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Behaviour of Slurry Infiltrated Fiber Concrete (SIFCON)

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ABSTRACT

Slurry Infiltrated Fiber Concrete (SIFCON) is one of the recently developed high performance and advanced construction materials. SIFCON could be considered as a special type of fiber concrete with high fiber content. The matrix usually consists of cement slurry or flowing cement mortar. This composite material has already been used for structures subjected to blast loading, repair of pre stressed concrete beams and safe vaults. It has an excellent potential for applications in the areas where ductility is needed. At present, very little is known about its behavior. This paper presents information regarding the behavior of SIFCON in compression, flexure and shear. Since most applications involve bending, the main thrust of the investigation was placed on the flexural behavior. More than 70 flexural specimens were tested under monotonic loading. The behavior under shear and compression was studied. Both strength and ductility aspects were studied. Cylinders were used for the tests in compression. The results of this investigation indicate that SIFCON can withstand stresses of 70, 30, 14 and 80 MPa in flexure, direct shear and compression respectively. The composite is extremely ductile in all four loading modes. Addition of silica fume increases the strength. Sand can be added to the slurry without reducing the strength considerably.

INTRODUCTION

Slurry Infiltrated Fiber Concrete (SIFCON) can be considered as a special fiber reinforced concrete. Normally, fiber reinforced concrete contains 1-3% fibers by volume, whereas SIFCON contains 6-20% fibers. The other major difference is in the composition of the matrix. In SIFCON, the matrix consists of flowing cement mortar slurry[1] as opposed to concrete in normal fiber reinforced concretes. The casting process is also different for SICON. In most cases, SIFCON is fabricated by distributing a bed of pre-placed fibers with cement slurry.

Even though SIFCON is a recent construction material, it has found applications in the areas of repair of bridge structures and defense structures. Since SIFCON can absorb a considerable amount of energy, it has a lot of potential for applications in structures subjected to impact and dynamic loading. However, these applications can be evaluated only after evaluating the basic workability and mechanical properties[1]. This paper presents information on the behavior of SIFCON in basic loading modes of axial compression, bending and shear. Since, in most applications the composite is expected to be in flexure, more emphasis is placed on flexural beheviour.

MATERIALS

The materials used consist of 53 Grade cement, silica fume, high range water reducing admixture and steel fibers. The high range water reducing admixture[2] used was a high molecular weight condensed naphthalene sultanate liquid. The steel fibers used were made from low carbon steel with a tensile strength of 1170 MPa. These fibers had hooked ends. Deformed and crimped fibers were also used in the investigation of compressive behavior (5).

MIX PROPORTIONS

Table 1 presents mix proportions for the various test specimens. The basic variables were fiber volumes and contents. Four fiber lengths and four volume contents were evaluated for beam specimens. The minimum possible fiber content of 6% and four fiber lengths were tested for direct shear strength. The lower fiber content was used because the composite has a high shear strength. For the tension specimens, fiber content was varied because it was felt that the amount of fibers will have more influence on the strength and ductility than fiber lengths. For all the aforementioned test specimens the slurry consisted of: 53 Grade cement, 10% silica fume(by weight of cement), 4.6% high range water reducing admixture (by weight of cement), and tap water. The water cement ratio was 0.3. some beam specimens were also made using just cement and cement plus sand for the slurry. Table 1. For the compression test specimens, water-cement ratio varied from 0.26 to 0.35 (5). More details including the use of other kinds of fibers can be found in Ref.5.

PREPARATION OF TEST SPECIMENS

SIFCON beam specimens were prepared using a 400 x 400 x 10 mm wooden mold. First the required amount of fibers were placed in the mold making sure that the fibers occupied the whole volume. Then the slurry was prepared and poured on the bed of fibers and vibrated using table vibrator to insure complete penetration. The specimen was taken out of the mold after 24 hours and cured on 100% humid room for 28days. Cylinders of diameter 150mm and height 300mm were also made using the slurry to determine its compressive strength. Fibers were aligned along the length of the cylinders. The specimens were cured by immersing them in water for 28 days.

TESTING

The beam specimens were tested using a Universal Testing Machine. A two point loading system was used within the middle third. The loading system was designed to eliminate axial forces in the beam. The load deflection response was recorded using dial gauges for each variable i.e. for a particular fiber length fiber content and slurry composition, there beams were tested. The first beam was subjected to a monotonically increasing load until the peak load is reached.

The shear specimens were also tested using a Universal Testing Machine. The slip in the shear plane was measured using a dial gauge. The dial gauge was placed in position by suing angles fastened to the specimens. The compression specimens were tested using a Compression Testing Machine[3]. The deformations were recorded using dial gauges of least count 0.01mm.

RESULTS AND ANALYSIS

Flexure

The results of the flexural behavior are presented in Table 2 and 3. The table provide the strength data and the information on the stiffness and ductility.

It should be noted that a at maximum load, the beam is not a homogeneous section and the behavior is not elastic and hence the values should be used only as relative indicators. Based on the results presented in Table 2. The following observations can be made.

