Evaluation of Stress Block Parameters for SCC with Recycled Concrete Aggregate

Neethu Elizabeth John, Akhil Raj S. R.

Abstract—The objective is to find the equivalent stress block parameters namely, the effective average concrete ratio and the stress block depth factor for Self Compacting Concrete(SCC)with recycled aggregate (RSCC). An experimental investigation is carried out on the stress strain characteristics of SCC by partially replacing 25, 50, 75 and 100 % of coarse aggregate by recycled concrete aggregate for varying design strength 30, 40, 50 MPa under monotonically increasing axial loading. A total of 45 cylinders are prepared to develop a stress strain model for RSCC. The results arethen compared with the existing models used for SCC and the Saenz model was found applicable for finding the stress block parameters. The proposed parameters were found to be lesser than the values for normal concrete specified by IS 456 and that these parameters could be used to determine the flexural strength of members mentioned above.

Index Terms--Recycled concrete aggregate, Saenz model, Self Compacting Concrete, steel fibre, stress block parameters

1 INTRODUCTION

SCC is a highly workable concrete which flows by its own weight. SCC was first developed in Japan by Hajime Okamura in 1986. The SCC can flow through and fill the gaps of reinforcement and corners of moulds easily without any need for vibration and compaction during the placing process [1]. Sustainability of SCC can be improved by replacing mineral aggregates by industrial waste like rubber, recycled aggregate, granite powder etc.

A large quantity of concrete wastes often produced from demolished old structures, tested concrete and excess or returned concrete. As the natural aggregate is becoming scarce and because of the increasing landfill charges, Recycled Concrete Aggregate (RCA) derived from concrete wastes has growing interest in construction industry [2]. In this context, the recycling of concrete wastes is carried out which would minimize the environmental pollution caused due to demolished waste disposal and can also reduce the huge consumption of natural aggregates in construction.

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Stress block parameters are predominantly used for the design of concrete structural members and offer an efficient and convenient way fordetermining the structural design components. The stress strain model when it's improved, more reliable will be the estimate of strength and deformation behaviour of concrete structural members [5], [6]. Since no stress strain studies have been carried out so far on SCC with recycled aggregate, a well-developed stress strain model is essential to enable a rational analysis of flexural members made using the above composites and to perform rapid design checks. In this paper an attempt has been made to develop a stress strain model for RSCC and also to evaluate the stress block parameters namely the effective average concrete stress ratio (α_1) and the stress block depth factor (β_1).

2 MATERIALS AND MIX ROPORTIONS

Portland Pozzolana Cement (PPC) of 53 grade satisfying IS12269:1987 is used for this experimental investigation. Coarse aggregates of maximum size 12.5 mm, specific gravity 2.85 is used for casting the cubical and cylindrical specimens. M sand passing through 4.75 mm sieve and having specific gravity 2.457 is used as fine aggregate for this study. Recycled concrete aggregate is obtained from the demolition waste of twelve year old building of Mar Baselios College of Engineering and technologyand has specific gravity2.588. This recycled aggregate is used as a replacement for natural coarse aggregate in different percentages. Silica fume obtained from ElkemPvt. Ltd. is used as the mineral additive in this study. Cerahyperplast XR-W40, which is a polycarboxylate ether based super plasticizer is used for this work. The preliminary tests were conducted for the materials before designing the mix. Constituents of the mix are given in Table 1.

SCC mix was developed according to Nan Su method of mix design for SCC [3]. Trial mixes need to be prepared for varying percentages of cement, silica fume (SF), fine aggregate (FA), natural coarse aggregate (NCA), Super plasticizer (SP) and water-cement ratio (w/c); and each mix is to be tested for its workability by conducting slump flow test, L- box test, V- funnel test and 28-day cube compressive strength as per EFNARC guidelines [4]. The fresh and hardened properties are given in Table 2. Test results shows that using 100% recycled aggregate was found comparable for all three mix when the workability and strength criteria were compared.

