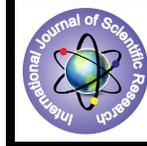


Evaluation of Strength And Modulus of Elasticity of Ferrocement Elements



Engineering

KEYWORDS : Ferrocement, Ultimate stress, ductility and Modulus of elasticity.

N.Jayaramappa

Associate Professor

Dr. H. Sharada Bai

Professor (Rtd), Faculty of Engineering-Civil, UVCE, Jnanabharathi Campus, Bangalore University, Bengaluru-560056, Karnataka, India

ABSTRACT

Ferrocement (FC) is defined as wire mesh reinforcement impregnated with cement mortar to produce elements of small thickness. Ferrocement offers several advantages such as light weight, ductility, resilience, toughness and crack resistance. Observing that studies where different properties of FC elements are compared considering tension test and flexure test are limited, present study is aimed at determining the behaviour of FC elements under flexural and tension.

500 mm X 500 mm X 30 mm size elements for flexure test and 100 mm X 500 mm X 30 mm size elements for tension test containing single, two, three and four layers of hexagonal chicken mesh and skeletal reinforcement were cast using cement mortar 1:3 (W/C= 0.5) and cured for 28 days. Corresponding elements were progressively tested under flexure and tension up to failure and their behaviors are compared.

1. Introduction

Ferrocement (FC) is defined as wire mesh reinforcement impregnated with cement mortar to produce elements of small thickness. The close spacing of the wire meshes in rich cement sand mortar and the smaller spacing of wires in the wire mesh layers imparts ductility and leads to a better crack arresting mechanism. Ferrocement has high durability, resilience, light weight, ease of construction, toughness and crack resistance. It has other advantages such as economy of materials, better utilization of human resources and architectural flexibility, and the basic technique is easily acquired. The floors/roof made with lighter materials lead to a decrease in the cost of formwork and supporting structure.

Limited research works in the recent times are available on the behaviour of ferrocement structural elements. Azad et.al., (2011) conducted tests on ferrocement discs to measure tensile stress-strain relationship including testing wide ranges of matrix strength. Equations were proposed for calculating tensile strength based on their test results and other results in the literature. Later an analysis was carried out for calculating the load deflection relationship of Ferrocement beams based on moment - curvature relationship and bending theory of elastic beam. Shaheen et.al.,(2013) investigated the possibility of the use of ferrocement concrete in construction of water supply pipe. This work presents the comparison between the performance of ferrocement pipe and reinforced concrete pipe under static load as starting step to study the performance of this type of pipe under impact load. Gangadharappa et.al.,(2013) investigated the effect of percentage replacement of sand by Blast Furnace Slag (BFS) and reinforcement with meshes under monotonic tensile loads. It was observed that replacement of BFS increases the ultimate strength up to a certain value and later decreases with increase in replacement. Randhir et.al.,(2014) described the results of testing flat ferrocement panels reinforced with different number of wire mesh layers and fibers. Test results showed that panels with more number of layers (with fibers) exhibited greater flexural strength and less deflection as that compared with panels having less number of layers of mesh.

In all the above studies, most of them have concentrated either on tensile strength of FC elements or on the flexural behavior with hardly any studies conducted wherein the similar properties are determined using two different tests.

Present study therefore is an effort to consider FC elements with same number of reinforcement meshes and compare their properties under flexure and tension.

2. Experimental Investigation

Ferrocement elements with varying volume fraction of reinforcement (V_f) are considered. Appropriate specimens for flexural test and tension test were prepared and tested accordingly under progressive loading from zero to failure. The flexural behaviour and tensile behaviour are studied and corresponding results are compared.

3. Materials Used

The materials used for preparation of Ferrocement Elements for each test, namely, cement, chemical Admixture, fine aggregate, water and wire mesh were tested in the laboratory as per relevant IS codes.

3.1 Cement

Ordinary Portland cement of 43 Grade conforming to the requirements of IS 12269-1987 is used in the experimental work. The quantity of cement required for the experiments was collected from single source. Tests were conducted to obtain specific gravity, normal consistency, initial & final setting time, compressive strength and reported in Table 1.

