International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013
ISSN 2229-5518

Toughness of Ferrocement Confined Reinforced Self Compacting Concrete (FCRSCC) Under Axial Compression

Vikas Khatuja, Vikram Singh Thakur, Ayush Singhania, Dr. C.B.K. Rao

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. Increase in the toughness of concrete confined with ferrocement shell and lateral tie confinement is found to be linear and a constitutive relation is presented.

Key Words– Compression, Confinement, Confinement Index, Ferrocement, Self-compacting Concrete, Specific surface factor, and Stress-Strain curves.

Notations-

T_c = Toughness for concrete confined with lateral ties only
T_{uc} = Toughness for unconfined concrete
T_{cf} = Toughness for specimens with ferrocement shell in addition to lateral ties
S_f = Specific Surface Factor [12]
C_i = Confinement Index [13]

◆

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 [2]. 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 [3]. The critical sections in statically indeterminate structures at which the first hinge forms are incidentally the sections having maximum shear force. 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 [7],[8],[9], and [10]. 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 [4], [5]. Further, it is established that the behaviour of normal strength concrete and concrete of higher strength is different [6].IS 456 – 2000 [11], 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 a major parameters namely toughness, and the stress-strain curve is studied.

- *Vikas Khatuja is a graduating student of Civil Engineering Department at National Institute of Technology Warangal, India, PH-+919642621990. E-mail: vikas.krish22@gmail.com*
- *Vikram Singh Thakur is an undergraduate student of Civil Engineering Department at National Institute of Technology Warangal, India, PH-+919849154310. E-mail: vikrampagalhai@gmail.com*
- *Ayush Singhania is a graduating student of Civil Engineering Department at National Institute of Technology Warangal, India, PH-+919966579994. E-mail: ayush.xiolt@gmail.com*
- *Dr. C.B.K. Rao is a Professor of Civil Engineering Department at NITW. \E-mail: raocbk@gmail.com*

OBJECTIVE

The experimental work is aimed to study the behaviour of confined SCC with ferrocement skin and prepare stress strain curve for FCRSCC.

MATERIALS AND MIX DESIGN

The program consisted of developing highly compatible SCC and Ferro cement layering with certain controlled variations. The primary materials used in the process are Cement (ASTM type -1, sp.gr 3.10), Fine aggregate (sp gr 2.64, Table 3), coarse aggregate (sp gr 2.53, Table 2), Fly ash (Class F sp gr 2.04), Silica fume, Mild steel are used for ties and Galvanised Iron wire mesh, and their mechanical properties are given in TABLE 4.

Mix design has performed for two grades of concrete, viz. 30 and 70MPa, as per EFNARC space guidelines and two mix proportions are given in Table 1. The preparation of mortar in Ferro cement confinement has been arrived by trials as 1:1 cement and sand, with addition of 10% Fly ash and replacement of cement by 8% silica fume to improve the strength of mortar. The water cement ratio was fixed at 0.382 throughout the process. Sulphonated Naphthalene Formaldehyde condensate based Water reducing plasticizer was used in appropriate proportions to ensure desired workability of the mix.

Galvanised woven wire mesh of square grid fabric was used in ferrocement. 0.4 mm and 0.56 mm nominal diameter galvanised iron wires were used as longitudinal reinforcement.6 mm nominal diameter mild steel were used as lateral reinforcement.

MIX DESIGN

The mix designs for SCC were developed based on literature (Nan Su, 2001), however the aggregate percentages were decided from minimum void ratio testing (H. Bouwers, 2005). The mixes were designed for target strengths of Mix-A (30Mpa), Mix-B (70Mpa). Several numbers of trials were conducted in order to ensure that the mixes conformed to EFNARC properties (EFNARC, 2002). The final mix designs for both the target strengths are given in Table 1.

TABLE 1:
MIX DESIGNS FOR 2 TARGETS

Mix	Mix-A	Mix-B	MORTAR
Cement	276	517.5	774.73
Fly ash	150	86	84.2
Silica fume	---	57.5	67.36
Sand	961	860	842.1
Coarse aggregate	808	786*	---
Water	200	185	296.61
SP (% powder content)	1.37%	2.41%	3.15%

*Maximum size of aggregates varied

TABLE 2 :
Grading of coarse aggregate with fineness modulus equal to 7.27

Sieve size	40 mm	20 mm	10 mm	4.75 mm
Percentage retaining	0	31.4	65.4	2.6

TABLE 3 :
Grading of fine aggregate with fineness modulus equal to 2.94

Sieve size	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm
Percentage retaining	2	4	10	30	48	3

Maximum sizes of aggregates in Mix B are reduced in order to obtain maximum packing accordingly as per Compressive Packing Model.