TABLE 1

MIX PROPORTION FOR THE CYLINDRICAL SCC SPECIMENS

Designation	RCA	NCA	RCA	FA	Cement	Silica	Water	SP
	%	kg/m³	kg/m³	kg/m³	kg/m³	%	w/c ratio	%
SCC30	-	**752.73**	**-**	**1008.4**	**400**	**5**	**0.336**	**1.6**
RSCC30-25%	25	564.55	161.59	1008.4	400	5	0.336	1.6
RSCC30-50%	50	376.36	323.18	1008.4	400	5	0.336	1.8
RSCC30-75%	75	188.18	484.77	1008.4	400	5	0.336	1.8
RSSCC0-100%	100	-	646.36	1008.4	400	5	0.336	1.8
SCC40	**-**	**802.05**	**-**	**953.21**	**450**	**6**	**0.314**	**1.5**
RSCC40-25%	25	601.54	172.36	953.21	450	6	0.314	1.5
RSCC40-50%	50	401.03	344.73	953.21	450	6	0.314	1.6
RSCC40-75%	75	200.51	517.09	953.21	450	6	0.314	1.7
RSCC40-100%	100	-	689.45	953.21	450	6	0.314	1.7
SCC50	-	**802.05**	**-**	**953.21**	**510**	**5**	**0.301**	**1.5**
RSCC50-25%	25	601.54	172.36	953.21	510	5	0.301	1.5
RSCC50-50%	50	401.03	344.73	953.21	510	5	0.301	1.5
RSCC50-75%	75	200.51	517.09	953.21	510	5	0.301	1.6
RSCC50-100%	100	-	689.45	953.21	510	5	0.301	1.6

3 TESTING

The stress strain characteristics were carried by testing 45 cylinders of height 300mm and diameter 150mm using a 1000kN UTM. For each mix total of three specimens were cast and the average of the three were taken for the analysis. While casting the specimens, two steel flats at 50 mm spacing from centre were inserted into the core concrete through the slots made in the cylindrical mould to measure the deformations using the LVDT (Linear Variable Differential Transducer). The core deformations corresponding to each 10 kN load over this 100mm gauge length were recorded using LVDT attached to the flats. The cylinders were subjected to monotonic axial compression until failure and the failure pattern was also taken. Fig. 1 shows the test set up.

Fig. 1. Test set up

TABLE 2

FRESH AND HARDENED PROPERTIES

Name	Slump flow	T 50cm slump	V-funnel time	V funnel at 5 minutes	L- box value	Compressive strength
	(mm)	(s)	(s)	(s)		(MPa)
SCC30	705	4.5	10	12	0.83	35.58
RSCC30-25%	705	4.5	10	12	0.83	34.89
RSCC30-50%	700	4.8	11	13	0.82	34.22
RSCC30-75%	695	4.8	11	14	0.82	33.75
RSSCC0-100%	695	5.0	11	14	0.81	32.00
SCC40	705	4.4	10	13	0.84	47.55
RSCC40-25%	702	4.3	10	13	0.83	47.11
RSCC40-50%	700	4.5	11	14	0.83	46.00
RSCC40-75%	700	4.6	11	14	0.82	45.55
RSCC40-100%	695	4.6	11	14	0.81	44.88
SCC50	706	4.5	9	12	0.84	55.68
RSCC50-25%	705	4.5	9	12	0.84	55.22
RSCC50-50%	705	4.6	10	13	0.83	54.45
RSCC50-75%	700	4.7	10	13	0.82	53.18
RSCC50-100%	700	4.8	11	14	0.81	52.78

4 RESULTS AND DISCUSSIONS

4.1 Stress Strain Characteristics

The stress strain curves were plotted for SCC and RSCCspecimens with 30, 40 and 50 MPa design strength. The peak stress and strain values for all the specimens are shown in Table 3. It was seen that the strain values corresponding to peak stress decreased as the strength of concrete increases. This indicates that as the strength of concrete increases the material becomes brittle [5], [6]. As the percentage of recycled aggregate increases it was found that the stress values decreased because as the aggregate are reused it loses some strength and tends to be brittle. The better performance of recycled aggregate in the present study may be due to high powder content and reduced coarse to fine ratio.

