A Study on Mechanical Properties and Fracture Behaviour of Chopped Fibre Reinforced Self Compacting Concrete

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Abstract— **The growth of Self Compacting Concrete is revolutionary landmark in the history of construction industry resulting in predominant usage of SCC worldwide nowadays. It has many advantages over normal concrete in terms of enhancement in productivity, reduction in labor and overall cost, excellent finished product with excellent mechanical response and durability. Incorporation of fibers further enhances its properties specially related to post crack behavior of SCC. Hence the aim of the present work is to make a comparative study of mechanical properties of self-consolidating concrete, reinforced with different types of fibers. The variables involve in the study are type and different percentage of fibers. The basic properties of fresh SCC and mechanical properties, toughness, fracture energy and sorptivity were studied. Microstructure study of various mixes is done through scanning electron microscope to study the hydrated structure and bond development between fiber and mix. The fibers used in the study are 12 mm long chopped glass fiber, carbon fiber and basalt fiber. The volume fraction of fiber taken are 0.0%, 0.1%, 0.15%, 0.2%, 0.25% ,0.3%. The project comprised of two stages. First stage consisted of development of SCC mix design of M30 grade and in the second stage, different fibers like Glass, basalt and carbon Fibers are added to the SCC mixes and their fresh and hardened properties were determined and compared. The study showed remarkable improvements in all properties of self-compacting concrete by adding fibers of different types and volume fractions. Carbon FRSCC exhibited best performance followed by basalt FRSCC and glass FRSCC in hardened state whereas poorest in fresh state owing to its high water absorption. Glass FRSCC exhibited best performance in fresh state. The present study concludes that in terms of overall performances, optimum dosage and cost Basalt Fiber is the best option in improving overall quality of self-compacting concrete**.

.*Keywords*— **SCC mixes , Different test, different fibre .**

I. Introduction

Self-compacting concrete was originally developed in Japan and Europe. It is a concrete that is able to flow and fill every part of the corner of the formwork, even in the presence of dense reinforcement, purely by means of own weight and without the need of for any vibration or other type of compaction. The growth of Self Compacting Concrete by Prof. H.Okamura in 1986 has caused a significant impact on the construction industry by overcoming some of the difficulties related to freshly prepared concrete. The SCC in fresh form reports numerous difficulties related to the skill of workers, density of reinforcement, type and configuration of a structural section, pump-ability, segregation resistance and, mostly compaction. The Self Consolidating Concrete, which is rich in fines content, is shown to be more lasting. First, it started in Japan; numbers of research were listed on the global development of SCC and its micro-social system and strength aspects. Though, the Bureau of Indian Standards (BIS) has not taken out a standard mix method while number of construction systems and researchers carried out a widespread research to find proper mix design trials and self-compact ability testing approaches. The work of Self Compacting Concrete is like to that of conventional concrete, comprising, binder, fine aggregate and coarse aggregates, water, fines and admixtures. To adjust the rheological properties of SCC from conventional concrete which is a remarkable difference, SCC should have more fines content, super plasticizers with viscosity modifying agents to some extent. As compared to conventional concrete the benefits of SCC comprising more strength like non SCC, may be higher due to better compaction, similar tensile strength like non SCC, modulus of elasticity may be slightly lower because of higher paste, slightly higher creep due to paste, shrinkage as normal concrete, better bond strength, fire resistance similar as non SCC, durability better for better surface concrete.

II. Experimental Investigation On Self-Compacting Concrete

In this study, the mechanical behavior of fiber reinforced self-compacting concrete of m30 grade prepared with basalt fiber, glass fiber and carbon fiber were studied. For each mix six numbers of cubes (150×150×150) mm, three numbers of cylinders (150×300) mm and six numbers prisms (100×100×500) mm were cast and investigations were conducted to study the mechanical behavior, fracture energy behavior, microstructure of plain scc, basalt fiber reinforced scc (bfc), glass fiber reinforced scc (gfc), carbon fiber reinforced scc (cfc). The observational plan was held up in various steps to accomplish the following aims:

1. To prepare plain SCC of m30 grade and obtain its fresh and hardened properties.
2. To prepare basalt, glass & carbon fiber reinforced SCC of m30 grades and study their fresh and hardened properties.
3. To analyze the load-deflection behaviour of SCC, BFRSCC, GFRSCC & CFRSCC.