PARAMETERS OF STUDY

In order to achieve the objective, it is proposed to consider two mixes of concrete viz. mix A, mix B as stated above, variation of volume of lateral ties, and ferrocement mesh reinforcement.6 mm diameter mild steel is used for lateral ties and spacing of lateral ties has been taken as 75mm, 100mm, 150mm, 300mm. Zero, 2 layer, 4 layer of GI wires mesh viz. P and Q are adopted for ferrocement reinforcement. Specimens are designated representing the parameters. Specimen designated AP2R5 stands for A for mix A, P for mesh P,2 for two layer of GI wire mesh,R5 for five number of lateral ties i.e. spacing of 75 mm between the lateral ties. The variables in the study were the specific surface factor (S_f) [12],which controls the behaviour of ferrocement and the confinement index (C_i) [13], which controls the behaviour of tie-confined concrete.

The specific surface factor (S_f) [12], is the product of the specific surface ratio and the yield strength of mesh wires in the direction of the force divided by the strength of plain mortar. The specific surface ratio is the ratio of the total surface area of contact of reinforcement wires present per unit length of the specimen in the direction of the application of load in a given width and thickness of the Ferrocement shell to the volume of mortar. The confinement index (C_i) [13],is a parameter which controls the behaviour of tie confined concrete. The parameters included in the confinement index are the strength, spacing and dimension of lateral ties, strength of concrete and core dimension of the specimen [10].

Toughness(T)[17]indicates how much energy a material can absorb before rupturing. The capacity of energy absorbing (toughness) is determined by calculating the area under experimental stress–strain curves like shown in figure 1

PREPARATION OF SPECIMENS

Reinforcement cage consist of lateral ties and longitudinal bars and ferrocement mesh. Longitudinal bars of 3.45 mm GI wire are used in order to form skeleton in longitudinal direction.

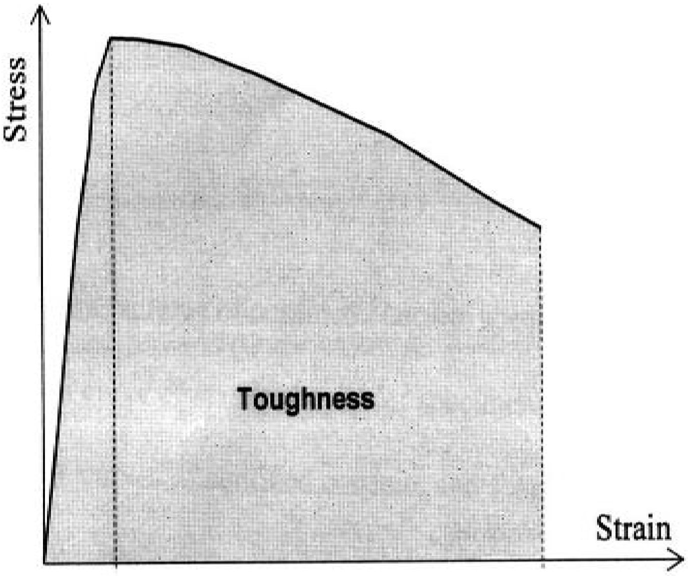


Fig 1: The typical stress–strain curve for determining toughness

CASTING OF SPECIMENS

The prepared cage of reinforcement was kept in the moulds and spacing bars of 10 mm are placed to obtain uniform cover of 10 mm. First, cover was filled with cement mortar and compacted and then core concrete was filled. Specimens were demoulded 48 hours after casting and then cured. Total 102 specimens were casted, of 34 parameters specifications, 3 specimen of each parameter.

TESTING

The cured specimens were capped with plaster of Paris before testing, to provide a smooth loading surface. Tinius–Olsen testing machine of 1810kN capacity was used for testing the cylinders under axial compression. From the studies of previous investigators who worked on concrete confined with ties, it was observed that the cover concrete spalled off at about 90% of the ultimate load. Specimens are tested under uniform strain rate and strains are measured using compressometer.