TABLE 3

PEAK STRESS AND CORRESPONDING PEAK STRAIN

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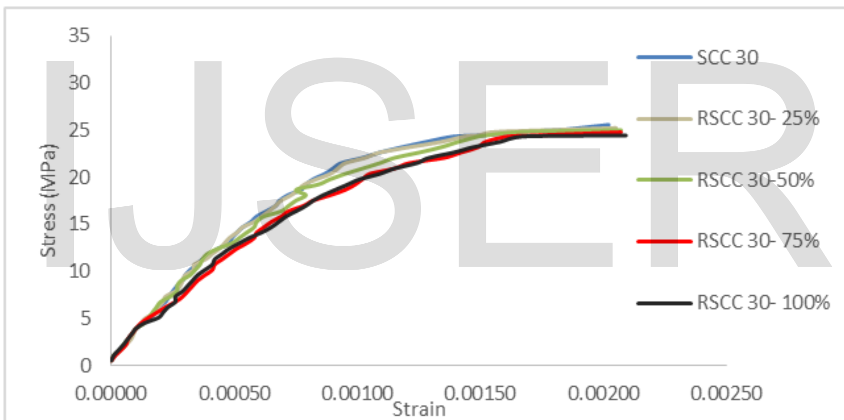
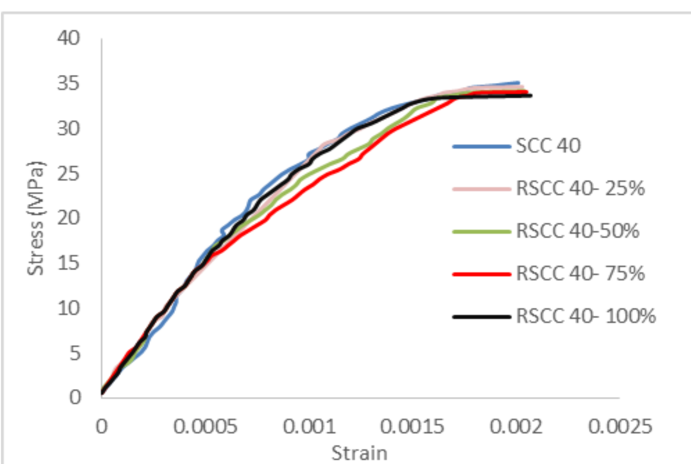
Mix designation	Peak stress (MPa)	Strain at peak stress	Mix designation	Peak stress (MPa)	Strain at peak stress
SCC 30	25.59	0.00202	RSCCC 40-75%	33.08	0.00205
RSCCC 30-25%	25.25	0.00205	RSCCC 40-100%	32.12	0.00207
RSCCC 30-50%	25.02	0.00207	SCC 50	39.75	0.00200
RSCCC 30-75%	24.80	0.00207	RSCCC 50-25%	37.59	0.00201
RSCCC 30-100%	23.02	0.00209	RSCCC 50-50%	36.69	0.00204
SCC40	35.10	0.00201	RSCCC 50-75%	34.99	0.00205
RSCCC 40-25%	34.65	0.00203	RSCCC 50-100%	34.08	0.00207
RSCCC 40-50%	34.20	0.00204			

