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Research Paper

STRESS-STRAIN MODEL FOR TIE CONFINED FIBER REINFORCED SELF COMPACTING CONCRETE

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Self Compacting Concrete (SCC) has become synonymous with the construction industry due to the inherent advantages it possesses such as strength through durability, reasonable cost of ingredients, adoptability for all types of moulds, architectural construction with aesthetic sense, better fire resistance and weather resistance. The development of SCC marks an important milestone in improving the product quality and efficiency of the building industry. The typical methods of compaction and vibration of normal concrete generates delays and additional costs in concrete. A structural reinforced concrete member can be theoretically analyzed, if the stress-strain behavior of its constituent material is known. This paper aims to develop stress block parameters for predicting the stress-strain behavior of Fiber Reinforced Self Compacting Concrete (FRSCC). The results of specimens tested under strain control rate of loading are presented. The behavior of tie confined FRSCC is used in formulating a constitutive relationship.

Keywords: Self Compacting Concrete, Glass Fiber, Confinement Index, Fiber Index, Stress Block Parameters, Stress-Strain Relationship

INTRODUCTION

Self-Compacting Concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort, and which is at the same time, cohesive enough to be handled without segregation or bleeding (Okamura *et al.*, 1995). It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. SCC reduces the intensive labor demand for vibration of highly congested sections. As this concrete can spread easily without any mechanical consolidation, the risk of separation of material constituents is also not present (Radix *et al.*, 2005). The performance of such a SCC can be ensured by preparing carefully to exhibit low

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yield value and a moderate viscosity to maintain high deformability and filling capacity of the form work, with minimum segregation and flow blockage (Ouchi *et al.,* 1996). In order for such a performance concrete to have a wider acceptance for casting complex and congested structural elements, particularly in seismic areas, with heavy reinforcement more knowledge of a good performance SCC is required.

Fiber is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat. The fiber is often described by some convenient parameter called "aspect ratio (l/d)". The aspect ratio of the fiber is the ratio of its length to its diameter (Yaman *et al.*, 2005). Some of the fibers that are commonly used are steel fibers, nylons, glass, polypropylene and carbon. Each type of fiber has its characteristics properties and limitations. The main objective of the study here is to develop a stress-strain model for Fiber Reinforced Self compacting Concrete (FRSCC). The main parameters involved in the investigation are the strength, spacing and diameter of lateral ties, dosage of fiber, strength of concrete and core dimensions of the specimen. These parameters controls the behavior of tie confined FRSCC. The non-dimensional parameters called Confinement index (C_i) and Fiber index (F_i) are identified involving all the parameters influencing the behavior of FRSCC.

The Confinement Index is defined as

$$C_i = \left(P_b - \overline{P}_b\right)\left(f_v / f_{c'}\right)\sqrt{\frac{b}{s}} \quad ...(1)$$

where, P_b is the ratio of the volume of ties to the volume of concrete, $\overline{P}_b$ is the ratio of the volume of ties to the volume of concrete corresponding to a limiting pitch (1.2 times the least lateral dimension). b is the breadth of the prism and s is the spacing of ties. The stress in the steel binder is given by $f_v = \varepsilon_v . E_s$ and is always limited to maximum yield strength. ε_v and E_s are the strains and modulus of elasticity of the binder steel. Fiber index (F_i), which indicates the degree of confinement provided by fiber. The Fiber index (F_i) is a product of weight fraction (w_f) of fiber and the aspect ratio (l/d) of the fiber. Due to the passive confinement of the fibers in the core concrete, there was a good bond with a core and cover. The fact that the inclusion of fibers is more beneficial in improving the crack resistance, flexural strength and energy absorption capacity of concrete, rather than other properties, is well-established.

$$F_i = \left(w_f\right)\left(l/d\right) \quad ...(2)$$

where, w_f is the ratio of the weight of fiber to weight of concrete, (l/d) is the ratio of length of the fiber to the diameter of the fiber.

RESEARCH SIGNIFICANCE

The construction of heavily reinforced concrete members, such as columns and beams in moment resisting frames in seismic areas, makes the placement of concrete quite difficult. The FRSCC is highly flowable, stable concrete which flows readily into place, filling formwork without any compaction and without undergoing any significant segregation. The construction of modern structures calls for the attention of the use of materials with improved properties in respect of strength, stiffness, toughness and durability. The addition of fibers along with the lateral ties was found to improve the deformation characteristics and especially the integrity of concrete. The present paper contributes mainly in the structural behavior and development of a model for FRSCC. The most fundamental requirement in predicting the behavior of FRSCC is the knowledge of stress-strain behavior of the constituent materials. This should be of interest to engineers considering the use of FRSCC for various structural applications.

FIBER REINFORCED SELF COMPACTING CONCRETE

The character and performance of Fiber Reinforced Concrete (FRC) change depending on the properties of concrete and the fibers. The properties of fibers that are usually of interest are fiber concentration, fiber geometry, fiber orientation, and fiber distribution (Steffen Grunewald, 2001). Glass and Glass fibers have various applications in concrete like crack control, prevent coalescence of cracks, and to change the behavior of the material by bridging of fibers across the cracks. In other words, ductility is provided with fiber reinforced cementitious composites because fibers bridge crack surfaces and delay the onset of the extension of localized crack). Fresh SCC must possess the key properties including filling ability, passing ability and resistance to segregation at required level. To satisfy these conditions EFNARC (EFNARC, 2002) has formulated certain test procedures. The details of mix proportions adopted in the present study are designed as per Nansu method of mix design (Nansu *et al*., 2001) is shown in Table 1 and the fresh properties of GFRSCC are shown in Table 2. Companion cube specimens of standard dimensions 150 mm x 150 mm were also cast and tested for the strength. The results of the compressive strength are also presented in Table 2.