The test was continued until the load dropped to about 60 to 70 percentage of the ultimate load in the post-ultimate region for both confined and unconfined concrete specimens are recorded.

Fig 2: Specimens at various stresses

Fig 3: Testing of specimens

EXPERIMENTAL STRESS-STRAIN CURVES

The general behaviour of the specimens under axial compression is explained in detail in the earlier paper [15]. The core area was considered to calculate the stress, since in most of the specimens; the cover started spalling off beyond the peak load. Even in the earlier investigations [16], the core area was considered to calculate the stress. Stress-strain curves were drawn for the three companion specimens of a set with the same origin and the average curve was taken to represent the set. Such average curves for all the specimens with a common origin are presented in Fig. 4.Area under stress strain curve of the specimens is calculated and is given in Table 6.

The toughness, varied linearly with specific surface factor for the same level of tie confinement. The prediction equations for the same are shown below. Fig. 5 represents the curve.

$$\frac{T_{cf}}{T_{uc}} = (1 + 2.0438\, C_i)(1 + 0.2015\, S_f)$$

$$T_c = (1 + 2.0438\, C_i)\, T_{uc}$$

BEHAVIOUR OF TEST SPECIMENS UNDER LOAD

(A) The load increased gradually in the initial stages up to about 75% of the peak load and thereafter the increase in load decreased till the ultimate load was reached. Test was continued until the peak load dropped to about 0.65 times the peak load. After reaching the peak load, strain continued to increase with very little reduction in stress. This phenomenon of increase in strain at a constant stress shows that the FCRSCC has a very good ductility.

(B) In FCRSCC fine vertical cracks appeared on the surface of the specimen at about 70% to 80% of the peak load.

(C) 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 behaviour of all the FCRSCC specimens up to 70% of the peak load of the confined RCC specimens was about the same. Beyond the peak load, the mesh wires started bulging and the mortar cover over the mesh reinforcement started spalling. The extent of spalling became severe only after the load dropped to about 0.70 to 0.80 times the peak load. The extent of spalling and the rate of decrease of load after the peak depended upon the specific surface factor (S_f) of the ferrocement shell if the confinement index was same. The higher the specific surface factor (S_f), the lower the rate of decrease of load and the extent of spalling was observed.

(D) Mesh P and mesh Q were tested on mix A. Both mesh P and mesh Q had given ductile failure but failure of specimens with mesh Q is more ductile than mesh P.

(E) Mesh Q was tested on mix A and mix B. In FCRSCC mix B brittle failures [14] were observed more than in FCRSCC mixA.

(F) High bulging is observed in cylinders having 300mm spacing between tie at centre of cylinders.

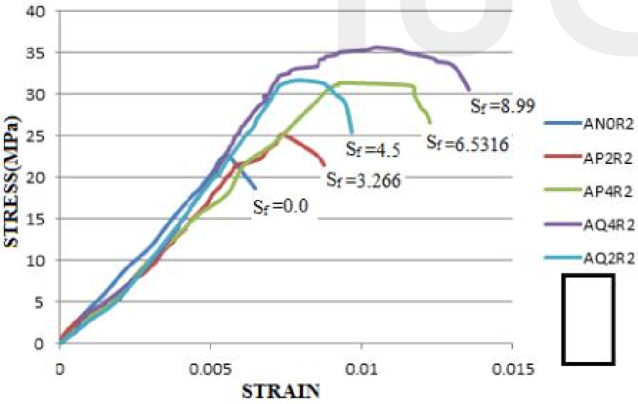
CONCLUSIONS

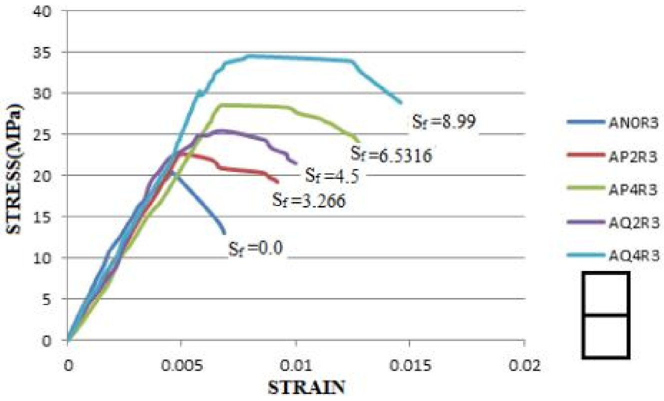
The following conclusions can be drawn from the experimental investigations on FCRSCC:

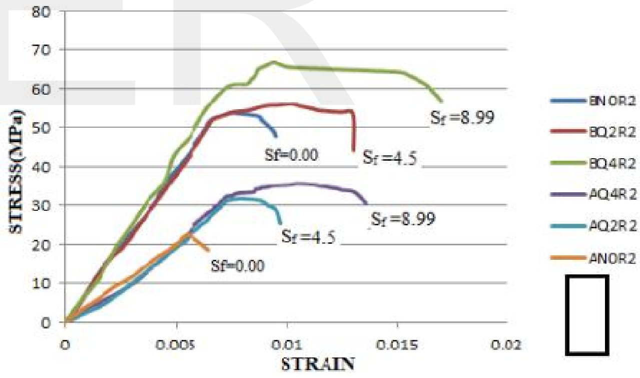
1. A Ferro cement shell, with high particle strength mortar between Ferro cement layers is an effective way of providing additional confinement of concrete in axial compression and has the advantage over lateral tie confinement of improving material performance under large deformations.
2. The additional confinement with the Ferro cement shell improved the toughness, 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 toughness of specimens with Ferro cement shell confinement varies linearly [14], [15].Variation depends on two parameters namely S_f and C_i (see Fig.5).

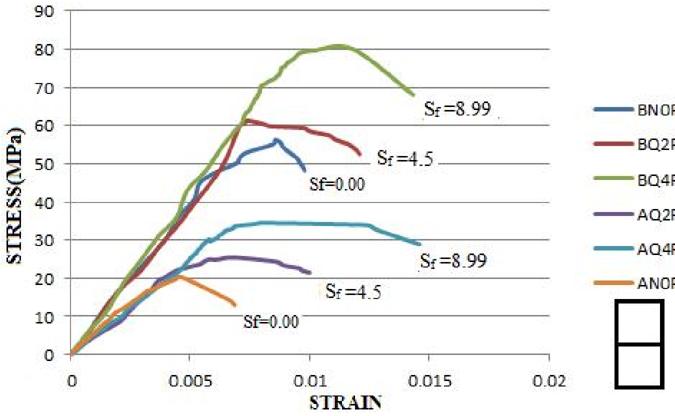
$$\frac{T_{cf}}{T_{uc}} = (1 + 2.0438\, C_i)(1 + 0.2015\, S_f)$$

