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STRUCTURAL BEHAVIOUR OF FERROCEMENT CONFINED REINFORCED SELF COMPACTING CONCRETE (FCRSCC) UNDER AXIAL COMPRESSION

Vikram Singh Thakur[1], Vikas Khatuja[1], C. Sumanth Reddy[1], K.V. Ratna Sai[1] and Dr. P. Rathish Kumar[1]

[1]*National Institute of Technology, Warangal, India.*
Dept of Civil Engineering, NIT, Warangal, A.P,India,
vikas.krish22@gmail.com, vikrampagalhai@gmail.com, *rateeshp@gmail.com*

ABSTRACT

In this paper, stress-strain diagrams for self-compacting concrete confined with ferrocement shell in addition to lateral tie confinement is presented, based on the experimental results of 102 cylinders of diameter 150mm and height 300 mm tested under axial compression. Increase in the strength and strain of concrete confined with ferrocement shell and lateral tie confinement is found to be linear. A constitutive relation is proposed for the first time for confined SCC to enable the engineers to apply the same for the designing such elements.

Key words. Confinement, Compression, Ferrocement, Self-compacting concrete, Stress-strain curves.

INTRODUCTION

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 typical methods of compaction and vibration of normal concrete generates delays and additional costs in concrete. This has necessitated the research and development of a Self-Consolidating Concrete with better Performance. It is known that framed structures must undergo large inelastic deformations to survive a major earthquake to dissipate energy by ductile behaviour of structural members. Much of this energy is dissipated in plastic hinges that are formed at predetermined locations. It can be seen that higher the degree of indeterminacy of the structure the more will be the concrete strain of failure and consequently rotation capacity required increases at the first hinge that will form in the structure.

The necessity of confining concrete by providing closely spaced circular stirrups to ensure adequate ductility is well established way back (Sheikh, 1982). The stirrup reinforcement provided has to take care of shear and simultaneously provide confinement, however it is established that only stirrup reinforcement provided beyond that required for resisting shear failure will only provide confinement. Hence considering the practical minimum spacing that can be provided at critical sections there is a limitation to the quantity of confinement that can be provided by stirrups. This limitation in confinement offered by ties necessitates the requirement of additional confinement at critical sections in reinforced concrete elements (Balaguru, 1988), (Ganesan , 1993), (Walliuddin, 1994), (Seshu, 1995).The additional confinement can be provided by ferrocement shell (casing). Such a concrete can be termed as Ferrocement Confined Reinforced Self Compacting Concrete (FCRSCC). The complete stress-strain curve of the material in compression is needed for the analysis and design of structures made of this material. In this investigation, the complete stress-strain curve for ferrocement-confined self-compacting concrete has been developed based on experimentation conducted on 150 x 300mm cylindrical specimens tested under axial compression. Review of literature revealed that the requirements of confining steel increases with the increase in strength of concrete (Yong, 1988), (Razvi, 1994).

Further, it is established that the behaviour of normal strength concrete and concrete of higher strength is different (Diniz, 1997).IS 456 – 2000, defines concrete of strength between M30 to M50 as standard concrete. Two grades of concrete have been tested. The effect of two variables Confinement Index and Specific Surface Factor that control the behaviour of tie and ferrocement confinement respectively are introduced and their effect on some of the major parameters namely ultimate strength, strain at ultimate strength, ductility and the stress-strain curve is studied.

RESEARCH SIGNIFICANCE

The present study focuses on understanding the behaviour of confinement of SCC with a ferrocement shell used as a supplementary confinement over and above the traditional tie confinement. It is understood that the ductility of concrete improves the rotational capacity of the structure, which will enhance the structural performance during the earthquakes, blasts and foundation settlements [Paulay, 1992]. The critical sections in statically indeterminate structures at which the first hinge forms are incidentally the sections having maximum shear force. Because of the practicable spacing requirements, supplementary confinement in the form of ferrocement shell becomes very important. The primary objective is aimed at studying the behaviour of confined SCC with ferrocement shell as an additional confinement and generating an analytical model for such a material important for design engineers. To this effect the stress strain curve for FCRSCC is proposed in this paper.