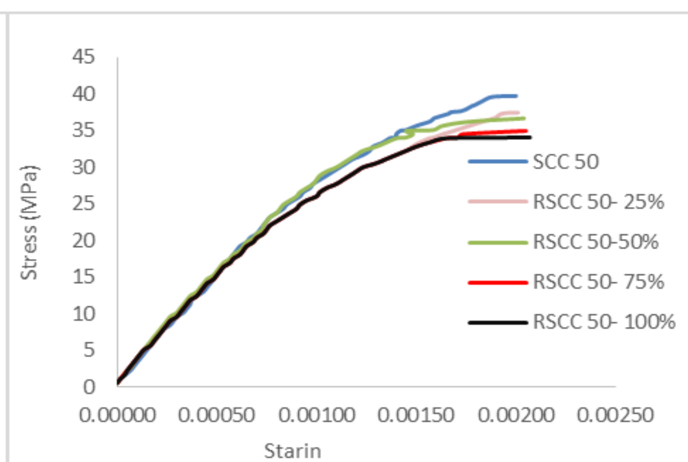
Since the mixing procedure adopted was TSMA (Two Stage Mixing Approach) [14], the fine particles fills into the pores and provides better strength as well as reduced water absorption The presence of interfaces between the new cement mortar–aggregate, old cement mortar–aggregate, and old cement mortar–new cement mortar may give rise to a progressive development of micro-cracks at these interfaces [7]. Thus, the strain was found to increase when the percentage of RCA was increased. Fig. 2 shows the stress strain graphs for all the specimens.



(a) Stress strain graphs for all SCC 30 mixes



(b) Stress strain graphs for all SCC 40 mixes



(c) Stress strain graphs for all SCC 50 mixes

Fig. 2. Stress strain curves for various mixes of SCC 30, SCC 40 and SCC 50

4.2 Evaluation of Stress Block Parameters [5], [15]

The Saenz stress-strain model of concrete was found applicable for SCC and recycled concrete aggregate from previous journals and so the same was verified with the prepared specimens. Experimentally the stress and the strains were recorded and stress strain graphs were plotted using the non-dimensional values (dividing each strain and stress by their peak values). To express the theoretical stress strain behaviour in non-dimensional form Saenz proposed the following equation

$$\frac{f}{f_u} = \frac{A'(\frac{\varepsilon}{\varepsilon_u})}{1+B'(\frac{\varepsilon}{\varepsilon_u})^2} \qquad (1)$$

Where, f / f_u = Stress ratio $\varepsilon / \varepsilon_u$ = Strain ratio f_u=Peak stress ε_u= Peak strain

The constants A′ and B′ are evaluated using boundary conditions pertaining to non-dimensionalized stress-strain curve for each mix type. The boundary conditions are (1) The point where curve departs from its straight line (2) The point of peak stress corresponding to peak strain [6].

There are two equations and two unknowns, the values of A′ and B′ can be found. With experimental strain and with constants A′ and B′, the theoretical stress ratio is found using the above equation and graph is plotted between theoretical stress ratio and experimental strain ratio. These non-dimensionalized theoretical stress-strain curves are then superimposed on the non-dimensionalized experimental stress strain curves. Thus if Saenz model is satisfied, the equations pertaining to this model would be used to find out the stress block parameters. The major equations used for finding the stress block parameters are shown below

Stress block parameter without partial safety factor (α_1') is given by "(2)"

$$\alpha_1' = \frac{A_b}{f_{cu} * \varepsilon_{cu}} \qquad (2)$$

Where, f_{cu} *and* ε_{cu} are the ultimate stress and strain, A_b is the area under the stress strain curve given by "(3)"

$$A_b = \frac{A}{2B} \log \left(\frac{1+B\,\varepsilon_{cu}^2}{1+B\,\varepsilon_1^2}\right) \qquad (3)$$