With SIFCON, it is possible to obtain flexural strength higher than 70 MPa. This value is an order of magnitude higher than the numbers reported for normal fiber reinforced concrete. If thicker specimens are used, the strength seems to decrease to about 35 MPa (3).

The flexural strength[1] seems to level off around 70 MPa. Increase in fiber content beyond a certain limit decreases the strength. This could be due to the lack of matrix presence between the fibers at higher volume content. The optimum fiber content is around 8%.

The length of fibers do not have a significant effect on the strength. The table 3 provides the results for the comparison of various matrix compositions[2]. Using the table the following points can be made. The addition of silica fume increases both the compressive strength of the matrix and the flexural strength. The relative magnitude of increase seems to be the same for both the cases. Sand can be added to the slurry up to a cement sand ratio of 1:1.5 without adversely affecting the strength.

Based on the load-deformation behavior it can be said that SIFCON is extremely ductile both under monotonic loading. The specimens could sustain about 90% of the peak load even under large deflections.

Shear

The shear strengths were computed using the peak load). The shear strength[4] for the four fiber lengths tested varied from 28.1 MPa to 33.3 MPa. These values compare with about 6 MPa reported for plain concrete. Here again, it can be seen that SIFCON can sustain large deformations before complete failure.

Compression

Typical stress-strain curves in compression are presented in Fig.1. Here again, the composite behaves in a very ductile manner. The average strength is about 80 MPa. The Ref.5 provides more details on the compression behavior of SIFCON for various matrix composites and different kinds of fibers.

CONCLUSIONS

The following conclusions can be drawn based on the results presented in this paper. It should be noted that the results pertain to the use of booked steel fibers.

- The flexural strengths of SIFCON could be an order of magnitude higher than that of normal fiber reinforced concrete.
- The tensile and shear strengths of SIFCON are about 14 and 30 MPa respectively. The shear strength is about 5 times the shear strength of plain concrete. The increase in compressive strength is about 50%.
- SIFCON exhibits extremely high ductility[5] in all the four modes of loading namely; flexure, tension compression and shear.
- Limited amount of fine sand can be added to the cement slurry[6] without adversely affecting strength properties.

Table 1: Fiber Content and Slurry Composition for various Test Specimens

Type of specimen	Fiber Length mm	Fiber Content, Percentage	Type of Slurry
Beam	30	6,8,10,12	Cement + 10% Silica Fume
	40	4,6,8,10	
	50	4,5,6,8	
	60	5,6,8,10	
	30,40,50,60	8	Cement
	30	8	Cement + Sand (1:1:, 1:1.5, 1:2)
Shear	30,40,50,60	6	Cement + 10% Silica Fume
Compression	30	10 to 12	Cement + Silica Fume + Fly Ash

Table 2: Flexural Strength of SIFCON

Fiber Length mm	Fibre volume (%)	Max. Stress, MPa	Strength of Slurry MPa
30	6	55.1	82.0
	8	16.7	87.5
	10	91.8	75.8
	12	62.5	80.6
40	6	47.1	66.1
	8	67.6	79.9
	10	75.3	76.5
	12	76.4	66.8
50	6	36.7	79.9
	8	58.8	75.8
	10	78.5	63.4
	12	73.3	75.1
60	6	49.3	82.0
	8	53.7	83.4
	10	72.0	79.2
	12	63.2	63.4

Table 3. Comparison of Flexural Strengths for Various Matrix Compositions

Fiber Length mm	Flexural Strength, MPa					Strength Ratio							
	Silica Fume + Cement	Cement	Cement + sand			SF + C / C		C + S / C					
			1:1	1:1.5	1:2	FS	CS	FS	CS	FS	CS	FS	CS
30	61.7	44.8	46.3	53.6	41.9	1.38	1.59	1.03	1.08	1.20	0.79	0.93	0.62
40	75.3	50.7				1.48	1.48						
50	73.5	53.7				1.37	1.60						
60	72.0	45.5				1.58	1.47						

FS-Flexural Strength, CS – Compressive Strength, SF – Silica Fume, C – Cement

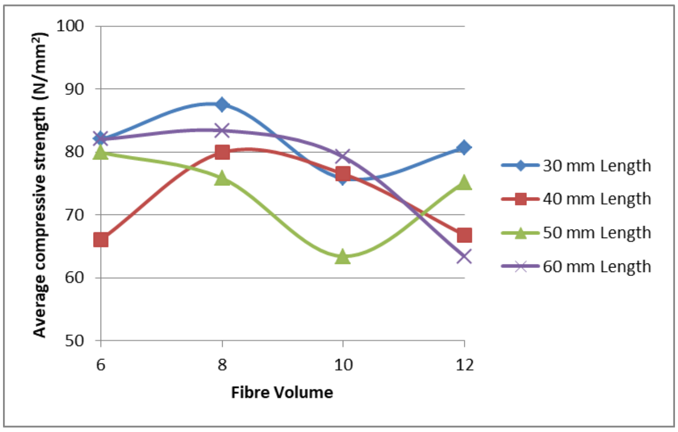

Figure 1: Envelope for slurry strength for different fibre volumes and lengths

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