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Mechanical and Durability Properties of Self-Compacting Concrete Reinforced With Carbon Fibers

Arvind Kumar Cholker, Manzoor Ahmad Tantray

Abstract**:** ***From past few years, researchers are working on conventional concrete reinforcing with carbon nano fibers and nano tubes to study its electrical behaviour. Reinforcing carbon fibers in conventional concrete makes concrete self-sensing that concrete can be used for health monitoring of structures, traffic monitoring, etc. Therefore the present study is performed on mechanical and durability properties of SCC concrete reinforced with carbon fibers. SCC mix used in present study is reinforced with carbon fibers from 0.5% to 2.5% by weight of cement. Different tests, namely slump flow, V-funnel, L-box and U-box test were conducted to check the rheological properties of freshly mixed SCC. Results obtained for all the mixes were within prescribed limits by EFNARC. The durability and mechanical properties of hardened concrete were studied to check different strengths. In mechanical properties, compressive strength was observed to increase when fiber dosage was up to 1% by weight of cement and later decreases as the dosage of fibers was increased from 1.5% to 2.5% by weight of cement. Split tensile strength, flexural strength was observed to be increasing for increasing dosage of carbon fibers. The durability of concrete also increased as fiber dosage.***

Index Terms**:** ***Self compacting concrete, Carbon fibers, Rheological properties, Mechanical properties.***

I. INTRODUCTION

In order to reduce the time of construction of concrete structures, minimize labour, cast the concrete with complicated shape and congested reinforcement, a new type of concrete has been used from the past three decades. This concrete is called as self compacting concrete (SCC) and can be defined as concrete which can flow in between the bars due to its self weight and flow ability filling all gaps within formwork [1].Use of SCC shortens the time of construction therefore reducing cost, which is very important for any construction from an economic point of view. Due to its special fresh properties like flowability under its own weight, resistance to segregation, filling and passing ability, it is extensively used in almost all parts of a building e.g. complicated and congested parts like beam-column joint, construction of the shear wall, high rise buildings where placement, compaction of concrete and use of vibrators is very difficult because of the presence of heavy reinforcement. In such places SCC reduces the efforts of construction and also the noise pollution caused due to vibration. SCC allows production of concrete which has uniform homogeneity, uniform strength and minimal concrete voids along with good finishing and durability properties without losing its strength. This workability is achieved by different parameters such as the use of super-plasticizers, more fine aggregates than conventional concrete, different mineral admixtures, smaller size of coarse aggregate. Hardened properties of SCC, replaced with fly ash are found to be better than conventional concrete [2–4].

There are many studies which used steel fibers [5-6], glass fibers[7], asbestos fibers for studying properties of concrete, but from past 3 decades nano technology in the form of carbon nano fibers [8-9], single and multi-walled carbon nano tubes [10-11] is being introduced in cement composites for different advantages like improving its properties, health monitoring [10-11], traffic monitoring etc. This is because; carbon fibers have very high strengths, high electrical conductivity, high thermal conductivity and most importantly high tensile strength. Many researchers have studied the responce of cement composites reinforced with carbon fibers and carbon nano tubes in conventional concrete. Therefore, the present study focuses on Self-Compacting Concrete composites, reinforced with carbon fibers, rather than the use of conventional concrete.

The major step in the preparation of cement composites reinforced with carbon fibers is the dispersion of fibers itself in a cement matrix. Many researchers have used different methods like mechanical and chemical techniques for dispersion of carbon fibers in cement. Mechanical methods include the use of ultrasonication and/or shear mixer [12], [13], whereas chemical method includes the use of Surfactants [14-16], use of Cement Admixtures [17-18], Covalent Functionalization [12] and combination of various Chemical Methods [13] followed by mechanical mixing techniques. There are many surfactants namely Sodium Dodecyl Sulfate (SDS), Sodium Dodecylbenzene Sulfonate (SDBS), Triton X-100 (TX10), Sodium Deoxycholate (NaDC), Gum Arabic(GA), Cetyl trimethyl ammonium bromide (CTAB), Polyvinyl pyrrolidone (PVP) etc. which have been used for dispersion of fibers. The main work of the surfactant is to reduce the surface tension of water which in turn improves the dispersion of any nano-material in water along with providing good stability. In the present study, SDBS surfactant has been used for dispersion of carbon fibers as it found to be effective [16]. Dispersion of carbon fibers is primarily done by shear mixer with the use of surfactant followed by mixing these fibers in concrete using superplasticizer admixture.