Table 1. Test result of ordinary portland cement

Sl. No	Properties	Test Results	As per IS 12269-1987
1	Normal Consistency (in %)	31.00	28 -35
2	Specific Gravity	3.076	
3	Setting Time(in Minutes) a)Initial Setting Time b)Final Setting time	85 Min 490 Min	Not less than 30minits Not more than 600minits
4	Compressive Strength(MPa) (70.6*70.6*70.6mm Cubes) 3 days strength 7 days strength 28 days strength	24.5 MPa 36.5 MPa 47.45 MPa	Not less than 22Mpa Not less than 33Mpa Not less than 43Mpa
5	Fineness of cement	3.56 percent	Not more than 10 %
6	Soundness	4.5 mm	Not more than 10 mm

3.2 Chemical Admixtures

Commercially available Poly- carboxylic ether based Super plasticizer (Glenium 6100) having specific gravity of 1.06 was used in this study.

Typical Properties as per manufacturer’s specifications are as follows

- Light brown liquid
- Relative Density : 1.09 ± 0.01 at 25°C
- pH : >6
- Chloride ion content : $< 0.2\%$

Dosage:

Optimum dosage of Glenium 6100 should be determined with trial mixes. As a guide, a dosage range of 500 ml to 1500 ml per 100kg of cementitious material is normally recommended from the manufacturer. Because of variations in concrete materials, job site conditions, and/or applications, dosages outside of the recommended range may be required.

3.3 Aggregate

Locally available natural river sand was used as fine aggregate in the mix. The tests on fine aggregate were conducted in accordance with IS 383 -1970 to determine physical properties. The Sand had Specific Gravity of 2.63, fineness Modulus of 3.74 and belonged to Zone-II.

3.4 Water

Potable water was used for conduction of experimental work.

3.5 Reinforcing Materials

The core portion of Ferrocement elements are chicken mesh of hexagonal shape and reinforcement bar (Fe-415) as skeletal steel.

3.5.1 Wire Mesh

Wire mesh was tested as per IS 1604-2012, the results are tabulated in table 2.

3.5.2 Reinforcement Bars

HYSD bars of 4mm, 6mm, and 8mm diameter used for FC elements as skeletal reinforcement (Fe-415) were tested as per IS 1786-2008, the results are tabulated in

table 2.

Table 2. Properties of reinforcing materials

Sl No	Type of Material	Properties	Values
1	Chicken (Hexagonal) mesh	Average diameter	0.45 mm
		Opening size of mesh	13 mm x 15 mm
		Yield strength	290 Mpa
2	Fe-415 Steel (IS-1786-2008)	Diameter	4mm 6mm 8 mm
		Yield strength	490 N/mm ²
		Ultimate strength	525 N/mm ²
		% elongation	14.25 %

4. Casting of Ferrocement elements

Ferrocement elements of two different sizes were cast to find their properties under flexure and tension.

4.1 Elements for Flexural Test

Ferrocement panels of dimension 500 mm x 500 mm and 30 mm thick (fig.1) were cast to study the flexural behaviour. The panels were prepared by fabricating 4 mm diameter mild steel rods at 240 mm c/c spacing in both directions as skeletal steel, to avoid any folds of the chicken mesh. The chicken mesh (required number) was spread over the steel mat, details of which are shown in fig.1.

Moulds of required dimensions were prepared using ply wood sheet. Moulds were placed on a clean and level surface after cleaning and oiling (fig. 2). The mortar mix was prepared with cement and sand of ratio 1:3 with w/c 0.5 and super plasticizer to get good workability. The cement mortar was then spread over the bottom surface of the mould up to a thickness of about 10 to 13 mm by evenly leveling and then compacted well. The reinforcement mat with steel rods and chicken mesh was then placed over the bottom mortar layer carefully and the leveling was checked. Another 10 to 13 mm thick cement mortar layer was placed over this layer and compacted well such that this mat was totally impregnated in to the mortar. It was then leveled to obtain a smooth finished surface. The specimen so prepared was allowed to set for 24 hours and the panel was demolded. The specimens were kept for curing under water up to 28 days. A typical specimen so obtained is shown in fig.3. Panels were prepared using the single layer mesh, double layer mesh, three layer mesh and four layer mesh reinforcement, skeletal steel remaining the same. The volume fraction of steel is 0.63%, 0.78%, 0.93%, and 1.08% respectively, for single layer, double layer, three layers and four layer of chicken mesh.