Based on the parameters of this study two variables have been proposed and investigated: (a) Confinement Index (C_i), a parameter including the strength, spacing and dimension of lateral ties, strength of concrete and core dimensions of specimen. This parameter controls the behaviour of tie-confined concrete. The increase in strength or strain at maximum stress of concrete is directly proportional to the Confinement Index

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

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 (1.5 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 respectively. ε_c is the strain at ultimate strength of plain concrete.

b) Specific Surface Factor (S_f), a product of the specific surface ratio and the yield strength of mesh wires in the direction of force divided by the strength of plain mortar. The specific surface ratio is the ratio of the total surface area of the contact of reinforcement wires present per unit length of the specimen in the direction of application of load in a given width and thickness of ferrocement shell to the volume of the mortar for the same width and thickness. This parameter controls the behaviour of ferrocement.

$$S_F = S_r \frac{f_y}{f_p}$$

Where, S_r is the specific surface ratio, f_y is the yield strength of wires and f_p is the plain mortar strength.

EXPERIMENTAL PROGRAM

Materials and mix design

The program consisted of developing Ferrocement based SCC a potential material with good applications particularly at beam column junctions that are expected to behave in a ductile manner. In order to develop a design methodology it is very important to understand the stress strain behaviour of this FCRSCC. A well planned experimental worked was designed. The program consisted of casting and testing of 102 cylinders of size 150 x 300mm each.Ordinary Portland cement (Sp. Gravity 3.15) was used in the investigation.Machine crushed hard granite chips passing through 12.5 mm and retained on 4.75-mm sieve was used as coarse aggregate(Sp.Gravity 2.53, Fineness Modulus 7.92). River sand (Sp.Gravity 2.64, Fineness modulus 2.94) was used for fine aggregate.For ferrocement shell, fine aggregate passing through 1.18-mm sieve was used and for the core concrete, fine aggregate passing through 2.36-mm sieve was used.The cement, fine aggregate, coarse aggregate and flyash used in the two mixes in kilograms per cubic meter of concrete are given in Table 1. The details of the constituent materials for mortar used for ferrocement shell are also given the Table 1.The fresh properties of the SCC for 30 Mpa and 70 Mpa used in the core portion of the specimens are respectively H-Flow of 680mm and 700mm, T_{50} time of 1.58 secs and 3.40 secs, V funnel time of 8.28secs and 8.0 secs, U box test values of 24 and 22 and V_5 minutes of 9.26 and 10.6 secs.

To accommodate the confinement effect due to lateral ties and ferrocement shell casing, two parameters confinement index and specific surface factor as explained earlier were considered. The variation of confinement due to lateral ties was due to the change in the spacing of the lateral ties, while the change in the confinement due to ferrocement shell was achieved by varying the number of layers of mesh (0,2,4) and the type of mesh(P and Q). The details of the cylinders tested are shown in Table 1 while the details of the mechanical properties are shown in Table 2.

Table 1. Mix details of the two grades of SCC

Mix	Cement	Fly ash	Silica fume	Sand	Coarse aggregate	Water	SP (% powder content)
Mix-A (30 Mpa)	276.00	150.0	---	961.0	808	200.0	1.37
Mix-B (70 Mpa)	517.50	86.0	57.50	860.0	786	185.0	2.41
Mortar	774.73	84.2	67.36	842.1	---	296.6	3.15

Table. 2 Mechanical Properties of Longitudinal Steel, Lateral Steel, Mesh Wires

Sl. No.	Designation	Diameter (mm)	Long. Spacing (mm)	Yield Strength (MPa)	Ultimate Strength (MPa)
1.	3.45 mm G.I.	3.45	--	315.0	402.4
2.	5.96 mm M.S	5.96	--	350.0	438.8
3.	Mesh - P	0.40	3.50	276.0	466.0
4.	Mesh - Q	0.56	3.63	380.0	608.0

The fabrication of reinforcement cages was done accordingly using ties and longitudinal steel, the wire mesh sufficient in number of layers to provide the required specific surface factor wrapped over the ties tightly. The mesh was stitched thrice so as not to fail by splitting. The prepared cage of reinforcement was kept in the mould carefully. Spacer rods of 2mm diameter galvanized iron wires were kept temporarily in between the layers of mesh to maintain spacing between the layers and spacing bars of 10 mm are placed to obtain uniform cover of 10 mm. The cylinders were cast in vertical position. First a GI plate is fitted temporarily all along the internal periphery of mesh while filling cover with mortar. Once the mortar got hardened, we removed that plate and then core concrete was filled.It is to ensure that mortar does not enter the core part. Specimens were demoulded 48 hours after casting and cured for 28 days. The cured specimens were capped with plaster of Paris before testing, to provide a smooth loading surface. Tinius-Olsen testing machine of 1810KN Capacity under strain rate control was used for testing the prisms under uniaxial compression. The test was continued until the load dropped to about 75 to 80 percent of the ultimate load in the confined and unconfined specimens.