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***** Correspondence Author
Arvind kumar cholker, Research Scholar, civil engineering department, National Institute Of Technology Srinagar Jammu and kashmir India
Dr. Manzoor Ahmad Tantray, Professor, civil engineering department, National Institute Of Technology Srinagar Jammu and kashmir India.

Present research is aimed to present the results of strength properties and water absorption values by conducting tests on Self-Compacting Concrete reinforced with carbon fibers in different proportions.

II. EXPERIMENTAL PLAN

A. Materials used

Concrete mix was prepared using commercially available Portland cement of 43-grade. Potable water was used with fixed water/cement ratio (w/c) of 0.4 for all sample preparations. A surfactant namely Dedocyl Benzenesulphonic acid sodium salt (SDBS) was also mixed in water for effective dispersion of fibers, as it is a good dispersion medium for carbon fibers [16]. CF's type SYC-TR-PU (supplied by Sunyoung Industry, China) as shown in Fig.1 was added with varying percentages in Self-Compacting Concrete. The properties of CF's are shown in Table1. Self-Compacting Concrete (SCC) is prepared in this study for effective dispersion of fibers and to attain good workability of concrete. For the production of SCC, Master GleniumSky 8866 superplasticizer (Supplied by BASF) by 2% by weight of cement was included for all mixes. The fine Aggregate of Zone IV and a coarse aggregate less than 10mm were used with a specific gravity of 2.69 and 2.74 respectively. Submit your manuscript electronically for review.

Table 1. Properties of carbon fiber

Carbon Content	%	95
Electrical Resistivity	w.cm	1.54x10-3
Elongation	%	2.3
Tensile Strength	mpa	4,810
Tensile Modulus	Gpa	225
Density	g/liter	1.78
Filament Diameter	µm	6.97
Length	Mm	6

Fig. 1 Carbon fibers

B. Sample Fabrication

SCC mix proportion was finalized after doing many trials with varying weights of cement, CA and FA as there is no standard mix design procedure available. In the present study, there is no use of fly ash for production of SCC because of the easier availability of cement with uniform quality and quantity in the market when compared to fly ash. Table 2 shows the quantities of different materials used in the production of 1m^3 of SCC without any fibers which is referred to as reference mix. Table 3 shows the specimen designations used for different mixes having varying quantities of carbon fibers and surfactant.

Table 2. Mix proportion of reference SCC

Material	Mass required per m3 (kg)
Cement	495
Water	188
Sand	786
Gravel	851
Plasticizer	8.4

Table 3. SCC Designation and Mix proportions of CF and Surfactant

Specimen designation	CNT dosage % of cement weight	Surfactant dosage % of carbon fibers
SCC 0	0	0
SCC 0.5	0.5	15
SCC 1	1	15
SCC 1.5	1.5	15
SCC 2	2	15
SCC 2.5	2.5	15

150mm Concrete cubes, cylinders of 150mm diameter and 300 mm height and prisms of 500 x 100 x 100 mm were prepared using reinforcing carbon fibers from 0 to 2.5%, with a step increment of 0.5% with respect to the mass of cement whose designations and proportions are shown in Table 3. For preparing samples first the surfactant (SDBS) was mixed with a required amount of water and mechanically stirred for 10 minutes with a shear mixer (speed 8000 R.P.M.) to get foam in water. Later, carbon fibers were added to this mix (foam) and stirred for further 20 minutes with the same mixer for uniform dispersion.