Table 1: Details of Mix Proportions for M20 and M40 Grade Concrete

S. No.	Designaiton	Grade of Concrete	Cement in Kg	CA Kg	FA Kg	Fly–Ash Kg	Glass Fiber (Kg)	Water (lit)	SP (lit)	VMA lit
1	GFRSCC1	M20	276	808	961	170	1.00	200	11.20	0.45
2	GFRSCC2	M40	412	781	913	166	1.00	193	16.0	0.48

Table 2: Fresh and Hardened Properties of SCC with Glass Fiber

S. No.	Designaiton	Slump Cone Test		V Funnel Test		L Box Test			
		H-Flow (mm)	T_{50} Time in Sec	Time for Complete Discharge Sec	T_5 min in Sec	Time for 0-200 mm Spread	Time for 0-400 mm Spread	H_2/H_1	Comp. Strength (Mpa)
1	GFRSCC1	680	4.50	9.72	12.50	3.15	6.20	0.82	32.87
2	GFRSCC2	700	4.61	10.50	13.20	3.00	6.11	0.82	54.26

EXPERIMENTAL PROGRAM

The program consisted of casting and testing of 150 prisms of size 150 x 150 x 300 mm cast in two Phases for examining the stress-strain behavior of M20 and M40 grades. In the first phase, 75 prisms of FRSCC for M20 and in the second phase 75 prisms of FRSCC for M40 were cast and tested. Each grade was cast in five batches. The prisms in each batch were divided into five sets. In each set three identical specimens were cast and tested after 28 days curing and the average behavior was taken to represent the behavior for that set of three specimens. Some additional 150 x 150 mm cubes were cast as companion specimens for predicting the compressive strength. The details of prisms casted are shown in Tables 3a and 3b.

Materials Used

Ordinary Portland cement with a compressive strength not less than 53 MPa [named 53 grade cement], at the end of 28 days was used in the study (IS: 12269, 1997). The Fine Aggregate (FA) used was standard river sand confirming to Zone-II as per IS-2386 (1997). Crushed granite was used as Coarse Aggregate (CA). The aggregate was properly graded through standard sieves [IS: 383, 1970] before using in the concrete works. The fly ash available locally was used as a partial replacement for cement, Cem-Fil Anti Crack, alkali resistant glass fiber, has been specially developed for the reinforcement of cementitious mortars and concrete mixes. Some characteristic features of Cem-Fil Anti-Crack HD are, its Specific gravity is 2.6; length of the fiber is close to 12 mm, aspect ratio 857:1, and Specific surface area being 105 m^2/kg. Conplast SP 337 superplasticizer (water reducing admixture) and Viscosity Modifying Agent (VMA) were added in optimum dosages for improving the properties of SCC. The 4 mm nominal diameter GI wire was used as longitudinal reinforcement in the prisms. The steel used as lateral reinforcement was 8 mm nominal diameter mild steel obtained from single lot. Two concrete strengths Viz., M20 (compressive strength not less than 20 MPa at the end of 28 days) and M40 (compressive strength not less than 40 MPa at the end of 28 days) were tested in the study.

Curing: The specimens were cured for 28 days in the curing tank. The water in the curing tank was changed at the end of 14 days. After completion of curing the specimens were kept in shade for one day and then tested.

Testing: The cured specimens were capped with plaster of Paris before testing to provide a smooth loading surface, to avoid any stress concentration during the application of load. A Tinius-Olsen testing machine of 1810 KN capacity was used for testing the prisms under axial compression. The prisms were tested under strain rate control, 0.1 mm/min. The same type of test set up followed for studying the stress-strain behavior of fibers based specimens which was adopted for no fiber concrete specimens.

The set up of two square frames along with the compressometer was used for measuring the strains. All the specimens were tested under a strain control of 0.1 mm/min and the load increased rapidly in the initial stage up to about 75 to 80% of the peak load and increased at a slower rate until the peak load was reached. Tests were continued until the peak load dropped to about 0.5 times the peak

Table 3a: Details of Prisms Tested (M20)

S. No.	Designation	Long. Steel		Lateral Steel		F_i	Cube Strength (MPa)	PI Prism Strength (MPa)	No. of Prisms
		No (mm)	Dia (mm)	Dia (mm)	Spacing (mm)				
1	AP00	-	-	-	-	0.000	32.62	23.33	3
2	AG01	4	3.94	7.96	150	0.000			3
3	AG02	4	3.94	7.96	100	0.000			3
4	AG03	4	3.94	7.96	75	0.000			3
5	AG04	4	3.94	7.96	50	0.000			3
6	AP10	-	-	-	-	0.089	32.87	23.82	3
7	AG11	4	3.94	7.96	150	0.089			3
8	AG12	4	3.94	7.96	100	0.089			3
9	AG13	4	3.94	7.96	75	0.089			3
10	AG14	4	3.94	7.96	50	0.089			3
11	AP20	-	-	-	-	0.179	33.14	23.714	3
12	AG21	4	3.94	7.96	150	0.179			3
13	AG22	4	3.94	7.96	100	0.179			3
14	AG23	4	3.94	7.96	75	0.179			3
15	AG24	4	3.94	7.96	50	0.179			3
16	AP30	-	-	-	-	0.268	33.28	23.96	3
17	AG31	4	3.94	7.96	150	0.268			3
18	AG32	4	3.94	7.96	100	0.268			3
19	AG33	4	3.94	7.96	75	0.268			3
20	AG34	4	3.94	7.96	50	0.268			3
21	AP40	-	-	-	-	0.357	33.53	24.08	3
22	AG41	4	3.94	7.96	150	0.357			3
23	AG42	4	3.94	7.96	100	0.357			3
24	AG43	4	3.94	7.96	75	0.357			3
25	AG44	4	3.94	7.96	50	0.357			3
								Total	**75**

Note: A=M20 Grade of Concrete.

