GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

ANALYTICAL MODELLING ON THE BEHAVIOR OF STEEL FIBRE REINFORCED SCC UNDER AXIAL COMPRESSION

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ABSTRACT

Steel fiber reinforced self-compacting concrete (SFRSCC) is a relatively new composite material which congregates the benefits of self-compacting concrete (SCC) technology with the profits derived from the fiber addition to a brittle cementitious matrix. The crack propagation can be reduced by addition of steel fibres in concrete. Addition of fibres reduces workability of concrete which is the major drawback. SFRSCC is a trending concrete where the required workability is obtained by addition of chemical admixtures such as Super plasticizer (SP) and Viscosity Modifying Agent (VMA). In the present work, an effort is made to make a comparative study of stress-strain behavior of M30 grade steel fiber Reinforced Self-Compacting Concrete (SFRSCC). Complete Stress – Strain behavior has been presented and an empirical equation based on mathematical model is proposed to predict the stress – strain behavior of such concrete under compression. The proposed mathematical equation shows good correlation with the experimental results. There is an improvement in the Axial Compressive Strength of SCC which could be due to the addition of the steel fibers

Keywords: Steel-fibre, Self – Compacting Concrete (SCC), Super plasticizer (SP), Viscosity Modifying Agent (VMA), Stress – Strain behaviour

I. INTRODUCTION

The self compacting concrete (SCC) which was developed by Prof Hajime Okamura in the year 1988, to address some durability problems, was received very well all over the world. The efficiency of self compacting concrete was further enhanced by introduction of randomly oriented short discrete fibres in many ways. Steel fibres are one such type of fibres which are successfully tried in the self compacting concrete matrix and proved to be a promising material in enhancing the properties of SCC by reducing the crack propagation, enhancing the ductility and energy absorption properties. An effort has been made in the present investigation to study the stress-strain behaviour of steel fibre reinforced self compacting concrete under axial compression with and without confinement in the form of steel hoops. In the fresh state, SFRSCC homogeneously spreads due to its own weight, without any additional compaction energy. To homogeneously fill a mold, SFRSCC has to fulfil high demands with regard to filling and passing ability, as well as segregation resistance. Driven by its own weight, the concrete has to fill a mold completely without leaving entrapped air even in the presence of dense steel bar reinforcement. All the concrete components have to be homogeneously distributed during the flow and at rest (Gräunewald 2004). A detailed description of the benefits provided by the fiber addition to concrete can be found elsewhere (Balaguru and Shah 1992, Casanova 1996, ACI 544.1R 1997). The fiber addition might also improve the shear resistance (Rosenbusch and Teutsch 2003). Recently, Gräunewald (2004) compared the mechanical behavior of SFRSCC to the behavior of current fiber reinforced concrete (FRC). The field of possible application of SFRSCC include: highways, industrial and airfield pavements; hydraulic structures, tunnel segments, bridges components and concrete structures of complex geometry which present high difficulties of being reinforced by conventional steel bars, especially those who have high degree of support redundancy. The study is focused on investigation of the properties of fresh and hardened states of M_{30} grade steel fibre reinforced self compacting concrete (SFRSCC). Analytical models were proposed for different confinements ranging from 0 to 1.591 percent volume confinement in the form of circular hoops. Further the ductility factor values are reported. A comparison of the behaviour of PSCC and SFRSCC is made.

II. LITERATURE REVIEW:

A. Ravichandran, K. Suguna and P. N. Ragunath [1] (2009): In this study high strength concrete (HSC) of 60 MPa containing hybrid fibres, combination of steel and polyolefin fibres, at different volume fraction of 0.5, 1.0, and 2.0% were compared in terms of compressive strength, splitting tensile and flexural properties with HSC containing no fibres. Based on the results they have concluded that fibres when used in hybrid form could result in enhanced flexural toughness compared to steel fibre reinforced concrete [HSFRC].The compressive strength of the fibre-reinforced concrete reached maximum at 1.5% volume fractions and the splitting tensile strength and modules of rupture improved with increasing volume fraction. Strength models were established to predict the compressive and splitting tensile strength and modules of rupture of the fibre-reinforced concrete.