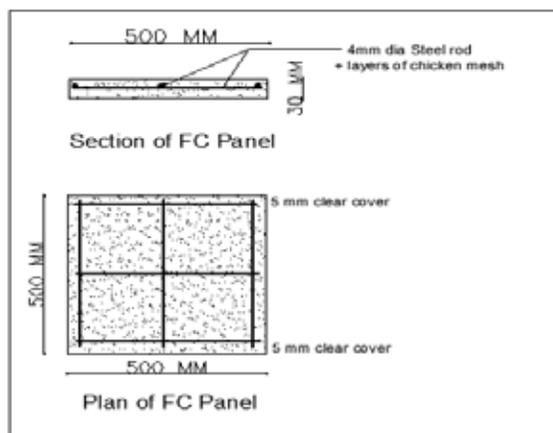


Fig.1 Details of flexure test specimen



Fig. 2 Mould and reinforcement details of panel



Fig. 3 Ferrocement panel element for flexure test

4.2 Ferrocement Elements for Tension Test

Tension test specimens of dimension 100 mm x 500 mm and 30 mm thick (fig. 4) were cast. The panels were prepared by fabricating 4 mm diameter HYSD bars in both directions along the boundary to avoid any folds of the chicken mesh which was spread over the steel mat. Moulds of required dimensions were prepared using ply wood sheet. Moulds were placed on a clean and level surface after cleaning and oiling. The mortar mix (same as that used for flexure test specimens) was prepared with cement and sand ratio of 1:3 with w/c ratio 0.5. To get good workability, poly-carboxylic ether based super Plasticizer (Glenium 600) was used. The cement mortar was then spread over the bottom surface of the mould up to a thickness of 8 to 9 mm by evenly leveling and then compacted well. The reinforcement mat with steel rods and chicken mesh was then placed over the bottom mortar layer carefully and the leveling was checked. Another 8 to 9 mm thick cement mortar layer was placed over this layer impregnating the mesh reinforcement mat, compacted well and leveled to obtain a smooth finished surface. Similar specimens were prepared with one, two, three and four layer meshes, skeletal steel remaining same to give V_f of 1.06, 1.18 %, 1.28% and 1.38% respectively. The specimens so prepared were allowed to set for 24 hours and panel was de-molded. The specimens were kept for water curing up to 28 days. Typical, specimens are shown in fig.5.

Mortar cubes of standard size (70.6mm X 70.6mm X 70.6 mm) with and without chicken mesh were also prepared and cured for 28 days (fig. 6). Mortar cubes without mesh and with mesh (for two cases of mesh parallel to load perpendicular to load) were tested as per IS12269-1987 and the results are presented in table.3. It is seen that mortar cubes with chicken mesh parallel and perpendicular to load had 35.43% and 51.36% higher strength respectively than that of plain mortar cubes.

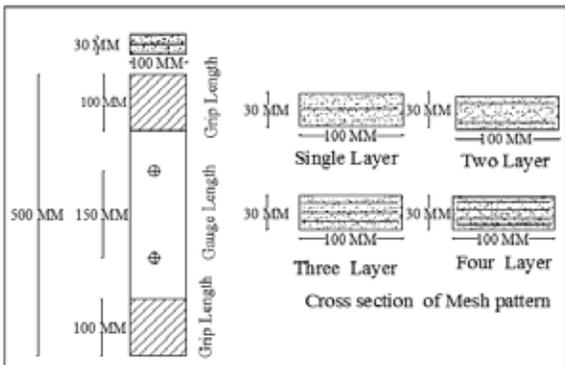


Fig. 4 Details of test specimen



Fig. 5 Samples for tension test



Fig. 6 Mortar cubes

Table 3. Compressive strength of mortar cubes

Sl No	Designation	Area of Cross-Section (mm ²)	%of Steel	Compressive Strength(Avg) N/mm ² @ 28 days
1	FC (1:3) Cubes(Mesh horizontal)	70.6*70.6*70.6	1.148%	47.17
2	FC(1:3) Cubes(Mesh vertical)	70.6*70.6*70.6	1.148%	52.72
3	Mortar cube(1:3)	70.6*70.6*70.6	0%	34.83

5. Testing of Ferrocement Elements

5.1 Flexural Test

The flexure test for the Ferrocement panels was conducted under pure bending condition. The panels were simply supported on two edges over an effective span of 444 mm and two point loads at equal distances from support were applied to obtain pure bending as denoted in fig. 7. The levels of the slab over the supports were checked and the load was applied incrementally, using hydraulic jack of 200 kN capacity with 1.0 kN accuracy, through loading frame. The maximum deflection at centre of span under each increment of load was read from dial gauge fixed at the bottom of the panel. The deflection at every 1.0kN load was recorded. The first crack load was also noted. The loading was continued till the panel failed. The specimens failed with single or two major cracks developed almost at the mid span along the loading direction as shown in fig.8. Table 4 shows typical readings recorded for specimen with volume fraction 0.78.