Table 3b: Details of Prisms Tested (M40)

S. No.	Designation	Long. Steel No (mm)	Long. Steel Dia (mm)	Lateral Steel Dia (mm)	Lateral Steel Spacing (mm)	F_i	Cube Strength (MPa)	PI Prism Strength (MPa)	No. of Prisms
1	BP00	-	-	-	-	0.000	53.19	39.56	3
2	BG01	4	3.94	7.96	150	0.000			3
3	BG02	4	3.94	7.96	100	0.000			3
4	BG03	4	3.94	7.96	75	0.000			3
5	BG04	4	3.94	7.96	50	0.000			3
6	BP10	-	-	-	-	0.089	53.44	39.84	3
7	BG11	4	3.94	7.96	150	0.089			3
8	BG12	4	3.94	7.96	100	0.089			3
9	BG13	4	3.94	7.96	75	0.089			3
10	BG14	4	3.94	7.96	50	0.089			3
11	BP20	-	-	-	-	0.179	53.76	39.95	3
12	BG21	4	3.94	7.96	150	0.179			3
13	BG22	4	3.94	7.96	100	0.179			3
14	BG23	4	3.94	7.96	75	0.179			3
15	BG24	4	3.94	7.96	50	0.179			3
16	BP30	-	-	-	-	0.268	54.05	40.17	3
17	BG31	4	3.94	7.96	150	0.268			3
18	BG32	4	3.94	7.96	100	0.268			3
19	BG33	4	3.94	7.96	75	0.268			3
20	BG34	4	3.94	7.96	50	0.268			3
21	BP40	-	-	-	-	0.357	54.26	40.32	3
22	BG41	4	3.94	7.96	150	0.357			3
23	BG42	4	3.94	7.96	100	0.357			3
24	BG43	4	3.94	7.96	75	0.357			3
25	BG44	4	3.94	7.96	50	0.357			3
								Total	**75**

Note: A=M40 Grade of Concrete.

load. Beyond the peak load, the strains increased at a rapid rate and were accomplished with a decrease in the load carrying capacity of the specimen.

STRESS-STRAIN BEHAVIOR OF FRSCC

A structural reinforced concrete member can be theoretically analyzed if the stress-strain behavior of its constituent materials is known (Saenz, 1964). Stress-strain relation of steel is not a big problem as there is very less material variation compared to that of concrete.

Concrete being produced at site has very much uncertainty; moreover, there is a significant variation in the behavior of FRSCC (Kumar *et al.*, 2011). Also, there is much variation in behavior of confined and unconfined concrete as well. Generally, in practice we use code specified stress-strain relation in the analysis and design, but generally they are recommended for normal vibrated concrete only. Now as the advancement in concrete technology has been promoting the use of FRSCC, the stress-strain relation for FRSSC is to be used in design.

The most common practice for confining concrete is by the use of lateral ties and inclusion of fiber in the core concrete. Thus our study is being done for the tie confined fiber reinforced self compacting concrete. Thus the spalling of cover was less in this type of confinement. The addition of fibers along with the lateral ties was found to improve the deformation characteristics and specially the integrity of concrete.

For the prediction of stress-strain relation of vibrated concrete confined with lateral ties, many empirical confinement models based on experimental investigation have been reported in the literature during last three decades. But there is no model for fiber reinforced self compacting concrete, so to predict the stress-strain relation of FRSCC confined with lateral ties, an empirical confinement model was developed based on experimental work.

Confinement Index (C_i), Fiber Index (F_i) Vs. Stress Ratio and Strain Ratio

Tables 4a and 4b shows the details of stress ration, strain ratio, ductility factor, confinement index and fiber index for M20 and M40 grade concretes. Figures 11(a) and 11(b) shows the relationship between stress ratio Vs confinement index and Strain ratio Vs confinement index. Similarly Figures 11(c) and 11(d) shows the details of stress ratio Vs. fiber index and strain ratio Vs. fiber index. The relationships between stress ratio, strain ratio, confinement index, fiber index for FRSCC is shown in Equations (5) and (6).

