6

As per guidelines of EFNARC, for slump flow by Abrams cone typical range of value is 650 to 800 mm, for T50 cm slump flow, range is 2 to 5 Sec and for v-funnel, range is 8 to 12 Sec. Hence from above observation the dose of superplastisizer is taken as 1% of volume of cement which satisfies the requirement of flow for SCC.

B. Fresh Concrete Test Results of Self Compacting Concrete:

Table III: Slump Cone Test by Abrams Cone

Sr No	Type of Steel Fibre	Aspect Ratio	Slump Flow by Abrams Cone (mm)	
			Horizontal Slump (mm)	T50 -Time (Sec.)
1.	0	0	715	2.89
2.	HK 80/60	80	660	4.90
3.	HK 50/30	50	690	4.30
4.	SF 80/130	80	670	5.00
5.	SF 50/80	50	700	4.70
6.	CR 50/30	50	705	4.10

Table IV: V-Funnel Test

Sr No	Type of Steel Fibre	Aspect Ratio	V-Funnel Test	
			Flow Time (Sec.)	Flow time at T5min. (Sec.)
1.	0	0	7.2	9.02
2.	HK 80/60	80	12.2	15.56
3.	HK 50/30	50	10.3	12.34
4.	SF 80/130	80	12.59	16.21
5.	SF 50/80	50	11.23	13.39
6.	CR 50/30	50	8.1	10.5

Table V: L-Box Test

Sr No	Type of Steel Fibre	Aspect Ratio	L Box Test		
			T20 Time (Sec)	T40 Time (Sec)	H_2/H_1 Ratio
1.	0	0	0.9	3.1	0.948
2.	HK 80/60	80	2.05	4.6	0.821
3.	HK 50/30	50	1.37	3.47	0.890
4.	SF 80/130	80	1.89	3.92	0.858
5.	SF 50/80	50	1.4	3.72	0.890
6.	CR 50/30	50	1.1	3.26	0.898

Table VI: U Box Test

Sr No	Type of Steel Fibre	Aspect Ratio	U Box Test		
			H_1 (mm)	H_2 (mm)	H_2-H_1 (mm)
1.	0	0	310	300	10
2.	HK 80/60	80	490	463	27
3.	HK 50/30	50	335	322	13
4.	SF 80/130	80	520	490	30
5.	SF 50/80	50	342	316	26
6.	CR 50/30	50	325	313	12

Table VII: J Ring Test

Sr No	Type of Steel Fibre	Aspect Ratio	J Ring Test		
			H_1 (mm)	H_2 (mm)	H_1-H_2 (mm)
1.	0	0	10	8	2
2.	HK 80/60	80	13	6	7
3.	HK 50/30	50	10	7	3
4.	SF 80/130	80	12	6	6
5.	SF 50/80	50	11	7	4
6.	CR 50/30	50	10	6	4

From the results of above mentioned tests carried out for the flow of fibre concrete, it shows that the SF 80/130 (aspect ratio=80) do not satisfy the requirement of V-funnel test. Also, all types of mixtures do not satisfy the requirement of V-funnel test at T5 min.

C. Test Results for Shear and Torsion Test:

Table VIII: Shear Strength on Beam of SCC at the End of 28 Days

Sr. No.	Type of Fibre	Deflection at Crack (mm)	Shear Force (kN)	Avg. Shear Force (kN)
1.	0%	35	3.73	3.56
		35	3.51	
		30	3.43	
2.	HK 80	55	7.19	7.29
		60	7.42	
		55	7.27	
3.	HK 50	50	6.31	6.18
		50	6.31	
		45	5.94	
4.	SF 80	40	5.21	5.57
		45	5.57	
		50	5.94	
5.	SF 50	35	4.10	4.47
		40	4.46	
		40	4.84	
6.	CF 50	40	4.84	5.20
		40	5.21	
		40	5.57	

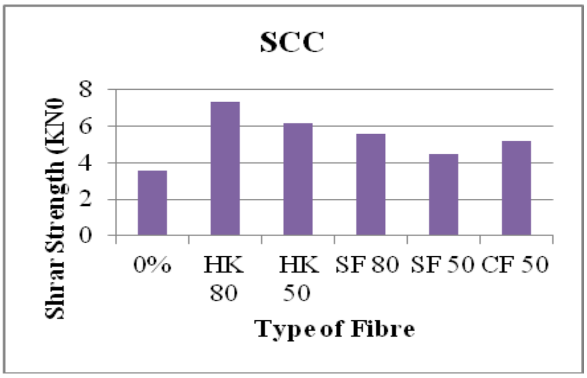

Fig. 2: Chart of Shear Strength at the End of 28 Days

It can be seen from Fig. 2, for SCC; shear strength of HK 80 is higher than all types of fibre. For SCC, maximum percentage increase in strength is 51.56%.