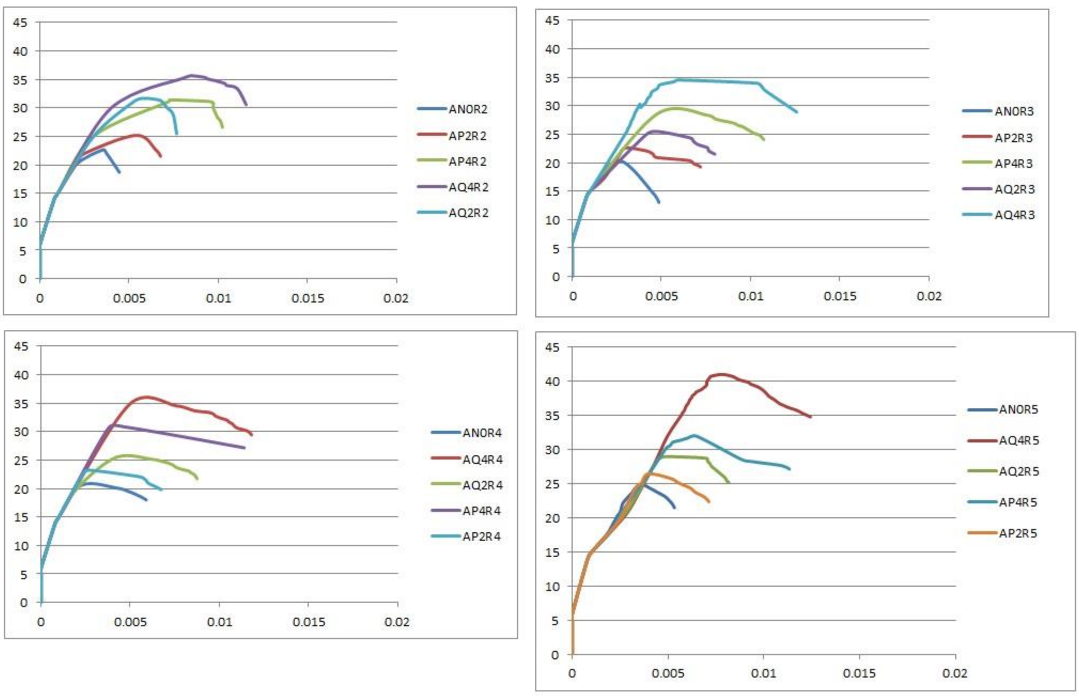
BEHAVIOUR OF TEST SPECIMENS UNDER LOAD

All the specimens were tested under a strain rate control of 670 µ mm/mm per minute. The load increased rapidly in the initial steps up to 75 percent of ultimate load and increased at a slower rate until the ultimate load was reached. Tests were continued until the load dropped by 20 to 25% of the ultimate load. Beyond the ultimate load the strains increased at a rapid rate and were accompanied with a decrease in the load carrying capacity of the specimen. This phenomenon of increase in strain at a constant stress shows that the FCRSCC has a very good ductility. In FCRSCC fine vertical cracks appeared on the surface of the specimen at about 70 to 80 percent of the peak load. With the increase in load, the number of cracks increased and the width of cracks increased at a reduced rate compared to that of specimens with lateral tie reinforcement only. The rate of decrease of load in the descending branch of the stress-strain curve depended upon the amount of reinforcement provided in the ferrocement shell, if the tie confinement is same. The higher the specific surface ratio, the lower was the rate of decrease of load. The maximum stress and the strain at ultimate load and the strain at 85% of the ultimate load in the descending portion of stress-strain curve increased as the specific surface ratio increased if the tie confinement is same. Even when there is only tie confinement the strain at ultimate load and the strain at 85% of ultimate load were more than those of plain specimens. Mesh P and mesh Q were tested on mix A. Both mesh P and mesh Q had shown ductile failure but failure of specimens with mesh Q is more ductile than with mesh P. Mesh Q was tested on mix A and mix B. In FCRSCC mix B, brittle failures (Kumar, 1998) were observed more than in FCRSCC mix A. High bulging is observed in cylinders having 300mm spacing between tie at centre of cylinders.