NON-DIMENSIONALISED STRESS-STRAIN CURVE

An examination of the curves in Figures 1 to 10 indicates that the behavior is similar for all the grades, meaning that the stress-strain behavior is linear upto 80-90% of the ultimate and non linear beyond this. The post peak stress-strain response for all the GFRSCC specimens is gradual and appears to have a consistent and constant gradient. This similarity leads to the conclusion that if the stress is expressed as stress ratio by dividing the stress at any level by the corresponding stress at ultimate and the strain ratio obtained by dividing the strain at any level by the

Table 4a: Confinement Index, Fiber Index, Peak Stress, Corresponding Strain, Ductility Factor (M20)

S. No.	Designa-tion	Confine-ment Index (C_i)	Fiber Index (F_i)	Peak Strength (f_u)	f_u/f_c	Peak Strain ($\in_u$)	$\in_u/\in_{c'}$	$\in_{0.85\,u}$ Ascend-ing x10^6	$\in_{0.85\,u}$ Descen-ding x10^6	Ductility Factor
1	AP00	0.00	0.000	23.33	1.000	0.00197	1.000	1188	2970	2.50
2	AG01	0.00	0.089	23.82	1.021	0.00202	1.025	1208	3208	2.66
3	AG02	0.00	0.179	23.71	1.016	0.00207	1.050	1226	3461	2.82
4	AG03	0.00	0.268	23.96	1.027	0.00212	1.074	1214	3806	3.14
5	AG04	0.00	0.357	24.08	1.032	0.00218	1.103	1229	4085	3.32
6	AP10	0.05	0.000	25.08	1.000	0.00257	1.000	1520	4910	3.23
7	AG11	0.05	0.089	26.28	1.048	0.00263	1.023	1513	5225	3.45
8	AG12	0.05	0.179	26.50	1.057	0.00271	1.056	1568	5689	3.63
9	AG13	0.05	0.268	26.72	1.065	0.00278	1.084	1480	6390	4.32
10	AG14	0.05	0.357	26.87	1.071	0.00285	1.109	1496	6790	4.54
11	AP20	0.16	0.000	27.07	1.000	0.00339	1.000	1550	6300	4.06
12	AG21	0.16	0.089	27.36	1.011	0.00351	1.036	1564	6494	4.15
13	AG22	0.16	0.179	27.66	1.022	0.00363	1.072	1598	7038	4.40
14	AG23	0.16	0.268	27.98	1.034	0.00375	1.108	1632	7480	4.58
15	AG24	0.16	0.357	28.08	1.037	0.00388	1.144	1560	7800	5.00
16	AP30	0.31	0.000	29.24	1.000	0.00430	1.000	1880	8900	4.73
17	AG31	0.31	0.089	29.56	1.011	0.00451	1.049	1920	9165	4.77
18	AG32	0.31	0.179	29.90	1.023	0.00472	1.098	1961	9390	4.79
19	AG33	0.31	0.268	30.14	1.031	0.00491	1.141	2007	9768	4.87
20	AG34	0.31	0.357	30.58	1.046	0.00513	1.193	1950	10110	5.18
21	AP40	0.67	0.000	35.50	1.000	0.00620	1.000	2435	12028	4.94
22	AG41	0.67	0.089	33.42	0.941	0.00649	1.047	2470	12300	4.98
23	AG42	0.67	0.179	34.18	0.963	0.00680	1.097	2552	12852	5.04
24	AG43	0.67	0.268	34.85	0.982	0.00710	1.145	2608	13526	5.19
25	AG44	0.67	0.357	35.08	0.988	0.00745	1.202	2540	13764	5.42

Table 4b: Confinement Index, Fiber Index, Peak Stress, Corresponding Strain, Ductility Factor (M40)

S. No.	Designation	Confinement Index (C_i)	Fiber Index (F_i)	Peak Strength (f_u)	f_u/f_c	Peak Strain ($\in_u$)	$\in_u/\in_{c'}$	$\in_{0.85u}$ Ascending x10^6	$\in_{0.85u}$ Descending x10^6	Ductility Factor
26	BP00	0.00	0.000	39.56	1.000	0.00235	1.000	1373	3380	2.46
27	BG01	0.00	0.089	39.84	1.007	0.00241	1.027	1340	3530	2.63
28	BG02	0.00	0.179	39.95	1.010	0.00248	1.053	1310	3620	2.76
29	BG03	0.00	0.268	40.17	1.015	0.00254	1.080	1270	3900	3.07
30	BG04	0.00	0.357	40.32	1.019	0.00260	1.106	1300	4082	3.14
31	BP10	0.03	0.000	41.50	1.000	0.00270	1.000	1610	4544	2.82
32	BG11	0.03	0.089	42.89	1.033	0.00280	1.037	1541	4782	3.10
33	BG12	0.03	0.179	43.29	1.043	0.00290	1.075	1564	5100	3.26
34	BG13	0.03	0.268	43.69	1.053	0.00298	1.104	1575	5425	3.44
35	BG14	0.03	0.357	44.38	1.069	0.00306	1.134	1584	5652	3.57
36	BP20	0.10	0.000	44.48	1.000	0.00365	1.000	1850	5328	2.88
37	BG21	0.10	0.089	44.88	1.009	0.00375	1.027	1836	5745	3.13
38	BG22	0.10	0.179	45.27	1.018	0.00397	1.088	1689	6068	3.59
39	BG23	0.10	0.268	45.87	1.031	0.00410	1.123	1763	6437	3.65
40	BG24	0.10	0.357	46.20	1.039	0.00423	1.159	1820	6678	3.67
41	BP30	0.18	0.000	46.64	1.000	0.00453	1.000	1950	7740	3.97
42	BG31	0.18	0.089	48.04	1.030	0.00475	1.049	2092	8400	4.02
43	BG32	0.18	0.179	48.36	1.037	0.00492	1.086	1960	8526	4.35
44	BG33	0.18	0.268	48.71	1.044	0.00510	1.126	1850	8910	4.82
45	BG34	0.18	0.357	49.37	1.059	0.00529	1.167	1950	9478	4.86
46	BP40	0.39	0.000	52.26	1.000	0.00580	1.000	2230	10540	4.73
47	BG41	0.39	0.089	50.60	0.968	0.00598	1.031	2428	11526	4.75
48	BG42	0.39	0.179	51.29	0.981	0.00620	1.069	2315	11600	5.01
49	BG43	0.39	0.268	51.78	0.991	0.00638	1.100	2350	11900	5.06
50	BG44	0.39	0.357	52.41	1.003	0.00658	1.134	2310	12320	5.33