Fig. 7 Loading arrangement of flexure test



a. Single layer mesh



b. Double layer mesh



c. Three layer mesh



d. Four layer mesh

Fig. 8 Typical crack patterns of slabs tested

Table 4. Flexure test measurement of ferrocement panel with two layer mesh ($V_f = 0.78$)

Sl No	Load (kN)	Mid span deflection (mm)	Remark
1	0.00	0.000	
2	1.58	0.073	
3	2.58	0.197	
4	3.58	0.573	
5	4.58	1.601	
6	5.58	5.050	Initial Crack
7	6.08	8.550	Failure

5.2 Tension Test

The tension test specimens obtained as in Sec. 4.2, were stiffened by steel plates on both faces at the ends to avoid stress concentration when they were gripped by shackles in the testing machine during loading. These plates also avoid the crushing of the FC specimens due to gripping force. Gauge length of 150 mm was marked in the central portion of the specimen. Such a specimen was mounted in the 100 t, UTM and tensile load was applied in increments of 1.0 kN, (fig .9).

At each increment of load the elongation of the Specimen over the gauge length was observed using the Demec gauge and the readings were tabulated. The loading was continued till the specimen failed. The Cracking load and Ultimate failure load were recorded. The testing procedure was repeated for all the specimens. Fig. 10 shows the typical failure of a tension specimen.

Table 5 shows typical load – elongation measurements recorded for the specimen with volume fraction of 1.18%.



Fig. 9 Loading arrangement of tension test



Fig. 10 Failure pattern of tension test specimen

Table 5. Ferrocement tension test result for double layer ($V_f 1.18\%$)

Sl No	Load (kN)	Stress (N / mm ²)	Elongation (mm)	Strain X 10 ⁻³	Remarks
1	0.0	0.000	0.000	0.000	
2	1.0	0.333	0.020	0.13	
3	2.0	0.661	0.033	0.22	
4	3.0	1.000	0.053	0.35	
5	4.0	1.333	0.073	0.49	
6	5.0	1.667	0.103	0.69	
7	6.0	2.000	0. 77	5.12	Crack Occurs
8	7.0	2.333	1.35	8.98	

9	8.0	2.667	2.17	14.47	
10	9.0	3.000	3.364	23.26	Fracture

6. Presentation and Discussion of Results

From the measurements made during the flexure test and tension test, relevant plots are drawn and required quantities are determined, presented and discussed.

It is to be expected that as the volume fraction of (V_f) FC elements changes, all quantities such as ultimate load, ultimate deflection, modulus of elasticity (ductility etc) also vary. i.e the performance of the FC elements vary. Hence to quantify this, Performance Evaluation Factor (PEF) for each quantity indicating increase in the quantity considered for higher V_f (2, 3& 4 number of meshes) in terms of the same quantity for minimum V_f adopted (single mesh) is defined as follows.

$$PEF \text{ for any quantity} = \frac{\text{Quantity corresponding to specimen with 2,3,4 layers of mesh ie higher } V_f}{\text{Same quantity resisted by specimen with one layer of mesh ie minimum } V_f}$$

For example PEF for ultimate load under flexure for specimen with 2 layers of mesh is given by

$$PEF \text{ for ultimate load} = \frac{\text{Ultimate load under flexure resisted by specimen with 2 layers of mesh}}{\text{Ultimate load under flexure resisted by specimen with one layer of mesh}}$$

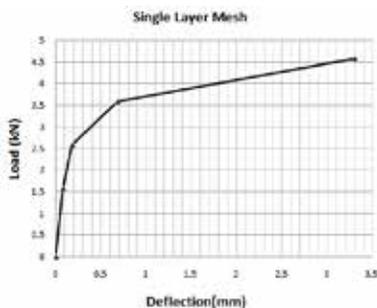
6.1 Flexure Test

From the recordings of load and corresponding centre span deflection (maximum deflection) throughout the loading range, the load versus deflection plots are obtained for the four categories (V_f) of the specimen considered. Table 4 shows typical load deflection measurement. Fig.11(a-e) depict the load-deflection plots obtained for specimens with different volume fraction (V_f) of 0.63, 0.78, 0.93 and 1.08.