$$T_c = (1 + 2.0438\, C_i)\, T_{uc}$$









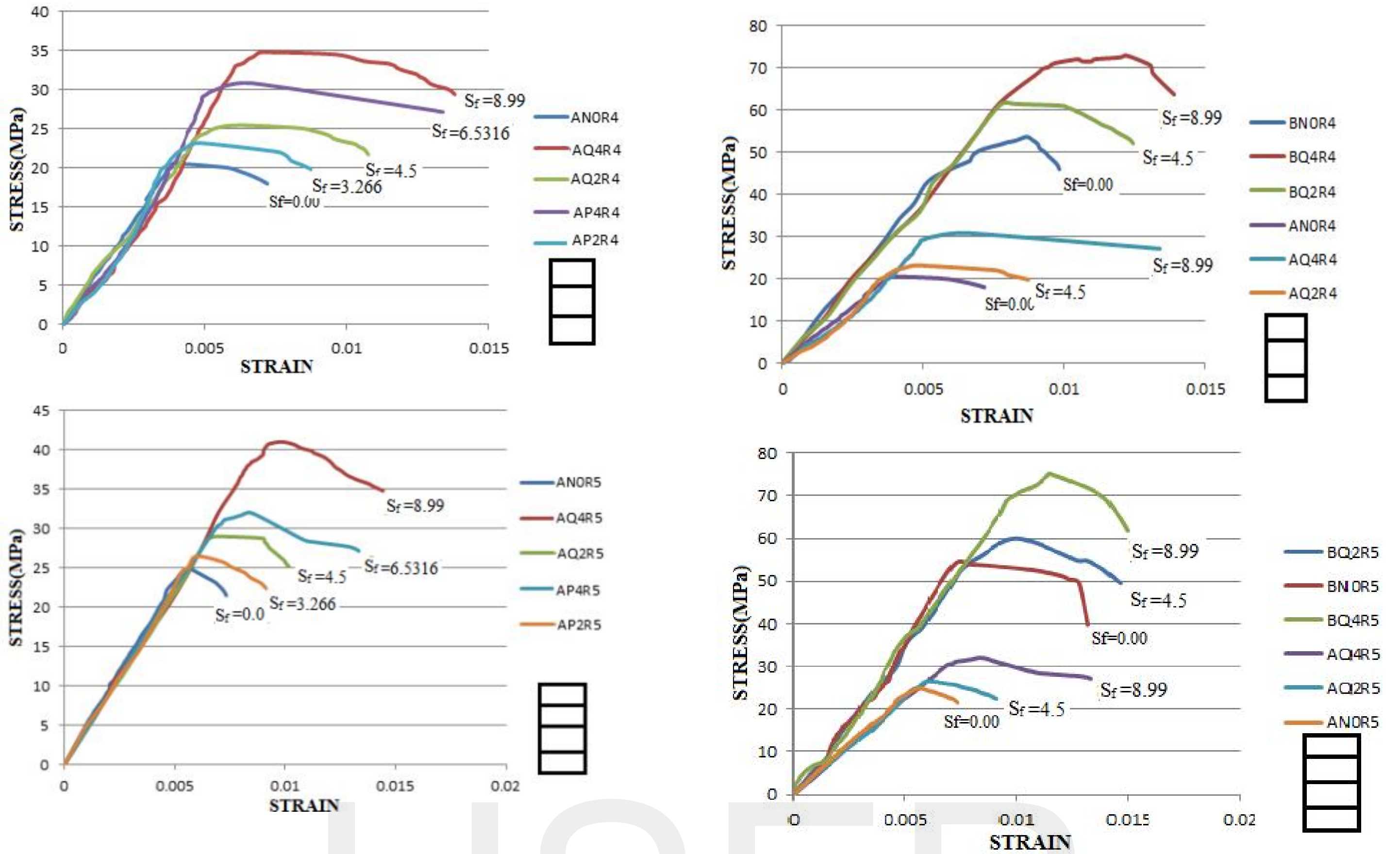


Fig 4: The stress-strain curves of various comparisons of confined ferrocement (Designation of specimens as per Table 5).