Figure 1: Stress Vs. Strain for C_i=0.0 (M20)

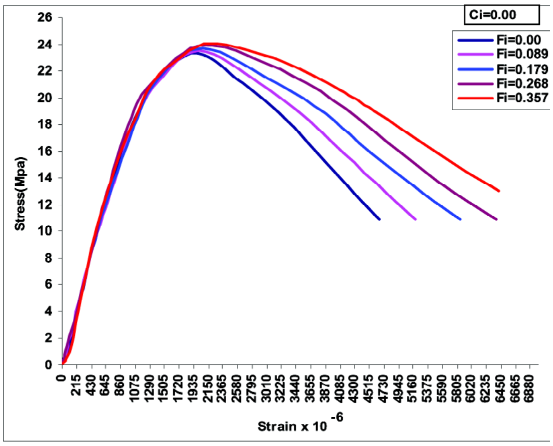


Figure 2: Stress Vs. Strain for C_i=0.03 (M20)

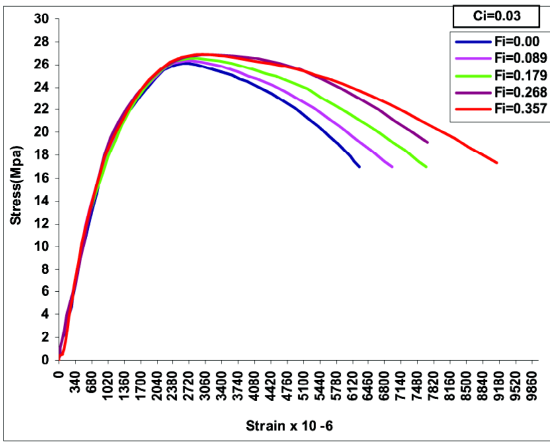


Figure 3: Stress Vs. Strain for C_i=0.14 (M20)

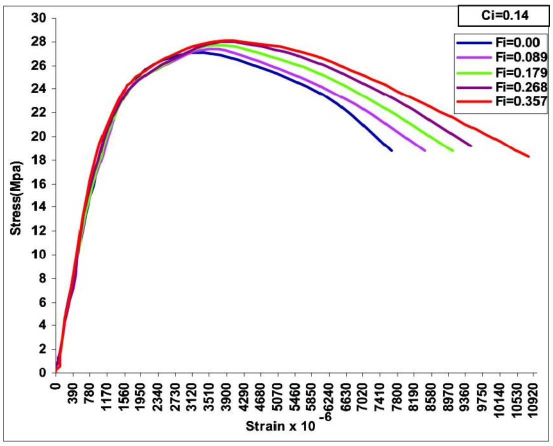


Figure 4: Stress Vs. Strain for C_i=0.28 (M20)

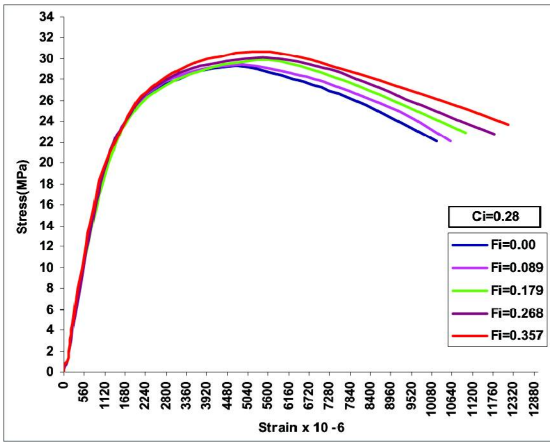


Figure 5: Stress Vs. Strain for C_i=0.64 (M40)

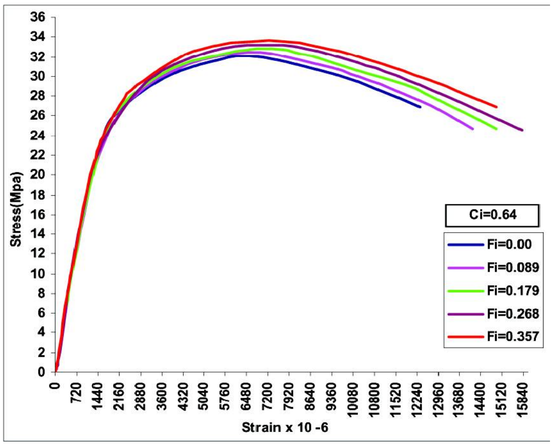


Figure 6: Stress Vs. Strain for C_i=0.0 (M40)

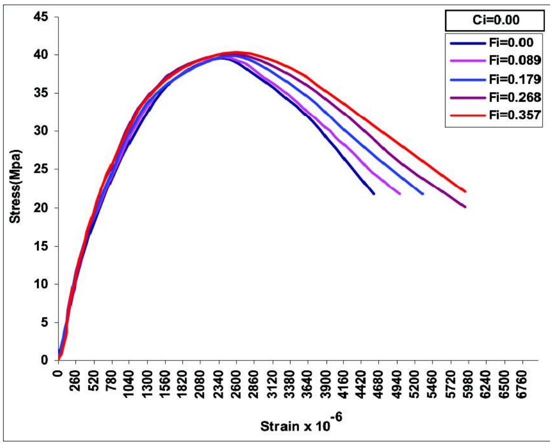


Figure 7: Stress Vs. Strain for C_i=0.02 (M40)