Table 1 Results of the Fresh Properties of Mixes

sample	Slump flow	T_{50} flow	L-Box(H_2/H_1)	V-Funnel	T5 Flow	Remarks
	500-750mm	2-5sec	0.8-1.0	6-12sec	+3sec	
PSC	720	1.6	0.96	5	9	Low viscosity (Result Satisfied)
BFC-1	680	2.1	0.89	8	12	Result Satisfied
BFC-1.5	645	2.5	0.85	8	13	Result Satisfied
BFC-2	620	3.8	0.81	9	14	Result Satisfied
BFC-2.5	580	5.2	0.68	10	16	High viscosity Blockage (RNS)
BFC-3	520	6	0.59	11	18	Too high viscosity Blockage (RNS)
GFC-1	705	2	0.9	7	10	Result Satisfied
GFC-1.5	665	3.8	0.88	7.7	11	Result Satisfied
GFC-2	650	4.7	0.84	8.5	12	Result Satisfied
GFC-2.5	640	5	0.82	9	12	Result Satisfied
GFC-3	530	5.9	0.7	11	15	Too high viscosity Block
CFC-1	560	4.8	0.8	10	14	Result Satisfied
CFC-1.5	410	–	–	18	–	Too high viscosity Blockage
CFC-2	260	–	–	23	–	Too high viscosity Blockage (RNS)

4.3 Hardened Properties

To compare the various mechanical properties of the FRSCC mixes the standard specimens were tested after 7 days and 28 day of curing. The results are summarized in Table 4.3.1

Table- 2 Hardened Concrete Properties of SCC and FRSCC

Mixes	7-Day compressive strength (MPa)	28-days compressive strength (MPa)	28-days split tensile	28-days flexural
PSC	33.185	40.89	4.1	7.37
BFC-1	31.11	38.67	3.11	7.84
BFC-1.5	34.22	49.77	4.95	11.4
BFC-2	37.77	50.99	5.517	11.78
BFC-2.5	45.48	61.4	4.52	11.92
BFC-3	20.89	32.89	4.24	7.54
GFC-1	24.88	40.89	2.97	7.44
GFC-1.5	33.77	46.19	4.81	9.74
GFC-2	32.89	47.11	4.95	10.08
GFC-2.5	31.55	45.33	3.96	9.46
GFC-3	23.55	39.11	3.678	8.32
CFC-1	24.44	42.22	3.82	7.52
CFC-1.5	43.11	62.22	5.23	12.32
CFC-2	40.89	55.2	4.52	10.54

Ultrasonic Pulse Velocity

The UPV meter acts on principle of wave propagation hence higher the density and soundness, higher the velocity of wave in it.

Table 3 Ultrasonic Pulse Velocity Results

Speci men	7-Days Avg. Upv Of Cube (M/Sec)	28-Days Avg. Upv Of Cube (M/Sec)
PSC	477.6	416.34
BFC-1	275.43	337
BFC-1.5	492	493.67
BFC-2	498.67	505.33
BFC-2.5	537.67	582.33
BFC-3	151.34	298.33
FC-1	299.34	399
GFC-1.5	486.67	473
GFC-2	454	483.67
GFC-2.5	296.67	469.33
GFC-3	153	374
CFC-1	296.67	434.34
CFC-1.5	518.6	629.66
CFC-2	508.34	574.67

Loads-Displacement Behavior And Toughness Index

The load deflection (vertical) diagrams obtained from electronic UTM clearly proved thataddition of fibers to SCC increase ductility whereas control beam PSC exhibited brittle behavior. The maximum increment was observed from carbon fiber than the basalt and the lowest from the glass fiber. In each series the mix which gave maximum compressive strength rendered maximum ductility. The area below the load deflection curve represents toughness. Almost same pattern of behavior were observed from all mixes.