The above-dispersed fibers in water were mixed with dry cement, sand, coarse aggregate and further mixing was done in a concrete mixer till SCC was obtained with the addition of 2% super-plasticizer. The fresh mix was poured into the steel moulds, kept in room temperature (28oC and RH 78%) for 24 hours followed by demoulding and curing in fresh water for 28 days.

C. Tests

Tests on Freshly mixed Concrete to qualify for SCC:

`The fresh mix of SCC prepared was tested to check its rheological properties. As discussed earlier the SCC should have four main characteristics, namely flowability, viscosity, passing ability and smooth surface after de-moulding [6]. Tests described in Table 4 were done on freshly mixed concrete: Complete procedure of testing is explained in EFNARC [19] and ACI 237R [20]codes.

Strength and Durability Test on Hardened concrete: Samples Cured for 7 days, 28 days and 90 days were tested to check mechanical properties along with water absorption test for durability.

III. RESULTS AND DISCUSSION

A. Carbon fibers dispersion in hardened concrete

Scanning Electron Microscopic (SEM) images of all the samples are shown in Fig. 2. SEM images show the dispersion of carbon fibers in hardened concrete. In 0.5% and 1% fiber dosage samples, fibers are hardly seen as shown in Fig.2 b and c. Fig 2 d, e and f show dosage of carbon fibers by 1.5%, 2% and 2.5%, in which fibers are clearly visible and in proportionally increasing quantity.

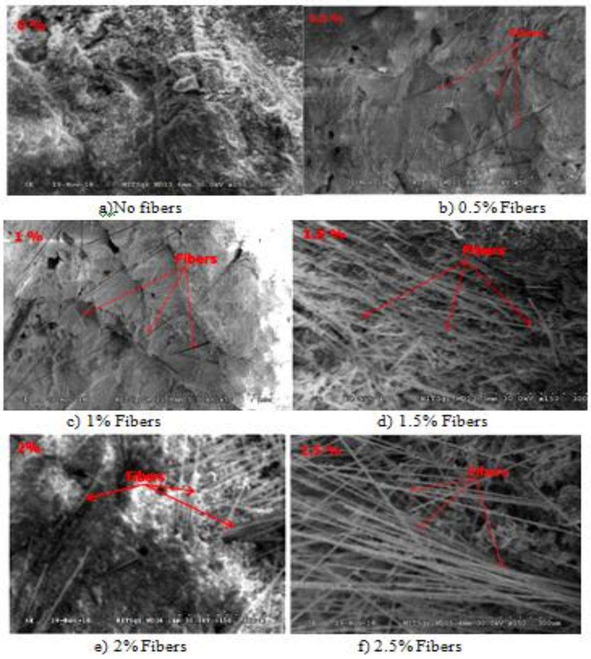

Fig. 2. SEM image of dispersed Carbon fibers in concrete

B. Rheological Properties of fresh concrete

Fresh mix prepared was tested for slump flow to check its flowability. Test results are shown in Table4. From obtained results, it can be seen that the measured diameter of flow is within the prescribed limits of EFNARC for all the mixes. It was observed that as fiber volume increases flow slightly decreases. The required time for flowing concrete for a diameter of 500mm i.e. T500 was also found and is shown in Table 5 and all the results fall within the limits prescribed by EFNARC.

Tables 6 and 7 give test results of L- box test and U-box test. These tests were conducted to check the flowing and passing ability of SCC through reinforcement. Results obtained for all the mixes fall within the prescribed limits of EFNARC. In L-box test results H1 represent horizontal distance on L-box filled with concrete and H2 represents vertical distance on L-box filled with concrete. Similarly, in the U-box test H1 represents distance on right side filled with concrete and H2 represents distance on left side filled with concrete.

V-funnel test was also conducted to check the filling ability and viscosity of freshly prepared SCC. In this test, V-funnel was filled with freshly mixed concrete and SCC was left to fall freely under the force of gravity noting the time for emptying the funnel. All the results obtained were within prescribed limits of EFNARC and are shown in Table 8.