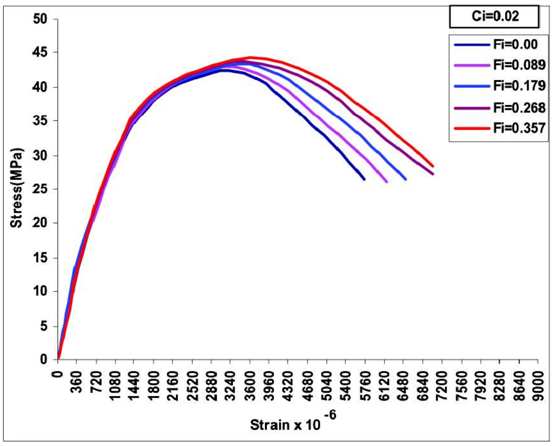


Figure 8: Stress Vs. Strain for C_i=0.08 (M40)

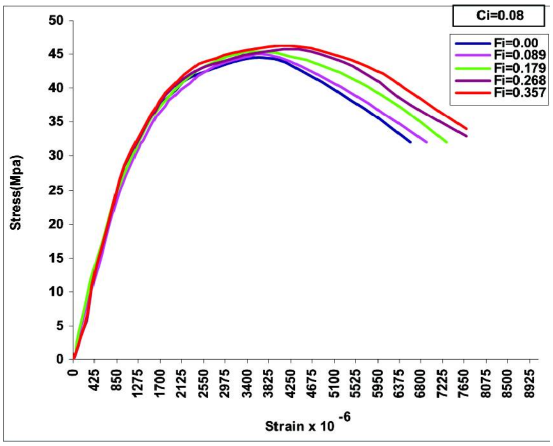


Figure 9: Stress Vs. Strain for C_i=0.17 (M40)

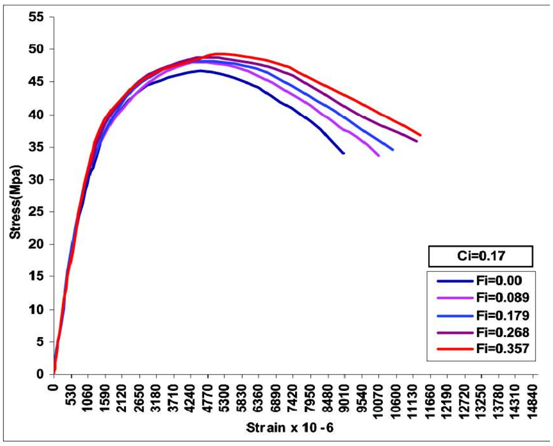
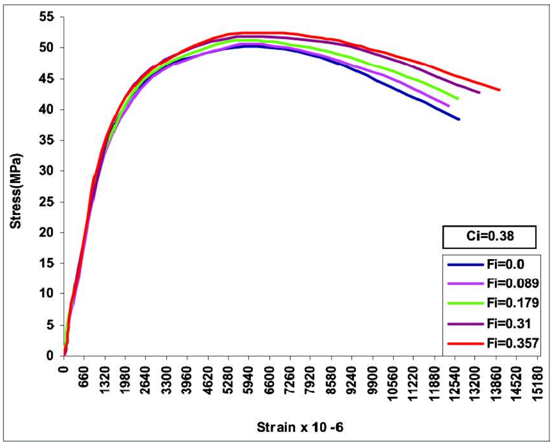


Figure 10: Stress Vs. Strain for C_i=0.38 (M40)



corresponding to the strain at ultimate strength, the plot of these two ratios falls into the same pattern. By non-dimensionalising the stress and strain as above the effect of Confinement Index (C_i) can be eliminated. Figure 12 shows the values of the non-dimensionalised stress as ordinate and the normalized strain as abscissa. The characteristic values and the analytical values are plotted in the Figure 13 and the photographs of the specimens after testing has shown in Figure 14. The stress-strain behavior can be represented by a general curve, which functions as a stress block. A single polynomial of the form originally proposed by Saenz (1964) for concrete is used in the current investigation.

Saenz proposed the following equation for stress-strain behavior of concrete in compression

$$f = \frac{A\varepsilon + D}{1 + B\varepsilon + C\varepsilon^2} \quad ...(3)$$

where, ε = strain in concrete and f = stress correspond to strain

To express the non-dimensional stress-strain curve of TCFRSCC, the strain ratio and stress ratio are taken as independent and dependent variables instead of strain and stress as proposed by Saenz. The following equation is proposed for non-dimensional stress-strain curve for TCFRSCC in axial compression.

$$\frac{f}{f_u} = \frac{A1(\varepsilon/\varepsilon_u)}{1 + B1(\varepsilon/\varepsilon_u) + C1\left(\frac{\varepsilon}{\varepsilon_u}\right)^2} \qquad ...(4)$$

where $A = A1(f_u/\varepsilon_u)$

$$B = B1(1/\varepsilon_u)$$

$$C = C1(1/\varepsilon_u^{\,2})$$

Relations obtained from the Figures 11(a) to 11(d) we will get the relations as,

The Confined Concrete Strength:

$$\frac{f_u}{f'} = (1 + 0.866C_i) + \ (1 + 0.101F_i) \qquad ...(5)$$

The Confined Concrete Strain:

$$\frac{\varepsilon_u}{\varepsilon'} = \ (1 + 3.761C_i) + (1 + 0.407F_i) \qquad ...(6)$$