Table 4 Load - Displacement Result

Specimen	Ultimate load(KN)
PSC	12.8
BFC-1	15.54
BFC-1.5	20.69
BFC-2	22.42
BFC-2.5	22.54
BFC-3	15.81
GFC-1	15.65
GFC-1.5	19.58
GFC-2	19.62
GFC-2.5	17.9
GFC-3	17.59
CFC-1	15.95
CFC-1.5	23.33
CFC-2	19.98

LOAD-CMOD BEHAVIOUR

The load vs. crack mouth opening deflection diagrams obtained clearly proved that addition of fibers to SCC increase ductility whereas control beam PSC exhibited brittle behavior. The maximum increment was observed from carbon fiber than the basalt and the lowest from the glass fiber. In each series the mix which gave maximum compressive strength rendered maximum ductility.

The area below the load deflection curve represents toughness. Almost same pattern of behavior were observed from all mixes.

The observations made during the tests (LOAD-CMOD) were used to draw the LOAD-CMOD curves. The ultimate load and the fracture parameters were determined.

Table 5 LOAD-CMOD RESULT FOR GFC

LOAD(KN)	CMOD(MM)					
	PSC	GFC-1	GFC-1.5	GFC-2	GFC-2.5	GFC-3
0	0	0	0	0	0	0
0.75	0	0	0.001	0	0	0
1	0	0	0.002	0	0	0
2	0.01	0.004	0.006	0	0	0
3	0.08	0.006	0.008	0	0.02	0
4	0.26	0.009	0.024	0	0.05	0.04
4.25	0.28	0.01	0.033	0	0.06	0.05
5		0.16	0.05	0	0.08	0.09
5.5		0.2	0.11	0	0.09	0.13
6		0.41	0.18	0	0.13	0.16
6.5			0.25	0.01	0.17	0.18
6.75			0.3	0.03	0.18	0.19

7				0.03	0.21	0.22
8				0.06	0.32	0.35
9				0.13	0.46	0.51
9.5				0.18	0.5	
10				0.22		
10.25				0.27		

Table 6 LOAD-CMOD RESULT FOR BFC

LOAD(KN)	CMOD(MM)					
	PSC	BFC-1	BFC-1.5	BFC-2	BFC-2.5	BFC-3
0	0	0	0	0	0	0
2	0.01	0	0.004	0	0	0
3.25	0.1	0.01	0.009	0	0	0
4	0.26	0.05	0.019	0.01	0	0.02
4.25	0.28	0.06	0.023	0.015	0	0.05
6		0.1	0.053	0.06	0.08	0.13
6.25		0.3	0.059	0.09	0.1	0.16
6.5		0.36	0.065	0.15	0.12	0.19
6.75			0.08	0.18	0.14	0.36
7			0.1	0.21	0.17	
7.75			0.33	0.28	0.23	
8					0.26	
9.75					0.36	
10.5					0.43	
10.75					0.45	

Table 7 LOAD-CMOD RESULT FOR CFC

LOAD(KN)	CMOD(MM)			
	PSC	CFC-1	CFC-1.5	CFC-2
0	0	0	0	0
2	0.01	0	0	0
3	0.08	0	0	0
4	0.26	0.01	0	0
4.25	0.28	0.02	0	0
4.75		0.05	0	0.02
5		0.07	0	0.02
6		0.13	0	0.07
6.5		0.18	0.01	0.08
7		0.2	0.03	0.13
8		0.25	0.06	0.21
9			0.12	0.3
9.5			0.15	0.35
10			0.21	
11			0.3	
11.75			0.34	

SORPTIVITY

Sorptivity is a measure of the capillary force exerted by the pore structure causing fluids to be drawn into the body of the material. It is calculated as the rate of capillary rise in a concrete prism placed in 2 to 5 mm deep water. For one-dimensional flow, the relation between absorption and sorptivity is given by, k = where, ¯ is the cumulative water absorption per unit area of inflow surface, k is the sorptivity and t is the elapsed time. The test was conducted in the laboratory.at selected intervals of 30min, 1hr, 2hr, 6hr, 24hr and 48hr; the sample was removed and was weighed after blotting off excess water. The gain in mass per unit area over the density of water (gain in mass/unit area/density of water) versus the square root of time was plotted. The slope of the best fitting line was reported as the sorptivity