Table IX: Moment Calculation for SCC at the End of 28 Days

Sr No	Type of Fibre	Deflection at Crack (mm)	Moment (kNm)	Avg. Moment (kNm)
1.	0%	35	2.46	2.35
		35	2.32	
		30	2.26	
2.	HK 80	55	4.75	4.82
		60	4.90	
		55	4.80	
3.	HK 50	50	4.16	4.08
		50	4.16	
		45	3.92	
4.	SF 80	40	3.44	3.68
		45	3.68	
		50	3.92	
5.	SF 50	35	2.71	2.95
		40	2.94	
		40	3.19	
6.	CF 50	40	3.19	3.44
		40	3.44	
		40	3.68	

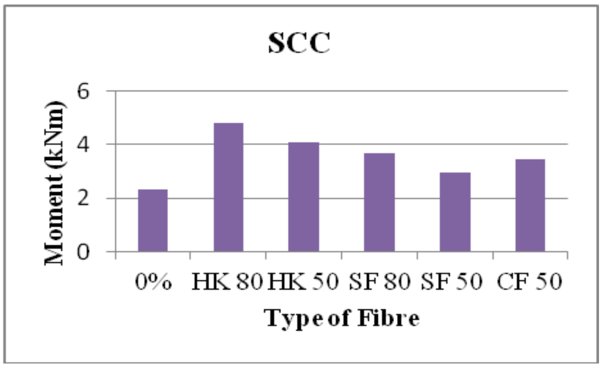

Fig. 3: Chart of Moment at the End of 28 Days

From Fig. 3, it is observed that the moment of SFRFC beam is greater for HK 80 beam for SCC. The higher moment is due to reason that the steel fibres resisting the load. From the observations and graphs it is seen that the steel fiber beam having maximum moment compare to beam without fibre. Average increasing in moment for SCC beam is 51.24%.

Table X: Torsion Strength on beam of SCC at the End of 28 Days

Sr No	Type of Fibre	Deflection at Crack (mm)	Torque (kNm)	Avg. Torque (kNm)
1.	0%	35	21.53	20.50
		35	21.53	
		30	18.44	
2.	HK 80	55	33.72	34.76
		60	36.85	
		55	33.72	
3.	HK 50	50	30.71	29.68
		50	30.71	
		45	27.63	
4.	SF 80	40	24.58	27.62
		45	27.58	
		50	30.71	
5.	SF 50	35	21.53	23.56
		40	24.58	
		40	24.58	
6.	CF 50	40	24.58	24.58
		40	24.58	
		40	24.58	

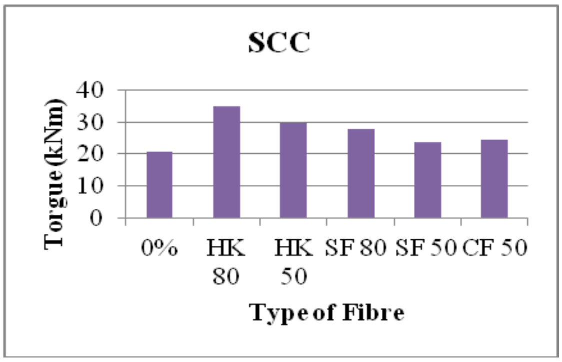

Fig. 4: Chart of Torque at the End of 28 Days

From Fig. 4, for SCC, the results are obvious that the torsional moment of fibre concrete is higher than the concrete without fibre. In this case also HK 80 fibre giving higher strength as compare to the strength of concrete mix with other type of fibres. Average increasing in torsional moment for SCC beam is 41.02%.

Conclusion

The present investigation has shown that it is possible to design a steel fibre reinforced self-compacting concrete incorporating fly ash. The SFRSCCs have a slump flow in the range of 660-715 mm, a flow time ranging from 2.89 to 5 sec, V-funnel flow in the ranging from 7.2 to 12.59 sec and 9.02 to 16.21 sec at $T_{5minutes,}$ a L-Box ratio ranging from 0.821 to 0.948, U-Box test value ranging from 10 to 30 mm and a J-Ring test value ranging from 2 to 7 mm. It was observed that it is possible to achieve self compaction with different types of steel fibre with different aspect ratio.

Although results obtained from all of the mixes satisfy the lower and upper limits suggested by EFNARC (The European Federation of Specialist Construction Chemicals and Concrete Systems), all mixes had good flow ability and possessed self-compaction characteristics.

The SCC developed shear strengths ranging from 3.56 to 7.29 kN at the end of 28 days.

The SCC developed moment strengths ranging from 2.35 to 4.82 kNm at the end of 28 days.

The SCC developed torsional strengths ranging from 20.50 to 34.76 kNm at the end of 28 days.

Also it is observed that for same aspect ratio the hook ended fibre showing pronounce improvement in all properties of concrete as compare crimped & straight fibre. There is decrease in the strength with decrease in aspect ratio of same fibre type. The straight fibres having less strength as compared with hook end and crimped fibres because of their shape. Due to the shape, it is obvious that the hook end and crimped fibre having good bond and anchorage in the matrix resulting in more strength.

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