Two sets of constants (A1, B1, C1) are proposed to be obtained because the descending portion of the stress-strain curve

Figure 11a: Stress Ratio Vs Ci

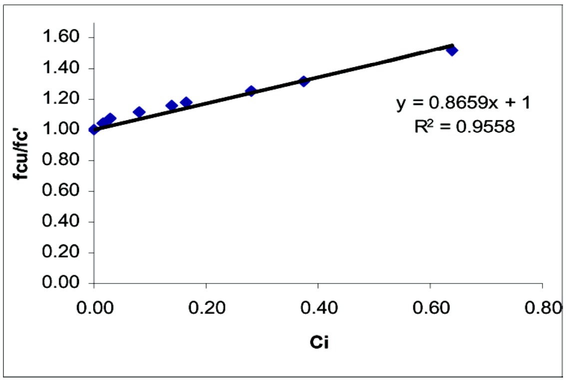


Figure 11b: Strain Ratio Vs Ci

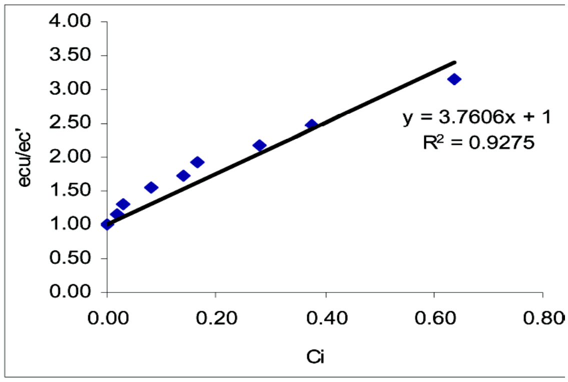


Figure 11c: Stress Ratio Vs Fi

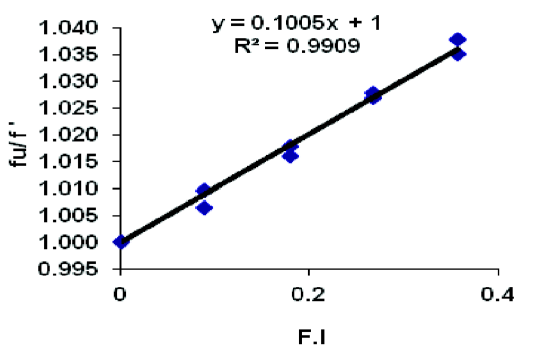
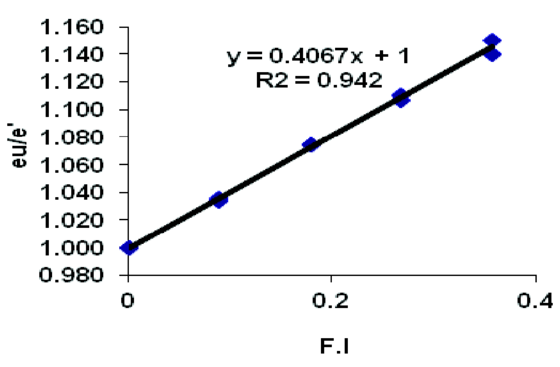


Figure 11d: Strain Ratio Vs Fi



(i.e., beyond ultimate) traced a slow downward trend. One set of constants represents ascending portion and other set represents the descending portion of the stress-strain curve. The following boundary conditions are use:

Boundary Conditions Common for both ascending and descending portions of Stress-Strain Curve

(i) At $\frac{\varepsilon}{\varepsilon_u} = 1$; $\frac{f}{f_u} = 1$;

(ii) At $\frac{\varepsilon}{\varepsilon_u} = 1$; $d(f/f_u)/d(\varepsilon/\varepsilon_u) = 0$;

Additional Boundary Condition for ascending portion of stress-strain curve

(iii) At $(\varepsilon/\varepsilon_u) = 0.3$; $(f/f_u) = 0.673$;

Additional Boundary Condition for descending portion of stress-strain curve

(iv) At $(\varepsilon/\varepsilon_u) = 1.58$; $(f/f_u) = 0.85$;

The conditions (iii) and (iv) are obtained from the experimental data. At $(\varepsilon/\varepsilon_u) = 0.3$ the curve deviates from the initial tangent. At $(\varepsilon/\varepsilon_u)$ = 1.58 the reduction in strength is 15 percent. Satisfying the boundary conditions the constants for ascending and descending portions of the curve were obtained:

A1 = 2.866, B1=0.866, C1= 1.0 (for Ascending Portion) and

A1= 1.206, B1= -0.794, C1= 1.0 (for Descending Portion).