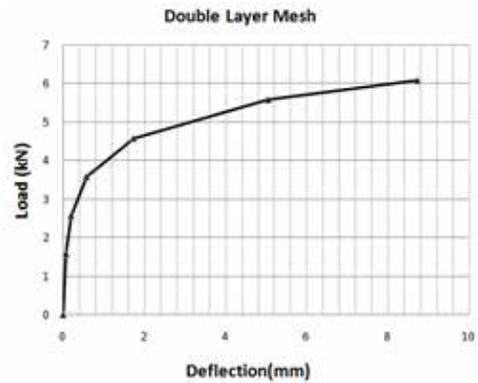
6.1.1 Load – Deflection Behaviour

Fig. 11a to 11d show separately the load-mid span deflection under flexure of FC slab elements with different volume fractions of reinforcement namely 0.63, 0.78, 0.93 and 1.08 and fig. 11e shows the combined behaviour. These figures show that the behaviour for a particular volume fraction and the overall behaviour for the different V_f considered have similar trends. The behaviour consists essentially of three zones, initial straight portion in the elastic range, second straight portion indicating elasto-plastic zone, and the later straight portion up to failure, wherein, for any small increment in load, large deflections are encountered indicating yielding of steel meshes. No drooping down of the curves is observed.

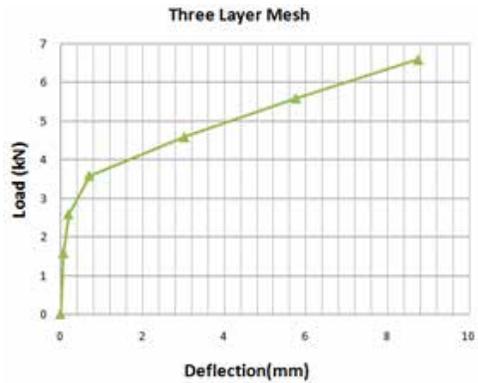
Table 6 reports the values of yield load (load at which the continuous yielding of the specimen commences (end of second straight portion), ultimate load and ultimate deflection for the flexural specimens with different V_f tested. Table 6 also reports the Performance Evaluation Factor (PEF) for ultimate load and PEF for E calculated as explained in Sec.6.1. 2



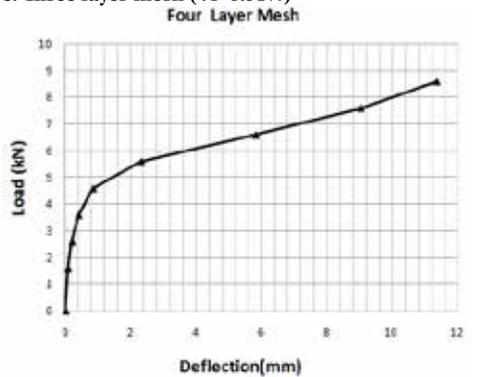
a. Single layer mesh ($V_f=0.63\%$)



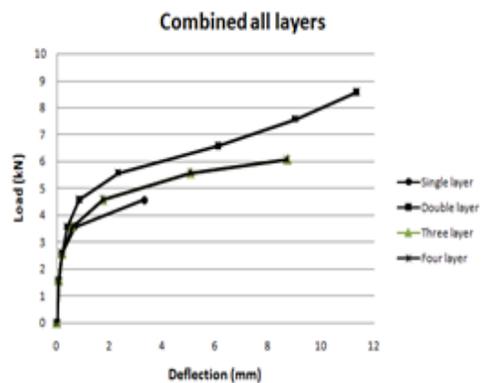
b. Double layer mesh ($V_f=0.78\%$)



c. Three layer mesh ($V_f=0.93\%$)



d. Four layer mesh ($V_f=1.08\%$)



e. Comparison of behaviour of different layers of $V_f \%$

Fig. 11 Load- deflection behaviour under flexure of F.C elements with different volume fraction

Table 6. Ultimate load , modulus of elasticity and their PEF of FC elements for flexure

Sl No	No of Mesh Layers	Volume fraction (%)	Load at Yield (kN)	Ultimate Load (kN)	Modulus of Elasticity (E_n)N/mm ²	Performance Evaluation Factor (PEF) for	
						Ultimate Load	E_n
1	Single	0.63	3.50	4.58	17812.58	1.000	1.00
2	Double	0.78	3.80	6.08	18082.39	1.33	1.02
3	Three	0.93	3.80	6.58	18653.26	1.44	1.05
4	Four	1.08	4.50	8.58	23805.34	1.87	1.34

As can be expected, as the number of mesh layers or V_f increases, there is considerable enhancement in load and deflection. The ultimate load varies for 4.58 kN to 8.58 kN and ultimate deflection varies from 3.34 mm to 11.35 mm as V_f varies from 0.63% to 1.08%. The PEF for ultimate load (i.e increase in ultimate load of FC panel with 2,3 and 4 layers of mesh (higher V_f) in comparison to that of specimen with single layer of mesh (least V_f) of specimens are found to be 1, 1.33, 1.44 and 1.87 for V_f % of 0.63, 0.78, 0.93 and 1.08 respectively.