Table 4. Tests and purpose

Sr. No.	Test Name	Purpose
1	Slump flow	To check the flowability of the freshly prepared mix
2	V – funnel	For knowing Viscosity property of fresh SCC
3	L-box and U-box	To check Passing ability and filling of SCC in between the bars

C. Mechanical performance

a. Compressive Strength:

Concrete cube specimens of dimension 150mm, cast with different carbon fibers fraction were tested for compressive strength. Results of compressive strength for 7, 28 and 90 days are shown in Fig. 3. Results indicate, reinforcing carbon fiber with 0.5% and 1% volume fraction (by weight of cement) tend to increase compressive strength by 6.5% and 7.5% when compared to plain SCC. With further increase in fiber volume, strength decreases drastically up to 2.5% as shown in Fig. 4. Addition of fibers beyond 1% by weight of cement reduced the strength by 0.48%, 2.6% and & 7.3% for 1.5%, 2% and 2.5% fiber respectively when tested for 28 days. The same trend was observed in 7 days and 90 days compressive strength. It should be noted that this SCC (without flyash or silica fume) did not show much deviation in strength for 90 days, as in case of SCC when fly ash or silica fume was used in the mix for replacing cement.

Table 5. Slump flow test results

Sr. No.	Mix Designation	Flow Dia(mm) Obtained in 30 seconds	Permissible range as per EFNARC	Time for 500mm Dia(T_{500})	Permissible range for T_{500}as per EFNARC
1	SCC 0	678	600-850	2.8	2-5
2	SCC 0.5	670	600-850	3	2-5

3	SCC 1	665	600-850	3.2	2-5
4	SCC 1.5	650	600-850	3.5	2-5
5	SCC 2	630	600-850	4.1	2-5
6	SCC 2.5	610	600-850	4.6	2-5

Table 6. L Box test results

Sr. No.	Mix Designation	H2/H1	Permissible limits of H2/H1
1	SCC 0	0.89	0.8-1
2	SCC 0.5	0.88	0.8-1
3	SCC 1	0.86	0.8-1
4	SCC 1.5	0.85	0.8-1
5	SCC 2	0.84	0.8-1
6	SCC 2.5	0.82	0.8-1