The behaviour of all the confined specimens up to 75 to 80% of the ultimate load of the plain specimen was about the same. Beyond the ultimate load, the bulging of wire mesh of the specimen and the mortar cover over the mesh of the specimen started spalling. In the case of plain cylinders also the load increased rapidly about 70 to 80% of the ultimate load and later the rate of increase became slow. Beyond the ultimate load the inlet valve of testing machine was almost closed to maintain a uniform strain rate. The average strain at the maximum load for plain specimens ranged between 0.12 and 0.20 percent. Spalling of the specimens was not observed up to 80 to 90% of the ultimate load. The mesh has sufficient bond with concrete even at failure load. It was not separated at any stage for any specimen. The separation of the cover of the specimen is observed near and beyond ultimate stage. The observations that up to 75 to 80% of the ultimate load, the stress strain curves for specimens with no confinement or with ferrocement shell are same leads to the conclusion that the initial tangent modulus of confined concrete is the same as the unconfined.

EXPERIMENTAL STRESS-STRAIN CURVES

From the observed data, for a given specimen, the longitudinal deformations were calculated from the average readings of the four dial gauges of the compressometer. The core area was considered to calculate the stress, since in most of the specimens the cover started spalling off beyond the peak load. Stress-strain curves were drawn for three companion specimens of a set with the same origin and the average curve was taken to represent the set. The experimental results of ultimate strength, strain at ultimate strength and strain at 85 percent of ultimate strength in the descending portion of the experimental stress-strain curves were noted (Figure 1). Table 3 shows the details of the tested specimens.