Similarly PEF for Ultimate deflection (i.e increase in Ultimate deflection of slabs with 2,3and 4 layers of mesh in comparison to that of single layer of mesh) are found to be 1, 1.28, 2.62 and 3.23 respectively , which are generally higher than that of ultimate load.

6.1.2 Modulus of Elasticity

For a simply supported member, subjected to two point loading at one third span points (fig.12) the maximum deflection is given by

$$\delta = \frac{PL^3}{56.35 E_f I} \tag{1}$$

Where P= ultimate load N

L = length of specimen between centre of supports, mm

E_n = modulus of elasticity N/mm²

I = moment of inertia, mm⁴

δ =deflection at centre of span, mm

From equation.1 Modulus of elasticity in N/mm²

$$E_{fl} = \frac{1000 L^3}{56.35 I} (P/\delta) \tag{2}$$

Where, (P/) is obtained from the initial straight line portion of load-deflection curves (fig. 11) in kN/mm.

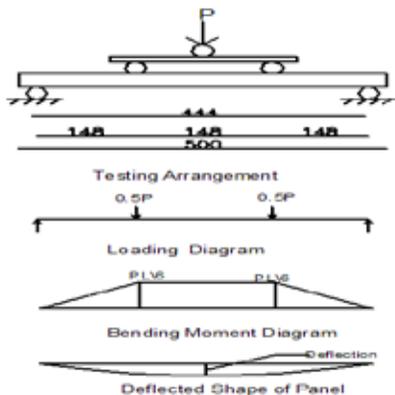


Fig .12 Flexure test details

E_n values obtained for panel elements with different volume fraction of reinforcement are listed in table 6. It is seen that E_n varies from 17488.99 to 22303.78 N/mm² as V_f varies from 0.63 to 1.08. The PEF for E_n are found to be 1.02, 1.05 and 1.34 for V_f = 0.78, 0.93 and 1.08 respectively.

6.1.3 Ductility of Slab Elements

From the load- deflection behaviour (fig. 11) it is seen that the slab elements exhibit large ductility imparted mainly by the reinforcement present.

The ratio of ultimate deflection to deflection at yield is calculated as the deflection ductility of different specimens and indicated in table 7. Here to be conservative yield deflection is taken as the deflection corresponding to upper point of the second straight portion of load-deflection behaviour depicted in fig. 11.

From table 7 it is clear that the ferrocement slab elements have high ductility varying from 4.18 to 13.5 as V_f increases from 0.63 to 1.08.

The PEF for ductility are found to be 1.28, 2.62 and 3.23 for panel with 2, 3 and 4 layer mesh contained Ferrocement slab elements.

Table 7. Ductility of FC elements under flexure

Sl No	No of Mesh Layers	Vol. Fraction (%)	Deflection at Yield (mm)	Ultimate Deflection (mm)	Ductility	PEF for Ductility
1	Single	0.63	0.80	3.34	4.18	1.00
2	Double	0.78	1.60	8.55	5.34	1.28
3	Three	0.93	0.80	8.74	10.93	2.62
4	Four	1.08	0.84	11.35	13.50	3.23

6.2 Tension Test

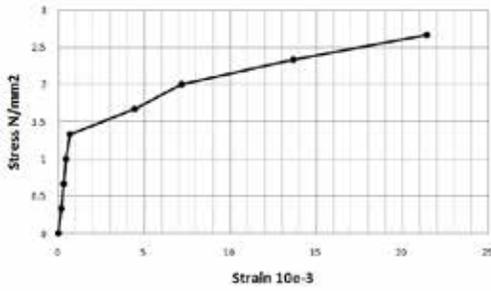
Incremental tensile loads applied and the corresponding elongation measured over the gauge length by the Demec gauge were recorded for each specimen. Using the readings, longitudinal stress verses longitudinal strain graphs were plotted and are shown in figure 13a to 13e.