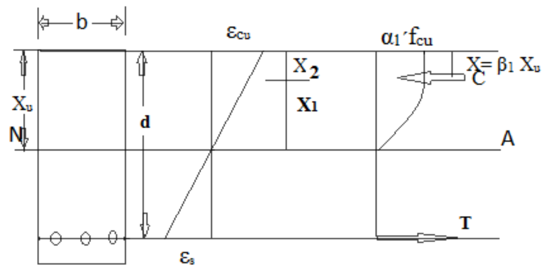


Fig. 3. Stress block diagram

Let x be the distance of the line of action of force C from the extreme top fibre and x is calculated from "(4)"

$$x = \frac{C_1\left(\frac{3}{8}x_1 + X_2\right) + C_2\left(\frac{x_2}{2}\right)}{C} \qquad (4)$$

$$\text{Let,} \quad x = \beta x_u \qquad (5)$$

x depends on x_1, x_2, C_1, C_2 and C which in turn depends on x_u. Thus, we get x in terms of x_u and the constant connecting that gives the value for β, the stress block depth factor. x_1 and x_2 are derived from similar triangles and given by "(6)" and "(7)"

$$x_1 = \frac{\varepsilon_u}{\varepsilon_{cu}} x_u \qquad (6)$$

$$x_2 = \frac{\varepsilon_{cu} - \varepsilon_u}{\varepsilon_{cu}} x_u \qquad (7)$$

Where C_1 and C_2 are the components of the compressive force component for parabolic portion and the rectangular portion given by "(8)" and "(9)"

$$C_1 = \frac{2}{3} x_1 \,(\alpha_1' f_{cu})\, b \qquad (8)$$

$$C_2 = x_2 \,(\alpha_1' f_{cu})\, b \qquad (9)$$

By using the principle of equilibrium, the compressive force is equal to the tensile force, the value of x_u / d is calculated. The equations for finding the compressive force C and tensile force T are given by "(10)" and "(11)"

$$C = \frac{b x_u}{\varepsilon_{cu}} \frac{A}{2B} \log \left(\frac{1+B\,\varepsilon_{cu}^2}{1+B\,\varepsilon_1^2}\right) \qquad (10)$$

$$T = E_s \left(\frac{\varepsilon_s - 0.002}{0.87}\right) A_{st} \qquad (11)$$

ε_1 = Initial strain in concrete ε_{cu} = Ultimate strain in concrete
E_s = Modulus of elasticity of steel
x_u = Depth of the neutral axis
b = Breadth of the section
A and B are the constants obtained from "(12)" and "(13)"

$$A = A'(f_u / \varepsilon_u) \qquad (12)$$

$$B = B'(1/ \varepsilon_u)^2 \qquad (13)$$

Idealization of stress-strain curve is assumed for deriving the expression for compressive force. Experimental data is to be extrapolated beyond the experimental ultimate stress point for idealization of the stress-strain curve. The extrapolation of the curve is done by obtaining further theoretical ultimate values of stress and strain. For this the equilibrium condition (Compressive force = Tensile force) is considered.

For getting the values for C from "(10)"we assign values for parameters x_u, ε_1,ε_{cu} and b.

x_u = 0.1d to 0.5d with an incremental value of 0.1d.
ε_{cu} = 1 x 10^{-4} to 1 x 10^{-3} at an interval of 1 x 10^{-4}
= 2 x 10^{-3} to 1 x 10^{-2} at an interval of 1 x 10^{-3}
= 2 x 10^{-2} to 1 x 10^{-1} at an interval of 1 x 10^{-2}
b = 100 mm
ε_1 = 0

For getting the values for tensile forces from "(11)", values are assigned for parameters A_{st}, E_s and ε_s

A_{st} =Area for 3 no's 8 mm bars (assumed)
E_s = 2.1 x 10^5 MPa
ε_s = 2.2 x 10^{-3} to 1 x 10^{-2} at an interval of 1 x 10^{-3}
d = 125mm