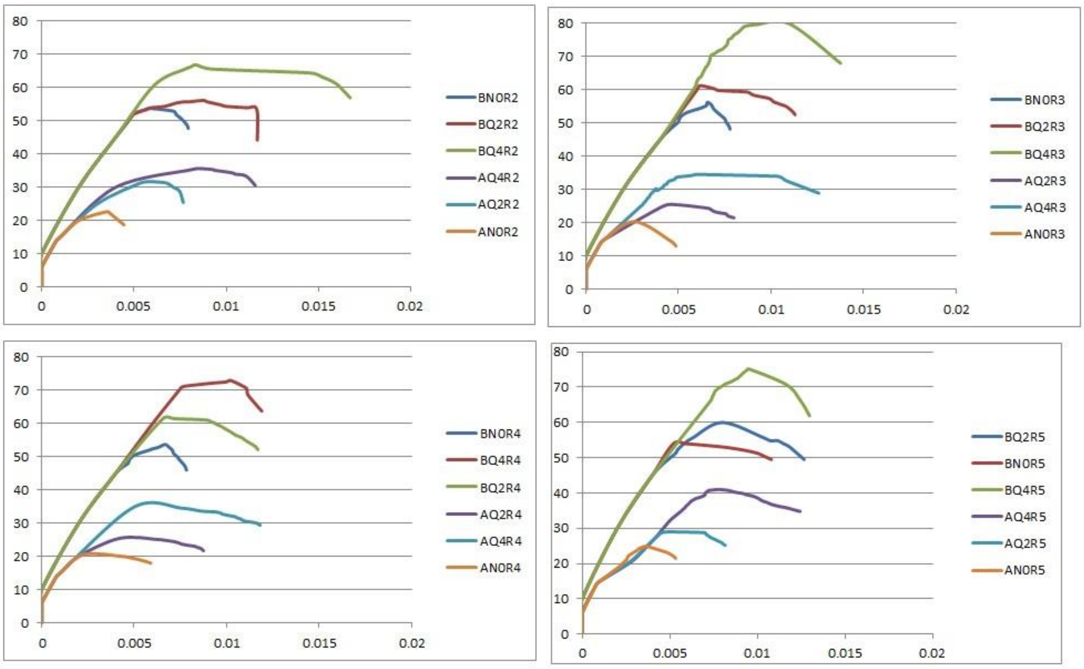


Figure 1. The stress-strain curves of Ferrocement Confined SCC Specimens

Table 3. Details of Prisms Tested

Designation Of Specimen	Long. Steel		Lat. Steel		Concrete Mix	Mesh	S_f	C_i	No. of layers of mesh
	No.	Dia. (mm)	Dia. (mm)	Spa. (cm)		Type			
AN0R0	4	3.450	-	NIL	A	-	0	0	0
AN0R2	4	3.450	5.960	30	A	-	0	0	0
AN0R3	4	3.450	5.960	15	A	-	0	0.068	0
AN0R4	4	3.450	5.960	10	A	-	0	0.156	0
AN0R5	4	3.450	5.960	7.5	A	-	0	0.25	0
AQ2R2	4	3.450	5.960	30	A	Q	4.5	0	2
AQ2R3	4	3.450	5.960	15	A	Q	4.5	0.068	2
AQ2R4	4	3.450	5.960	10	A	Q	4.5	0.156	2
AQ2R5	4	3.450	5.960	7.5	A	Q	4.5	0.25	2
AQ4R2	4	3.450	5.960	30	A	Q	8.99	0	4
AQ4R3	4	3.450	5.960	15	A	Q	8.99	0.068	4
AQ4R4	4	3.450	5.960	10	A	Q	8.99	0.156	4
AQ4R5	4	3.450	5.960	7.5	A	Q	8.99	0.25	4
AP2R2	4	3.450	5.960	30	A	P	3.26	0	2
AP2R3	4	3.450	5.960	15	A	P	3.26	0.068	2
AP2R4	4	3.450	5.960	10	A	P	3.26	0.156	2
AP2R5	4	3.450	5.960	7.5	A	P	3.26	0.25	2
AP4R2	4	3.450	5.960	30	A	P	6.53	0	4
AP4R3	4	3.450	5.960	15	A	P	6.53	0.068	4
AP4R4	4	3.450	5.960	10	A	P	6.53	0.156	4

AP4R5	4	3.450	5.960	7.5	A	P	6.53	0.25	4
BN0R0	4	3.450	5.960	NIL	B	-	0	0	0
BN0R2	4	3.450	5.960	30	B	-	0	0	0
BN0R3	4	3.450	5.960	15	B	-	0	0.027	0
BN0R4	4	3.450	5.960	10	B	-	0	0.06	0
BN0R5	4	3.450	5.960	7.5	B	-	0	0.11	0
BQ2R2	4	3.450	5.960	30	B	Q	4.5	0	2
BQ2R3	4	3.450	5.960	15	B	Q	4.5	0.027	2
BQ2R4	4	3.450	5.960	10	B	Q	4.5	0.06	2
BQ2R5	4	3.450	5.960	7.5	B	Q	4.5	0.11	2
BQ4R2	4	3.450	5.960	30	B	Q	8.99	0	4
BQ4R3	4	3.450	5.960	15	B	Q	8.99	0.027	4
BQ4R4	4	3.450	5.960	10	B	Q	8.99	0.06	4
BQ4R5	4	3.450	5.960	7.5	B	Q	8.99	0.11	4

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ULTIMATE STRENGTH

The ultimate strength of concrete confined with ferrocement shell in addition to lateral ties increased with an increase in specific surface factor. The axial load carrying capacity of the specimen is assumed to consist of three parts viz., i) The load taken by the longitudinal bars provided (P_s), which is equal to $A_s.f_y$, where A_s= Area of longitudinal steel, f_y=Yield strength of longitudinal steel(Table 2) ii) The load taken by the tie confined concrete which is equal to $f_{cb}.A_c$, where f_{cb}=strength of tie confined concrete, A_c=Gross cross sectional area iii) The additional load carrying capacity due to confinement offered by ferrocement shell. Since the ultimate load carrying capacity 'P' is experimentally determined.($P-A_sf_y$) gives the contribution of load carrying capacity due to confinement of both the types as above. The value is non-dimensionalised by dividing with $f_{cb}.A_c$. This means that $(P-A_sf_y)/f_{cb.}A_c$, gives the strength of the concrete as a ratio of strength of concrete confined by lateral ties only. An examination of plot Figure 2 shows that there is a linear relationship between $(P-A_sf_y)/(f_{cb}.A_c)$ and S_f for the same level of confinement.