6.2.1 Stress- Strain Behaviour

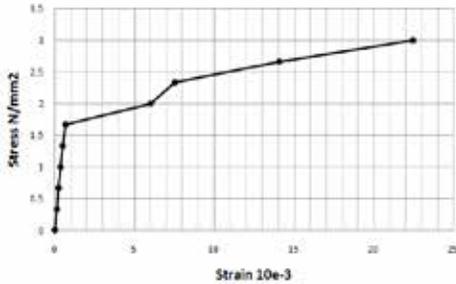
The stress -strain plots of the specimens under tension are depicted in figure (13a-to 13d) for the four V_f values considered. The trend of behavior for all V_f are similar with initial straight portion, a small initial yield zone and the strain hardening zone. This is similar to the stress- strain behavior of steel and hence, the tensile behaviour of FC can be said to be controlled by the magnitude of reinforcement present. Higher the V_f , higher the ultimate load resisted and larger the ultimate tensile strain. Specimen with higher V_f also exhibit slightly extended strain hardening zone as is evident from fig. 13d. Fig. 13e shows the comparative stress strain plots of all specimens tested.

Table 8 reports the values of yield stress, ultimate stress and the corresponding PEF for ultimate stress & ultimate strain, as well as values of modulus of Elasticity (E_c) discussed in Sec 6.2.2.

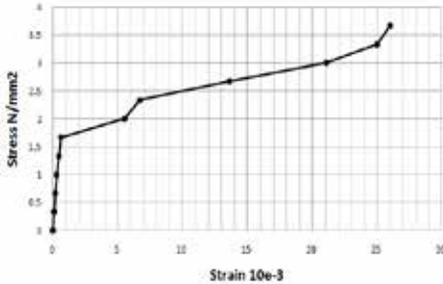
It can be seen that the PEF for ultimate stress are 1.13,1.25, and 1.38 respectively, for V_f = 1.18, 1.28 and 1.38,



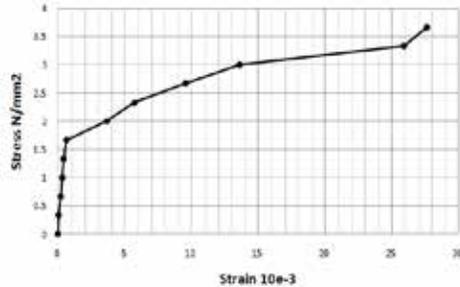
a. Single layer mesh (Vf=1.06%)



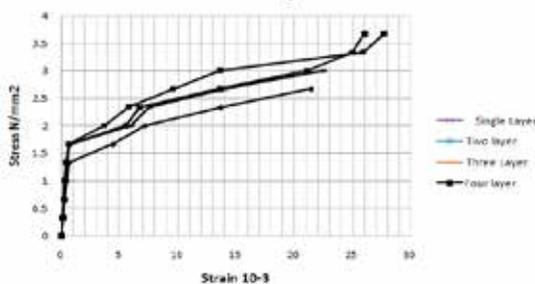
b. Two layer mesh (Vf=1.18%)



c. Three layer mesh (Vf=1.28%)



d. Four layer mesh (Vf=1.38%)



e. Comparison of behaviour of different layers of Vf %

Fig. 13 Stress- strain behaviour of F.C elements with different volume fraction under tension

Table 8. Modulus of elasticity and different PEF under tension test

Sl No	No of Mesh Layers	Vol-ume frac-tion (%)	Yield Stress (N/ mm ²)	Ulti-mate stress (N/ mm ²)	Ulti-mate Strain 10 ⁻³	Modulus of Elasticity (E _t) N/mm ²	Performance Evaluation Factor (PEF) for	
							Ulti-mate stress	E _t
1	Single	1.06	1.67	2.67	21.42	21413.27	1.00	1.00
2	Double	1.18	2.00	3.00	23.26	27371.67	1.13	1.28
3	Three	1.28	2.00	3.33	26.02	28479.67	1.25	1.33
4	Four	1.38	2.00	3.67	27.64	29753.91	1.38	1.39

6.2.2 Modulus of Elasticity under Tension

The slope of the initial linear portion of the stress strain curve is calculated as the modulus of elasticity under tension. The calculated E_t values for different V_f are tabulated in table 8 and varies from 21413.27 N/mm² to 29753.91 N/mm² for V_f = 1.06 to 1.38 .

It is clear that provision of more number of meshes increases the stiffness of the element and hence E is maximum for the specimen with maximum V_f adopted. In terms of specimen with single layer of chicken mesh, E_t values increase by 1.28, 1.33 and 1.39 times respectively for specimens with 2, 3, and 4 layers of chicken mesh.