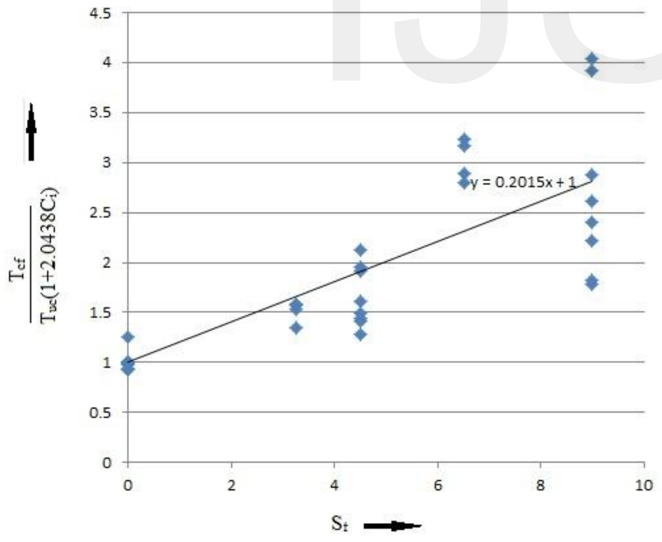
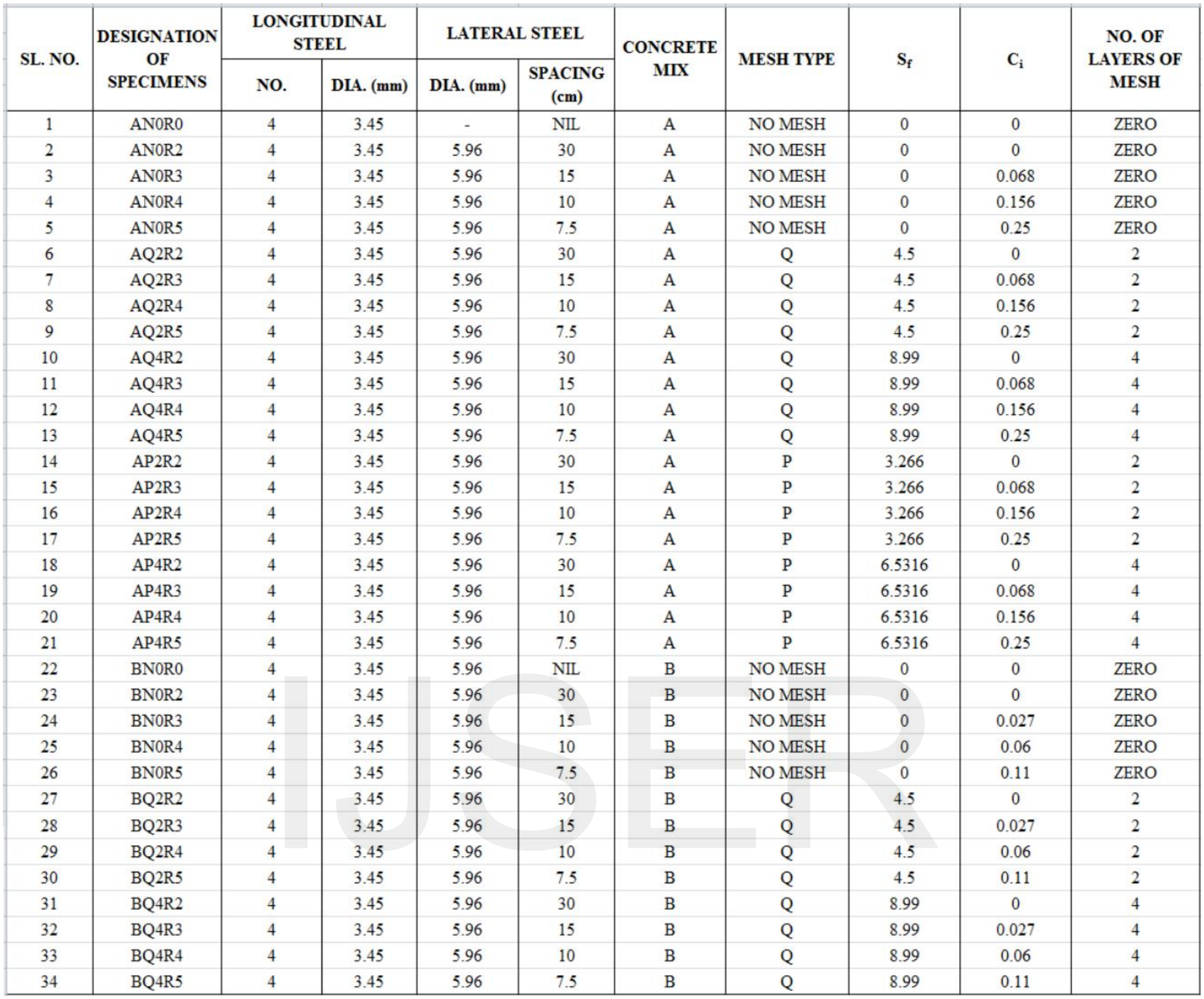


Fig. 5 Toughness Curve

Table 4: Mechanical Properties of Longitudinal Steel (G.I. Wires), Lateral Steel and Mesh Wires.

Sl. No.	Designation	Diameter (mm)	Long. Spacing (mm)	Yield Strength (MPa)	Ultimate Strength (MPa)
1.	3.45 mm G.I.	3.450	--	315.0	402.4
2.	5.960 mm M.S	5.960	--	350.0	438.8
3.	Mesh - P	0.4	3.5	276	466
4.	Mesh - Q	0.56	3.625	380	608