T.Suresh Babu,M.V.Seshagiri Raoand D.Rama Seshu [2] (2008) have made to study mechanical properties and stress-strain behaviour of self compacting concrete glass fibre reinforced self compacting concrete was arrived based on Nan-Su method of mix design proportion was fine tuned by using Okamura's guidelines. Five self compacting concrete with different mineral admixtures like fly ash, ground granulated blast furnace slag and rice husk ash were taken for investigation with and without incorporating glass fibres. Incorporation of glass fibres by 0.03% i.e. 600grams/m of concrete increased the strengths at 28 days by 2.0 to 5.5% in compression,3.0 to7.0% in tension, and 11.0 to 20.0% inflexure.Also incorporation of glass fibres enhanced the ductility of self compacting concrete.

T. Jiang J.G. Tang (2007) [3] Many stress–strain models have been developed for fibre-reinforced polymer (FRP)–confined concrete. These models fall into two categories: (a) design-oriented models in simple closed-form expressions for direct use in design; and (b) analysis-oriented models in which the stress–strain curve is generated via an incremental process. This paper is concerned with analysis-oriented models, and in particular, those models based on the commonly accepted approach in which a model for actively confined concrete is used as the base model. The paper first provides a critical review and assessment of existing analysis-oriented models for FRP–confined concrete. For this assessment, a database of 48 recent tests conducted by the authors' group is presented; this database includes 23 new tests, which have not previously been published. This assessment clarifies how each of the key elements forming such a model affects its accuracy and identifies a recent model proposed by the authors' group as being the most accurate. The paper then presents a refined version of this model, which provides more accurate predictions of the stress–strain behaviour, particularly for weakly confined concrete. A model affects its accuracy and identifies a recent model proposed by the authors' group as being the most accurate. The paper then presents a refined version of this model, which provides more accurate predictions of the stress–strain behaviour, particularly for weakly confined concrete.

NRD Murthy, RamaSeshu D, MVS Rao [4] (2007) Have discussed the stress-strain behaviour of ordinary and fly ash concrete with steel fibres. The design was as per IS mix design code 10262-1982. Cement was replaced by fly ash up to 40% at regular intervals of 10%.Plain cylinders with 1% steel, cylinders with fly ash 10% and 1% steel, 20% fly ash and 1% steel,30% fly ash and 1% steel and 40% fly ash and 1% steel were cast. The split tensile strength of plain concrete was evaluated. Concrete with fly ash and steel showed an improvement on ductile behaviour. They proposed and empirical equation to predict the behaviour of such concrete under compression. The static moduli of elasticity of concrete at various percentage replacements of fly ash are reported. The energy absorption capacity of steel fibred fly ash concretes was evaluated. The percentage of steel fibres added is kept constant at1% and aspect ratio as 75 for all types. The normalized stress-strain curves were plotted and the proposed equation showed a good correlation with experimental values.

Mahesh Y.V.S.S.U and Manu Santhanam[5](2004) :Authors made an attempt to correlate field test methods for flow behaviour of SCC, so that these can be used interchangeably. Based on laboratory work, the slump flow value and the U-box test can be used to qualitatively characterize the SCC mixture as acceptable or unacceptable.Visosity of SCC mixture decreases with an increase in the water to powder-ratio. The decrease in viscosity is indicated by drop by drop in T50 and V-funnel flow time and the T50 slump flow, thus the two stages can be used interchangeable in the field.

III. EXPERIMENTAL PROGRAMME

In the first phase of the investigation, 30MPa self compacting concrete (SCC) with steel fibres was developed satisfying all the basic requirements of fresh SCC. In the second phase, the mechanical behaviour of SFRSCC was studied. Using the stress-strain results under axial compression, mathematical models were developed and compared.

IV. MATERIALS USED

53 grade ordinary Portland cement confirming to IS 12269, river sand confirming to zone II and coarse aggregate confirming to IS 2386 were used in the present investigation. Type II fly ash obtained from Vijayawada thermal power plant confirming to IS 3812 was used. Super plasticizer (SP) and viscosity modifying agents (VMA), with poly carboxylic ether based were used in the development of SCC. Steel fibres of 0.4 mm diameter, 12 mm length with an aspect ratio of 30 were used in developing SFRSCC. The mix details are shown in Tables 1 and 2. All the SCC mixes satisfied the EFNARC guidelines.