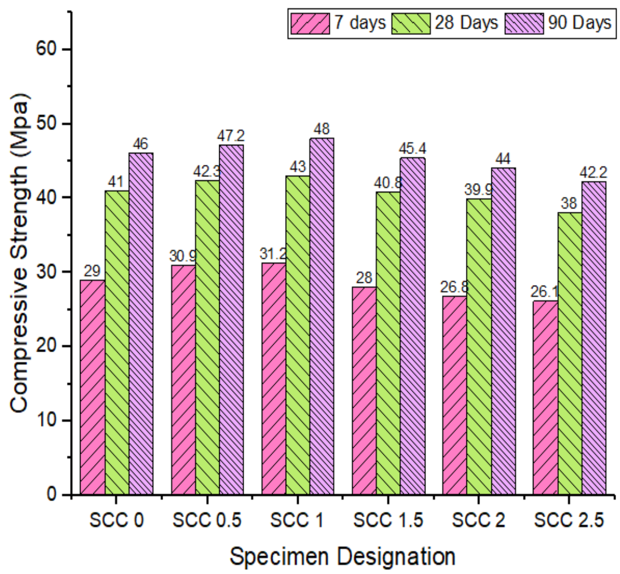

Fig. 3. Compressive strength results for various mixes

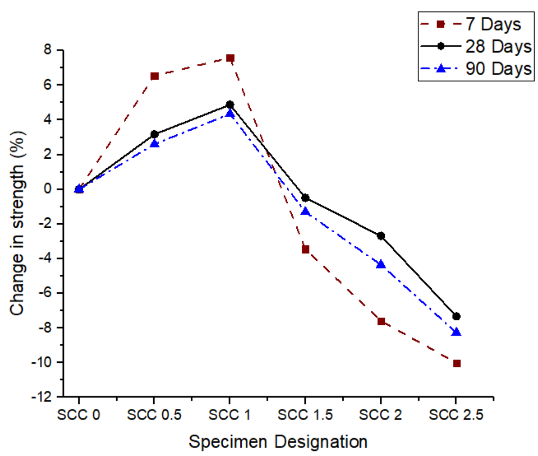

Fig. 4. Percentage Change in compressive strength

b. Split Tensile Strength:

Fig. 5 shows the split tensile strength of concrete cylindrical specimen of dimension 150mm diameter and 300mm length cast with different dosage of carbon fibers. Results showed enhancement in split tensile strength in a good amount as fiber dosage increased. For 0.5% fiber dosage the strength increased by 5%, similarly 12.6%, 22.1%, 28% and 34.2% increase in strength was observed for 1%, 1.5%,2%
and2.5% fiber dosage respectively with respect to SCC without carbon fibers tested for 28 days. Similar behaviour was observed for 7 and 90 days test results. The increase in strength was because of crack bridging due to presence of fibers.

Table 7. U Box test results

Sr. No.	Mix Designation	H2-H1	Permissible limit of H2-H1
1	SCC 0	0	0
2	SCC 0.5	0	0
3	SCC 1	0	0
4	SCC 1.5	0	0
5	SCC 2	0	0
6	SCC 2.5	0	0

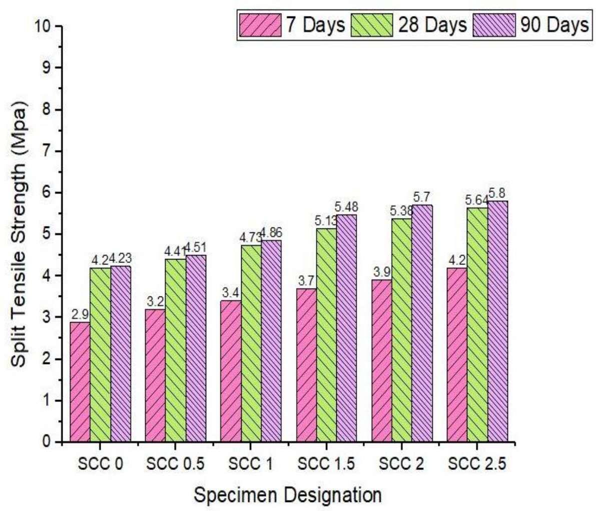

Fig. 5. Split tensile strength results for various mixes

c. Flexural Strength:

Beam samples of standard dimensions 500mmx100mmx100mm were tested under two-point loading to obtain the flexural strength. Fig. 6 shows the results obtained for flexural strength at 28th day. It can be seen from results that as the dosage of fibers increased flexural strength increased. For 0.5%,1%,1.5%,2% and 2.5% fiber dosage the increase in strength was observed as 4.4%, 14.63%, 25.6%, 36.5% and 47.5% respectively compared with no fiber dosage beam sample.