Table 5: Details of Cylinders Tested



SL. NO.	DESIGNATION OF SPECIMENS	LONGITUDINAL STEEL		LATERAL STEEL		CONCRETE MIX	MESH TYPE	S_f	C_i	NO. OF LAYERS OF MESH
		NO.	DIA. (mm)	DIA. (mm)	SPACING (cm)					
1	AN0R0	4	3.45	-	NIL	A	NO MESH	0	0	ZERO
2	AN0R2	4	3.45	5.96	30	A	NO MESH	0	0	ZERO
3	AN0R3	4	3.45	5.96	15	A	NO MESH	0	0.068	ZERO
4	AN0R4	4	3.45	5.96	10	A	NO MESH	0	0.156	ZERO
5	AN0R5	4	3.45	5.96	7.5	A	NO MESH	0	0.25	ZERO
6	AQ2R2	4	3.45	5.96	30	A	Q	4.5	0	2
7	AQ2R3	4	3.45	5.96	15	A	Q	4.5	0.068	2
8	AQ2R4	4	3.45	5.96	10	A	Q	4.5	0.156	2
9	AQ2R5	4	3.45	5.96	7.5	A	Q	4.5	0.25	2
10	AQ4R2	4	3.45	5.96	30	A	Q	8.99	0	4
11	AQ4R3	4	3.45	5.96	15	A	Q	8.99	0.068	4
12	AQ4R4	4	3.45	5.96	10	A	Q	8.99	0.156	4
13	AQ4R5	4	3.45	5.96	7.5	A	Q	8.99	0.25	4
14	AP2R2	4	3.45	5.96	30	A	P	3.266	0	2
15	AP2R3	4	3.45	5.96	15	A	P	3.266	0.068	2
16	AP2R4	4	3.45	5.96	10	A	P	3.266	0.156	2
17	AP2R5	4	3.45	5.96	7.5	A	P	3.266	0.25	2
18	AP4R2	4	3.45	5.96	30	A	P	6.5316	0	4
19	AP4R3	4	3.45	5.96	15	A	P	6.5316	0.068	4
20	AP4R4	4	3.45	5.96	10	A	P	6.5316	0.156	4
21	AP4R5	4	3.45	5.96	7.5	A	P	6.5316	0.25	4
22	BN0R0	4	3.45	5.96	NIL	B	NO MESH	0	0	ZERO
23	BN0R2	4	3.45	5.96	30	B	NO MESH	0	0	ZERO
24	BN0R3	4	3.45	5.96	15	B	NO MESH	0	0.027	ZERO
25	BN0R4	4	3.45	5.96	10	B	NO MESH	0	0.06	ZERO
26	BN0R5	4	3.45	5.96	7.5	B	NO MESH	0	0.11	ZERO
27	BQ2R2	4	3.45	5.96	30	B	Q	4.5	0	2
28	BQ2R3	4	3.45	5.96	15	B	Q	4.5	0.027	2
29	BQ2R4	4	3.45	5.96	10	B	Q	4.5	0.06	2
30	BQ2R5	4	3.45	5.96	7.5	B	Q	4.5	0.11	2
31	BQ4R2	4	3.45	5.96	30	B	Q	8.99	0	4
32	BQ4R3	4	3.45	5.96	15	B	Q	8.99	0.027	4
33	BQ4R4	4	3.45	5.96	10	B	Q	8.99	0.06	4
34	BQ4R5	4	3.45	5.96	7.5	B	Q	8.99	0.11	4

Table 6.Area of Stress-Strain Curves of Specimens

Sno.	Designation of Specimens	Area under stress-strain Curves of specimens	Increased toughness (ratio of areas of particular specimen to specimens without any confinement)	Specific Surface Factor (Sf)	Confinement Index (Ci)
1	AN0R0	0.081	1	0	0
2	AN0R2	0.08166	1	0	0
3	AP2R2	0.12567	1.538942	3.266	0
4	AP4R2	0.236	2.890032	6.5316	0
5	AN0R3	0.081467	0.997631	0	0.068
6	AP2R3	0.128288	1.571	3.266	0.068
7	AP4R3	0.228136	2.793729	6.5316	0.068
8	AN0R4	0.080382	0.984348	0	0.156
9	AP2R4	0.109618	1.342375	3.266	0.156
10	AP4R4	0.263936	3.232136	6.5316	0.156
11	AN0R5	0.076032	0.931076	0	0.25
12	AP2R5	0.129479	1.585592	3.266	0.25
13	AP4R5	0.25822	3.16214	6.5316	0.25
14	AQ2R2	0.173913	2.129721	4.5	0
15	AQ4R2	0.319601	3.913801	8.99	0
16	AQ2R3	0.159353	1.951417	4.5	0.068
17	AQ4R3	0.329272	4.032232	8.99	0.068
18	AQ2R4	0.156078	1.911321	4.5	0.156
19	AQ4R4	0.234799	2.875327	8.99	0.156
20	AQ2R5	0.105056	1.28651	4.5	0.25
21	AQ4R5	0.196715	2.408947	8.99	0.25
22	BN0R0	0.3223	1	0	0
23	BNOR2	0.322347	1	0	0
24	BQ2R2	0.518912	1.609793	4.5	0
25	BQ4R2	0.843615	2.617102	8.99	0
26	BN0R3	0.322664	1.000985	0	0.027
27	BQ2R3	0.46321	1.436992	4.5	0.027
28	BQ4R3	0.714384	2.216196	8.99	0.027
29	BN0R4	0.301789	0.936225	0	0.06
30	BQ2R4	0.453713	1.40753	4.5	0.06
31	BN4R4	0.588932	1.827014	8.99	0.06
32	BN0R5	0.403104	1.250528	0	0.11
33	BQ2R5	0.482785	1.497719	4.5	0.11
34	BQ4R5	0.57521	1.784445	8.99	0.11