V. SPECIMEN PREPARATION AND TESTING:

Cubes of 150 x 150 x150 mm and cylinders of 150 mm diameter 300 mm length were cast for studying the compressive strength and stress-strain behaviour of M_{30} grade concretes with steel fibres. The specimens were cured as per BIS specifications and tested in 1000 KN strain controlled universal testing machine.

VI. RESULTS AND DISCUSSION:

Experimental results database (Tables 1-2) shows that the major cement type that is used is ordinary Portland cement, the major fillers that are used in the mix designs are fly ash. The test results of fresh properties of SCC are shown in Table 3. The compressive strength of cubes and cylinders for the SCC with different types of fibres are shown in Table 4. The optimum fibre dosages are arrived at based on trial mixes.As shown in Table 4 the compressive of PSCC and SFRSCC are 35.31 MPa and 37.91MPa respectively. Although, the available peak strain data is limited but application of its relationship for using in proposed compressive stress strain relationship is appropriate. Figure-1 shows Stress-Strain behavior of PSCC and SFRSCC without confinement. Figure-2 shows the normalized Stress-Strain behavior of PSCC and SFRSCC without confinement. Figure-3 shows the actual Stress-Strain curve behavior comparing with analytical model. Figure-4 shows the normalized Stress-Strain curve behavior comparing with analytical model. From the stress-strain curves from Fig 1 the values of ultimate strength (f_u), strain at ultimate strength (ε_u), and strain at 85% for ascending ($\varepsilon_{0.85u}$ Asc) and descending portion ($\varepsilon_{0.85u}$ Dsc) were obtained for different SCC mixes which are shown in Table 5.

Table 1 Mix Proportion details of M_{30} grade plain mix

Grade of concrete	Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Fly Ash kg/m^3	Water kg/m^3	SP lt/m^3	VMA lt/m^3
M_{30}	330	860.6	794.4	150	186	6.75	0.33

Table 2 Mix Proportion details of M_{30} grade SFRSCC mix

Grade of concrete	Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Fly Ash kg/m^3	Steel Fibre kg/m^3	Water kg/m^3	SP lt/m^3	VMA lt/m^3
M_{30}	330	860.6	794.4	150	31.42	186	6.75	0.33

Table 3 Fresh properties of PSCC and SFRSCC satisfying EFNARC specifications

S. No	Fresh concrete properties					Remarks	Designation
	Slump Test		V Funnel Test		L Box Test		
	Slump mm	T50 time Sec.	Time for Discharge	T5 min. Sec.	H2/H1		
1	655	2.08	6.17	20.53	0.60	RNS	PSCC-1
2	642.5	3.92	8.66	14.95	0.634	RNS	PSCC-2
3	670	2.68	3.93	8.31	0.947	RS	PSCC
4	580	6.80	9.55	15.60	0.756	RNS	SFRSCC-1
5	620	6.24	8.55	11.60	0.926	RNS	SFRSCC-2
6	655	4.27	6.17	9.82	0.88	RS	SFRSCC

RNS – Results not satisfactory in fresh state
RS – Results satisfactory in fresh state

Table 4 Fibre dosage details and strength properties

S.No	Designation	Fibre dosage (kg/m^3)	Cube compressive strength (MPa)	Cylinder compressive strength (MPa)
1	M_{30} PSCC	-	35.31	26.82
2	M_{30} SFRSCC	31.42	37.90	27.67