By substituting these values we get the values of C and T for each Xu values. The value of Xu for which C=T is identified by plotting C/T graph vs. strain. From the graph the strain for the equilibrium condition is noted which is named as the theoretical ultimate strain value. Using this value, the area is calculated using the "(3)" and by taking f_u = f_{cu} the stress block parameter α_1'(**effective average concrete stress ratio**) is found from "(2)". The modified parameter α_1 is found by dividing this with the partial safety factor of 1.5. Other parameters in the "(14)" being known, the theoretical ultimate value of stress f_{cu} is obtained from it.

$$C = \alpha_1' f_{cu}\, b\, x_u \qquad (14)$$

Thus we know the value of theoretical f_{cu}, the stress strain curve is extrapolated until this value and the idealization of the stress strain curve is compared. If the experimental and the theoretical stresses are almost same then the assumption is true and we can proceed further with the equations mentioned above for finding the stress block parameters given by "(2)" and "(5)".The regression coefficients R^2 are given in table 4 which is obtained from Fig. 4 and they seem to be nearer to unity and this suggest that the proposed values of constants A′ and B′ could be used further for finding the stress block parameters. The stress block parameters for the prepared specimens were calculated and given in Table 4. The average of these are given in Table 5.

TABLE 4

VALUES OF STRESS BLOCK PARAMETERS FOR VARIOUS MIXES

Type of concrete	Design strength	A'	B'	R^2	α_1	β_1	Xu/d
SCC	30-0%	2.24	1.24	0.90	0.34	0.41	0.37
	40-0%	1.94	0.94	0.91	0.34	0.42	0.37
	50-0%	1.715	0.715	0.95	0.34	0.42	0.37
RSCC (Design strength-Recycled concrete aggregate %)	30-25%	2.205	1.205	0.89	0.36	0.42	0.37
	40-25%	1.806	0.806	0.95	0.34	0.42	0.37
	50-25%	1.656	0.656	0.96	0.30	0.42	0.37
	30-50%	2.289	1.289	0.88	0.35	0.42	0.37
	40-50%	1.816	0.816	0.95	0.34	0.42	0.37
	50-50%	1.816	0.816	0.95	0.34	0.42	0.37
	30-75%	2.301	1.301	0.89	0.35	0.42	0.36
	40-75%	1.856	0.856	0.96	0.34	0.42	0.37
	50-75%	1.701	0.701	0.96	0.34	0.42	0.36
	30-100%	2.356	1.356	0.89	0.35	0.42	0.36
	40-100%	1.787	0.787	0.96	0.34	0.42	0.36
	50-100%	1.806	0.806	0.96	0.34	0.42	0.36

TABLE 5

AVERAGE VALUES OF STRESS BLOCK PARAMETERS

Type of concrete	Stress block parameters		
	α_1	β_1	Xu/d
SCC	0.34	0.42	0.37
RSCC	0.34	0.42	0.37
RSCCSF	0.33	0.41	0.38
Normal concrete (IS 456)	0.36	0.42	0.48

Fig. 4 shows an illustration of the non dimensionalized graph for SCC 50. Here the graph satisfies Saenz model, which shows that the Saenz model is applicable for SCC 50.The ultimate strain value can be obtained from Fig. 5 by taking the average strain of the coinciding points. The idealisation of stress strain curve is shown in Fig. 6. Likewise graphs for all the 24 mixes were prepared in the same manner and if they satisfy the same, then the equations pertaining to this model could be used for finding out the stress block parameters namely the effective average concrete stress ratio (α1), the effective stress block depth factor (β1) and the neutral axis depth to effective depth ratio (Xu/d).