REFERENCES

1) ACI Committee, 363, 1984 *'State of the Art report on High Strength Concrete'*, ACI Jl. 81(4), July-Aug, pp 364-411.

2) Sheikh, S.A., 1982 *'A comparative study of confinement models'*, ACI J, 79(4), pp 296-305.

3) Paulay, T &Priestely, M.J.N., 1992 *'Seismic design of reinforced concrete and masonry buildings'*, John Wiley & Sons, New York.

4) Yong, Y.K., Nour, M.G., and Nawy, E.G., 1988*'Behaviour of laterally confined high strength concrete under axial loads'*, ASCE, JSD, Vol.114, No.2, Feb, pp 332-351.

5) Razvi, S.R., and Saatcioglu, M., 1994 *'Strength and deformability of confined high strength concrete columns'*, ACI Struct. Jl. 91(6), pp 678-687.

6) Diniz, M.C., Sofia and Dan M. Frangpol, 1997 *'Reliability bases for high strength concrete columns'*, ASCE JSE, 123(10).

7) Balaguru, P, 1988 *'Use of Ferrocement for confinement of concrete'*, Proc. Third Int. Conf. On Ferrocement, Roorkee (India), pp 296-305.

8) Ganesan, N and Anil, J., 1993 *'Strength and behaviour of RC columns confined by Ferrocement'*, Jl. Of Ferrocement, 23 (2), pp 99-108.

9) Walliuddin, A.M., and Rafeeqi, S.F.A., 1994 *'Study of behaviour of plain concrete confined with ferrocement'*, Jl. Of Ferrocement, 24(2), 139-145.

10) Seshu,D.R., 1995 *'Behaviour of concrete confined with ferrocement shell in addition to rectangular stirrups and its application in flexure of RC structures'*, Ph.D thesis submitted to Kakatiya University, Warangal (India)

11) IS 456 – 2000, *' Indian Standard Code of Practice for Plain and Reinforced Cement Concrete'*, New Delhi.

12) Rao, C.B.K., and Rao, A.K., 1986 *'Stress-strain curve in axial compression and Poisson's Ratio of Ferrocement'*, Jl. Of Ferrocement, 16(2), 117-128.

13) Reddy,S.R., 1974 *'Behaviour of concrete confined with rectangular binders and its applications in flexure of reinforced concrete structures'*, Thesis submitted to J.T University, Hyderabad (India) for Ph.D degree.

14) Kumar, G.R., 1998 *'Improvement in the flexural behaviour of prestressed concrete sections confined with lateral ties and Ferrocement shell in critical zones'*, Ph.D. thesis submitted Kakatiya University, Warangal (India)

15) Kumar, G.R., 2001 *'Behaviour of high strength concrete confined with ferrocement shell in addition to lateral ties'*, Jl. Of Ferrocement 31(2), pp 213-222.

16) Pessiki, S., and Pieroni, A, 1997 *'Axial load behaviour of large scale spirally reinforced high strength concrete columns'*, ACI, SJ, 94(3), pp 304 – 314.

17) METIN HUSEM∗ and SELIM PUL **"**Investigation of stress–strain models for confined highstrength concrete**"** *S¯adhan¯a* Vol. 32, Part 3, June 2007, pp. 243–252. © Printed in India.