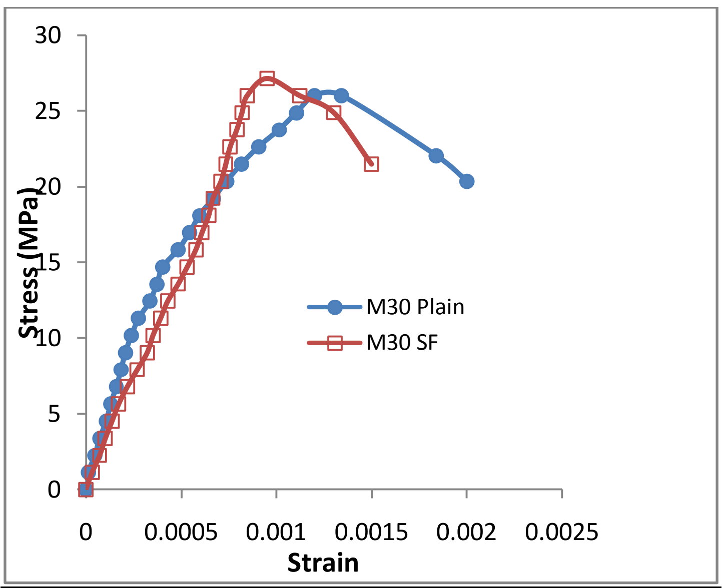

Fig. 1 Stress-Strain behavior of different types of SCC

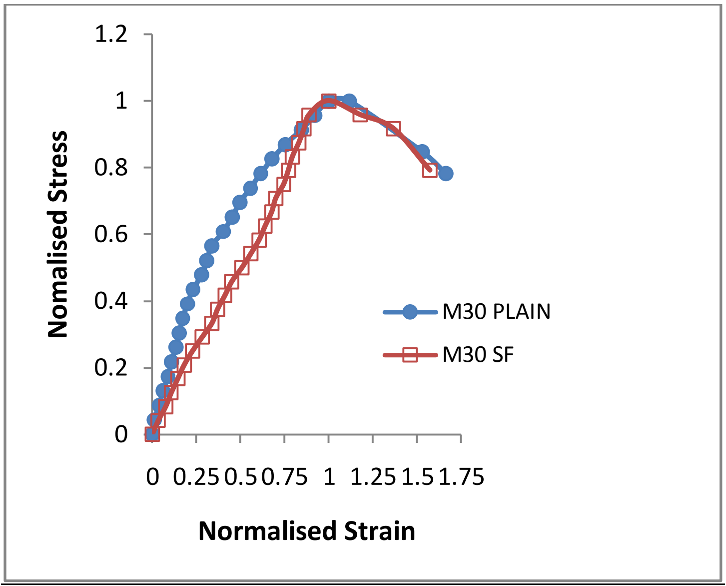

Fig. 2 Normalised Stress-Strain behavior of different types of SCC

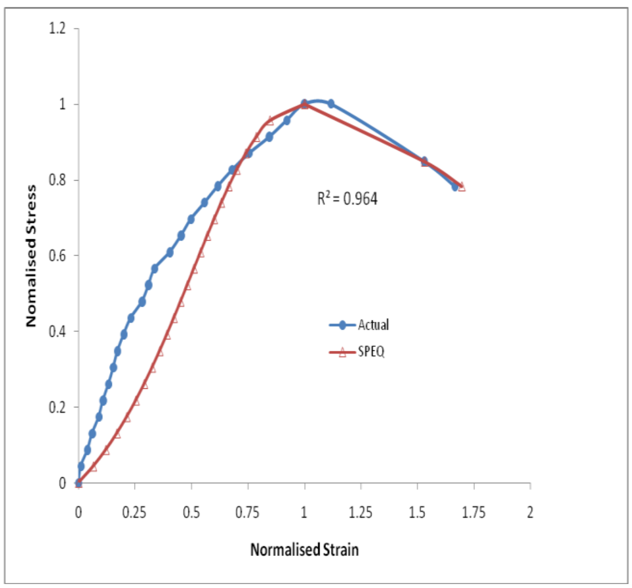

Fig. 3 Comparison of actual and model Stress-Strain curves for SCC

ISSN 2348 – 8034
Impact Factor- 4.022

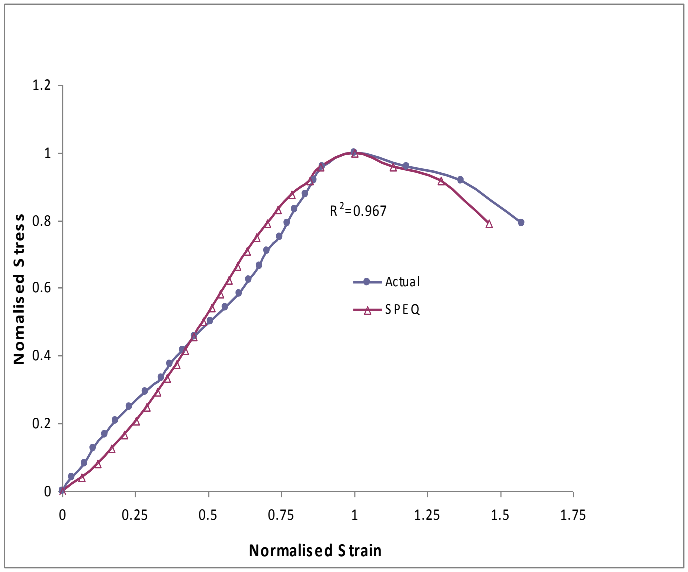

Fig. 4 Comparison of actual and model Stress-Strain curves for SFRSCC

Fig. 5 Cylindrical specimen subjected to axial compression

Table 5 Peak Stress and Peak Strain

Sl. No	Designation	Peak stress N/mm^2	f_u/f'	Strain at peak stress	$\varepsilon_u/\varepsilon'$	$\varepsilon_{0.85u}$ Asc x 10^{-6}	$\varepsilon_{0.85u}$ Dsc x 10^{-6}
1	M_{30} PSCC	26.02	1.045	0.00120	1.00	867	1516.62
2	M_{30} SFRSCC	27.15	1.000	0.00095	1.26	772	1395.33

VII. STRESS-STAIN BEHAVIOR

From the Stress-Strain curve shown in Fig.1, it can be observed that the behavior is almost similar for plain SCC and SFRSCC. However it is observed that stress and corresponding strain increases with the introduction of fibres. Further it is also observed that the increase in stresses and strains are more in SFRSCC. Single polynomial equations (SPEQ) were proposed for different types of SCC mixes as shown below.

The model is taken in the form of

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

Where f is the stress and ε is the strain at different levels. The non dimensional stress-strain equation is given in the form

$$f/f_u = \frac{A(\varepsilon/\varepsilon_u)+D}{1+B_1(\varepsilon/\varepsilon_u)+C(\varepsilon/\varepsilon_u)^2} \quad \text{------------ (2)}$$

The boundary conditions for ascending and descending portion of the stress-strain curve are