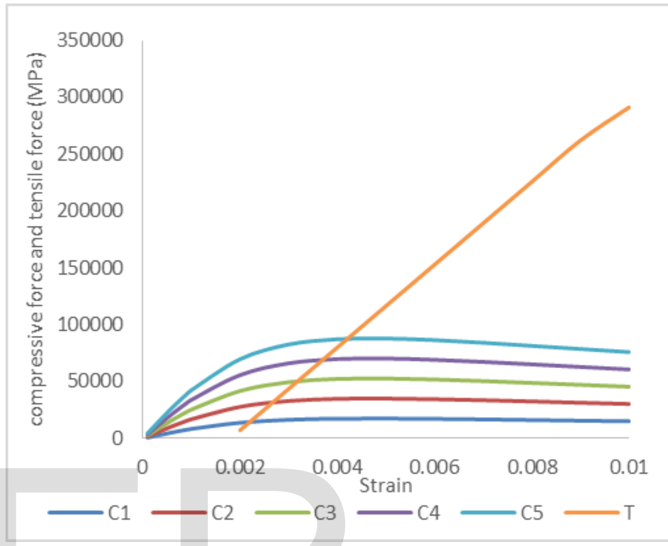


Fig.5. Force strain curve for SCC 50

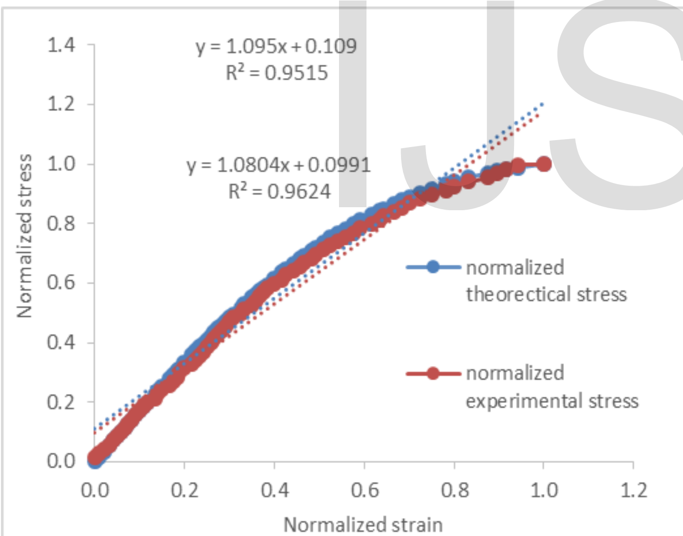


Fig.4. Non dimensionalized stress strain curve for SCC 50

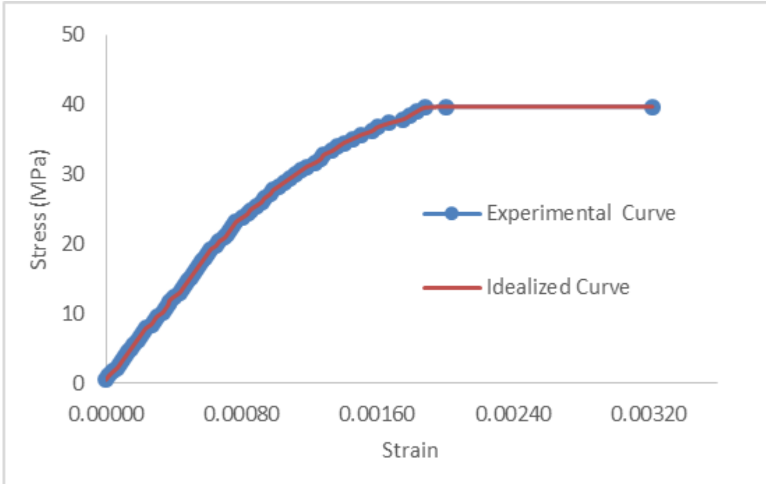


Fig.6. Extrapolated Stress strain graph for SCC 50

5 CONCLUSIONS

The Saenz stress strain model was found to be applicable for all the SCC,RSCC and RSCCSF mixes. The proposed stress block parameters as in Table 5 for the mixes such as effective average concrete stress ratio (α_1), the effective stress block depth factor (β_1) and the neutral axis depth to effective depth ratio (Xu/d) were found to be lesser than the values for normal concrete specified by IS 456 and that these parameters could be used to determine the flexural strength of members made using the above composites.

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