Table 8 Capillary Water Absorption Test Results

Sample	Initial	Weight(gm.)					
	Wt.(gm.)	30min	1hr	2hr	6hr	24hr	48hr
GFC	7499	7509	7510	7512	7514	7519	7521
BFC	7471	7483	7486	7488	7490	7496	7500
CFC	7604	7618	7620	7623	7626	7632	7640

CONCLUSION

From the present study the following conclusions can be drawn

1. Addition of fibers to self-compacting concrete causes loss of basic characteristics of SCC measured in terms of slump flow, etc.]
2. Reduction in slump flow was observed maximum with carbon fiber, then basalt and glass fiber respectively. This is because carbon fibers absorbed more water than others and glass absorbed less.
3. Carbon fiber addition more than 2% made mix harsh which did not satisfy the aspects like slump value, T50 test etc. required for self-compacting concrete.
4. Addition of fibers to self-compacting concrete improve mechanical properties like compressive strength ,split tensile strength, flexural strength etc. of the mix.
5. There was an optimum percentage of each type of fiber, provided maximum improvement in mechanical properties of SCC.
6. Mix having 0.15% carbon fiber, 0.2% of glass fiber and 0.25% of basalt fiber were observed to increase the mechanical properties to maximum.
7. 0.15% addition of carbon fiber to SCC was observed to increase the 7-days compressive strength by 29.9%, 28-days compressive strength by 47.6%, split tensile strength by 27.56%, flexural strength by 67.16%.
8. 0.25% addition of basalt fiber to SCC was observed to increase the 7-days compressive strength by 37.05%, 28-days compressive strength by 50.16%, split tensile strength by 34.56%, flexural strength by 61.736% 2% addition of glass fiber to SCC was observed to increase the 7-days compressive strength by 1.76%, 28-days compressive strength by 15.21%, split tensile strength by 20.73%, flexural strength by 36.77%.
9. The FRSCC mixes exhibited increase in ductility measured through load deflection diagrams. The basalt fiber reinforced SCC exhibited maximum increment than carbon and glass FRSCC.
10. The load vs. crack mouth opening displacement diagrams for FRSCC exhibited increase in fracture energy properties of the mixes. This is owing to crack arresting mechanism of the fibers in the matrix. In this regard the carbon fiber exhibited best performance, then the basalt and then glass fiber.
11. Correlation graph between compressive strength and avg. UPV values for 28 days indicated good correlation for carbon FRSCC (R^2= 1), basalt FRSCC (R^2 =0.9845) and glass FRSCC (R^2 =0.9748). These values represent sound concrete having uniform distribution of fibers and concrete ingredients, dense structure in all FRSCC mixes.
12. The SEM analysis of microstructure of FRSCC exhibited good physical bond between all types of fiber and the hydrated matrix. A dense structure of matrix was observed in each mixes owing to addition of silica fume. No apparent variation was observed between mix of 7days and 28 days.
13. Capillary absorption of water by FRSCC mixes were determined by sorptivity test. The higher sorptivity coefficient was observed for carbon FRSCC mixes because carbon fibers absorbed more water. Least values were observed by basalt FRSCC.
14. The performance of carbon fiber reinforced SCC mixes was better than basalt FRSCC and glass FRSCC mixes. Then carbon fiber FRSCC exhibited best mechanical properties with comparatively lower volume fraction but its effect on SCC fresh properties was just reverse. Itsinclusion reduced flow-ability, deformability because it absorbs more water. Other drawback is that it is costliest than other two types of fibers.
15. Glass FRSCC exhibited improvement in all mechanical properties especially in early ages, with higher volume fraction. It showed better performances in fresh state. Apart from being cheapest its performance in fresh state but displayed minimum strength, highest sorptivities. The microscopic study (SEM) exhibited better bond development than other two types in early days.
16. 17. Basalt FRSCC exhibited better properties in fresh state and hardened state compared to the Glass FRSCC. In terms of the cost it is cheaper than carbon hence basalt fiber performance is overall best compared with glass and carbon fiber.

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