At $\varepsilon/\varepsilon_u=0$; $f/f_u=0$; At $\varepsilon/\varepsilon_u=1$; $f/f_u=1$; At $\varepsilon/\varepsilon_u=1$; $d(f/f_u)/d(\varepsilon/\varepsilon_u)=1$

Additional boundary conditions used for ascending portion are as follows:
For plain SCC: at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.721$;
For SFRSCC; at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.809$.

Additional boundary conditions used for descending portion of stress-strain curve are
For plain SCC: at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=1.524$;
For SFRSCC; at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=1.464$.

Based on the above conditions, the constants for ascending and descending portions of the curve are as follows:
A=1.027; B=-0.973; C=1; D=0 for SCC (Plain); A=0.84; B=-1.164; C=1; D=0 for SFRSCC.

The non dimensional stress-strain graphs are shown in Fig.3 and 4. The regression coefficients for SCCand SFRSCC are 0.964 and 0.967 respectively.

VIII. CONCLUSIONS

1. PSCC and SFRSCC concrete of M30 grade satisfying EFNARC guide lines can be prepared with improved performance.
2. It is observed that there are improvements in stress strain behaviour for both PSCC and SFRSCC.
3. The compressive strength of concrete was improved by 6.23% for PSCC and 7.13% for SFRSCC.
4. In the case of PSCC and SFRSCC there is a gradual reduction in stress with increase in strain when compared to plain SCC indicating more strain absorbing capacity.
5. Different analytical models in the form of single polynomial equations were proposed for PSCC and SFRSCC

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ISSN 2348 – 8034
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