A regression analysis conducted to fit a straight line between the above two parameters resulted in the equation

$$(P-A_sf_y)/(f_{cb}.A_c)=(.9958+0.0535S_f)$$

$$(P-A_sf_y- f_{cb}.A_c)/(f_{cb}.A_c)=(1+0.56C_i)$$

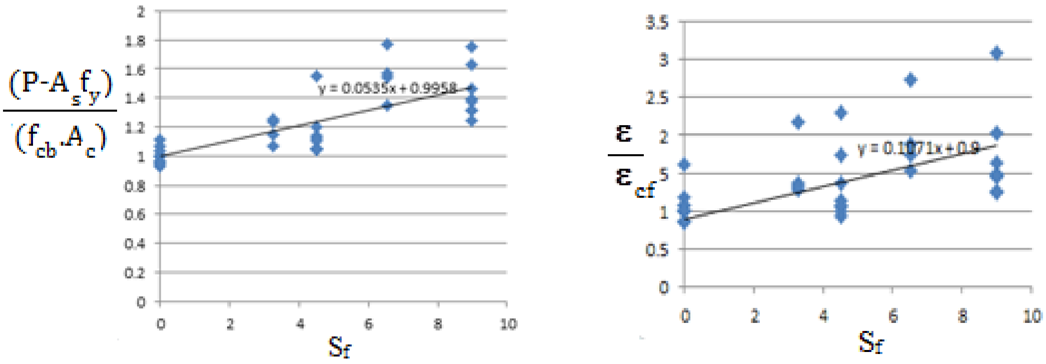

Figure 2. Stress and Strain ratio v/s S_f

STRAIN AT ULTIMATE STRENGTH

The strain at ultimate strength increased with an increase in specific surface factor. Figure 2 shows the plot between the ratio of observed strain (ε) at the ultimate strength of concrete confined by a ferrocement shell, in addition to lateral ties, to the theoretical strain (ε_{cf}) at ultimate strength of concrete confined with lateral ties only and the specific surface factor (S_f). An examination of this plot clearly indicates that there is a linear relationship between S_f and the ratio of strain at the ultimate strength of concrete confined by ferrocement shell in addition to lateral ties to the strain of concrete confined by lateral ties only. A regression analysis conducted to fit straight line between the parameter ($\varepsilon/\varepsilon_{cf}$) and S_f resulted in the equation.

$$(\varepsilon/\varepsilon_{cf}) = (.9+0.1071S_f)$$

$$(\varepsilon_{cf}/\varepsilon_c) = (1+2.15C_i)$$

Where ε=strain at ultimate for concrete without any confinement.

CONFINED CONCRETE DUCTILITY

The ductility of Ferrocement confined concrete as expressed by the strain at 85% of the ultimate strength in the descending portion of the stress strain curve, is increased with an increase in the specific surface factor. The observed strain at 85% of the ultimate strength ($\varepsilon_{.85}$) is expressed in terms of the theoretical strain (ε) given by the equation (5). The following relationship is obtained between the $\varepsilon_{0.85}/\varepsilon$ ratio and the specific surface factor.

$$\varepsilon_{0.85}/\varepsilon = \left\{\left(5.139C_i^{0.286}\right)\right\}\left(2.337+0.055S_F\right)$$

The investigation has shown that the ferrocement shell confinement has very pronounced effect on ductility of concrete. It is found necessary to introduce a factor, called Ductility Factor. The ductility factor is defined as a non-dimensional parameter and is the ratio of strain at 85% of peak stress in the post ultimate (descending) portion of the stress–strain curve of confined concrete as above.

CONCLUSIONS

The following conclusions can be drawn from the experimental investigations on FCRSCC:

1. A Ferro cement shell, with high particle strength mortar between Ferro cement layers is an effective way of providing additional confinement of concrete in axial compression and has the advantage over lateral tie confinement of improving material performance under large deformations.

2. The additional confinement with the Ferro cement shell improved the ultimate strength, the strain at ultimate strength and the ductility of concrete increases with the increase of confinement.

3. The major advantage of FCRSCC over FCRC is that tie with spacing about 7.5cm can also easily be provided due to good passing ability of SCC which results in improvement of ductility of concrete .

4. With the increase of specific surface factor ultimate stress and strain of specimens with Ferro cement shell confinement varies linearly (Kumar,2001), (Kumar , 1998).Variation depends on two parameters namely S_f and C_i(Figure 2).

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