Thus the stress-strain equation for the ascending portion of self compacting concrete is

$$\frac{f}{f_u} = \frac{2.866(\varepsilon/\varepsilon_u)}{1 + 0.866(\varepsilon/\varepsilon_u) + 1.0\left(\frac{\varepsilon}{\varepsilon_u}\right)^2} \quad ...(7)$$

While the stress-strain equation for the descending portion of Self compacting concrete is

Figure 12: Normalised Stress Vs. Normalised Strain

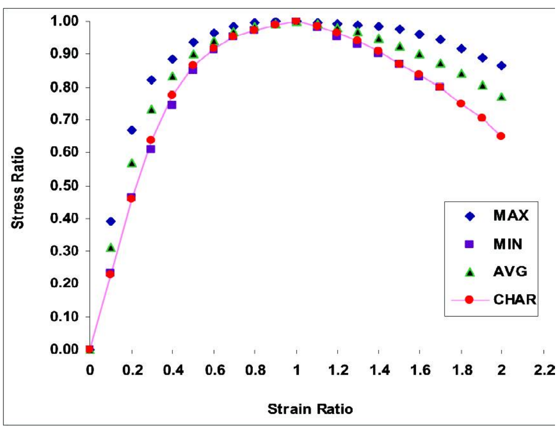


Figure 13: Stress Ratio Vs. Strain Ratio

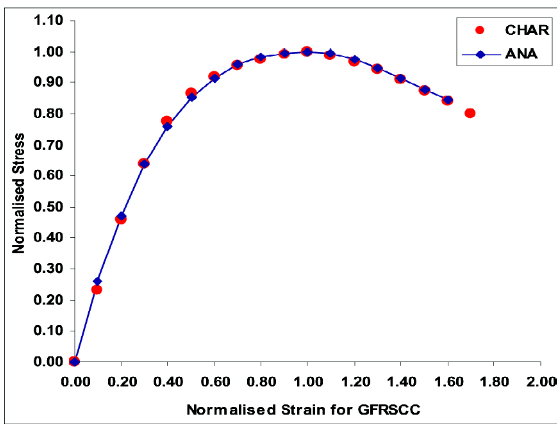
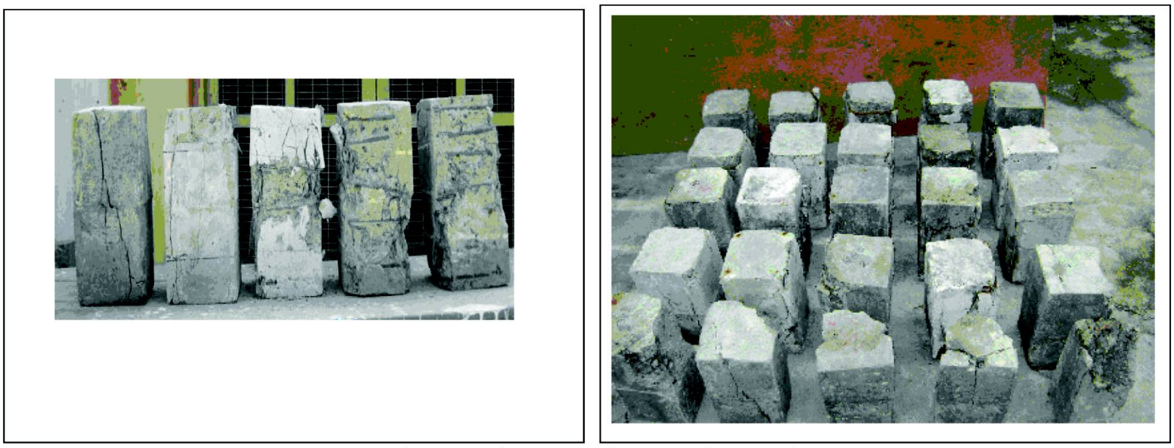


Figure 14: Prism Specimens After Testing



$$\frac{f}{f_u} = \frac{1.206(\varepsilon/\varepsilon_u)}{1-0.794(\varepsilon/\varepsilon_u)+1.0\left(\frac{\varepsilon}{\varepsilon_u}\right)^2} \quad ...(8)$$

Hence, the generalized stress-strain equation for TCFRSCC can be written as

$$f = \frac{A\varepsilon}{1+B\varepsilon+C\varepsilon^2} \quad ...(9)$$

where $A = A1(f_u/\varepsilon_u)$,

$B = B1(1/\varepsilon_u)$,

$C = C1(1/\varepsilon_u^2)$

CONCLUSION

1. The confinement studies on SCC proven that there is an increase in peak stress, strain at peak stress and strain at 85% of peak stress with increase in confinement index and fiber index.
2. With the addition of glass fiber, the ascending portion of the load-deflection changes very slightly, but the descending portion becomes less steep, which resulted in a higher ductility and toughness of the material.
3. The improvement in strength and strain at peak stress were developed by regression analysis are:

$$\frac{f_u}{f'} = (1+0.866C_i)+ \quad (1+0.101F_i)$$

$$\frac{\varepsilon_u}{\varepsilon'} = (1+3.761C_i)+(1+0.407F_i)$$

4. The non-dimensional characteristic equation proposed in this investigation can be used to predict the constitutive behavior of Tie Confined FRSCC in axial compression with reasonable accuracy.
5. The stress-strain equations for ascending and descending portions are given separately as

For the ascending portion of FRSCC:

$$\frac{f}{f_u} = \frac{2.866(\varepsilon/\varepsilon_u)}{1+0.866(\varepsilon/\varepsilon_u)+1.0\left(\frac{\varepsilon}{\varepsilon_u}\right)^2}$$

The descending portion of FRSCC:

$$\frac{f}{f_u} = \frac{1.206(\varepsilon/\varepsilon_u)}{1-0.794(\varepsilon/\varepsilon_u)+1.0\left(\frac{\varepsilon}{\varepsilon_u}\right)^2}$$

6. The ultimate moment and corresponding curvature of the confined FRSCC section can be determined by using the stress block parameters arrived at in this investigation.

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