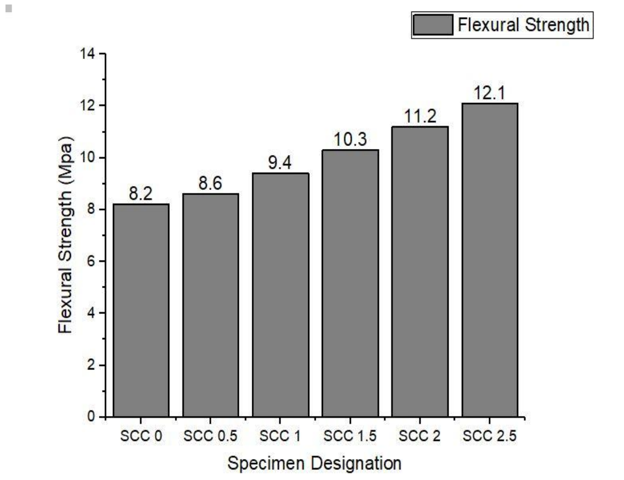

Fig. 6. Flexural strength results for various mixes

D. Durability

a. ***Water Absorption:***

Durability test was conducted on concrete cubes of 150mm dimension. Water absorption test for 28 days was conducted on self-compacting concrete to check its durability. Results of the durability test on samples cast with different dosage of carbon fibers are shown in Fig. 7. It can be observed that as fiber dosage increased, the water absorption capacity of concrete cubes decreased proving improvement in durability. This is because of the amount of reduction of pores in the concrete that is occupied by carbon fibers resulting in less water penetration.

Water absorption capacity decreases by 1.85%, 7.5%, 15%, 20.7% and 26.4% for 0.5%, 1%, 1.5%, 2% and 2.5% fiber dosage respectively compared to no fiber SCC.

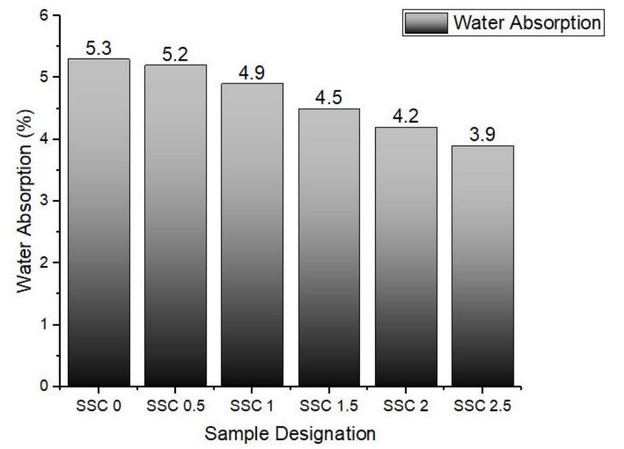

Fig. 7. Water absorption results for various mixes

IV. CONCLUSION

Different mechanical strengths (compressive, split tensile, flexure) and durability test(water absorption) were conducted on SCC reinforced with varying carbon fibers percentages(0,% 0.5%, 1%, 1.5%,2% and 2.5%) by weight of cement. From the test results obtained following broad conclusions can be made:

- Reinforcing carbon fibers only up to 1% by weight of cement was found to be advantageous for compressive strength because the addition of carbon fibers beyond that level decreased the compressive strength. This is because added fibers create void packets in the concrete due to formation of fiber-agglomerates as shown in SEM images. Therefore the presence of such voids tends to decrease the strength of concrete in compression.
- Split tensile strength also increased as carbon fiber dosage was increased. The increase in split tensile strength for 7, 28 and 90 days for 2.5% fiber dosage were observed to be 44%, 34.5% and 54% respectively compared with SCC without carbon fibers. Split tensile strength increased due to the presence of carbon fibers which acted as bridging between cracks during splitting of the cylinder. Therefore, as fiber volume increased, there was an increase in split tensile strength.
- As carbon fiber dosage was increased, an increase in flexural strength was observed for all specimens. For 28 days increase in flexural strength of 2.5% fiber dosage SCC was observed to be 47% when compared with SCC without carbon fibers. Improved compressive strength was due to filling of pores effectively in the concrete by carbon fibers and also due to increase in the area of surface reactivity.
- The water absorption capacity of SCC tended to decrease as the dosage of fibers increased resulting in improved durability. This was because of the presence of fiber in SCC in the pores and increase in the reactive area of fibers than cement.

From the above results, it can be concluded that the compressive strength of SCC reinforced with carbon fibers up to 1% was increased but beyond that it tended to decrease. On the other side, the split tensile strength and flexural strength increased as the dosage of fiber in SCC increased. Durability in terms of water absorption also improved as fiber volume increased.

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