6.2.3 Ductility

Table 9 shows the values of ductility calculated for tension specimens with different V_f. The ductility is calculated as the ratio of ultimate strain to yield strain. FC pecimen under tension have enormous ductility varying from 4.51 to 8.46 as V_f varies from 1.06% to 1.38%. The PEF for ductility represented in table 9 shows that enhancing V_f from 1.06 to 1.18,1.28 and 1.38 results in PEF for ductility of 1.01, 1.04 and 1.88 respectively. Ferrocement specimens have large ductility which makes ferrocement as a suitable material under earthquake loads.

Table 9. Ductility for different V_f under tension

Sl No	No of Mesh Layers	Vol. Frac-tion (%)	Yield Strain 10 ⁻³	Ultimate Strain 10 ⁻³	Ductility	PEF for Ductility
1	Single layer	1.06	4.75	21.42	4.51	1.00
2	Double layer	1.18	5.12	23.26	4.54	1.01
3	Three layer	1.28	5.53	26.02	4.71	1.04
4	Four layer	1.38	3.27	27.64	8.46	1.88

7. General Discussion

The variations of E and Ductility with V_f of FC elements under bending are compared with corresponding variations under tension.

Table 10. Comparison of normalised values of V_f and E_t

Sl No	Vol. Fraction (%)		Modulus of Elasticity		E _n / V _f		E _t / V _f		Ductility	
	Flex-ure	Ten-sion	Flexure (E _n)	Tension (E _t)	Flexure	Tension	Flex-ure	Ten-sion		
1	0.63	1.06	17812.58	21413.27	28273.94	20201.19	4.18	4.51		
2	0.78	1.18	18082.39	27371.67	23182.55	23196.33	5.34	4.54		
3	0.93	1.28	18653.26	28479.67	20057.27	22249.74	10.93	4.71		
4	1.08	1.38	23805.34	29753.91	22041.98	21560.80	13.50	8.46		

7.1 Comparison of Variation of E under Flexure and Tension

Fig. 14(a) displays the comparison of variation of modulus of elasticity under flexure (E_{fl}) and tension (E_t) of FC elements tested for different V_f . It is seen that there is a slight increase in E_{fl} with increase in V_f where as the rate of increase in E_t because of increase in V_f values is considerably higher than flexure specimens. For the only common value of $V_f = 1.08\%$ of flexure (1.06% in tension) E_{fl} is found to be 10.05 % higher under flexure (E_{fl}) than under tension (E_t). Magnitude of E_t exceed E_{fl} because of the higher magnitude of V_f .

Because the V_f values adopted for flexure test and tension test are different, the E values obtained from two tests i.e E_{fl} and E_t are normalised by dividing each E value by corresponding V_f . Such normalised values for each test obtained are shown in table 10. It is interesting to see that the E_{fl}/V_f and E_t/V_f values are almost equal. The average value for flexure test (= 23235.5) and for tension test (= 21802.02) differ by only 6.17%.

7.2 Comparison of Variation of Ductility with V_f of FC Elements under Flexure and Tension

The variation with V_f of ductility of FC elements under flexure and tension are depicted in fig. 14b.

It is seen that FC elements have high ductility in general and that shown by FC flexural elements are higher than that of tensile elements (table 10 and fig 14b). The normalized values of ductility i.e. ductility per unit V_f are shown in table 11. It is seen that ductility per unit V_f values of FC element under flexure are higher than that under tension. The difference in these values may be because of the changes in position of mesh layers with respect to applied load.

flexure and under tension can be idealised to consist of three straight lines, Elastic zone, elasto plastic zone and plastic zone.

The ultimate load, ultimate deformation, modulus of elasticity and ductility of FC elements under flexure and tension increase with increase in volume fraction.

Under flexure, as V_f increases by 1.71 times, the ultimate load increases by 1.87 times , E increases by 1.34 times and ductility increases by 3.23 times.

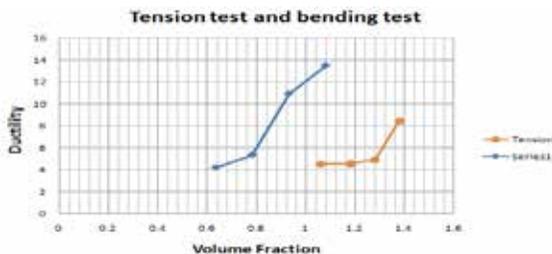
As V_f increases by 1.3 times , the ultimate strength, E and ductility under tension increase by 1.37, 1.34 and 2.62 times respectively.

The average value of modulus of elasticity per unit volume fraction of FC elements under flexure and tension are almost equal varying by only 6.16 %.

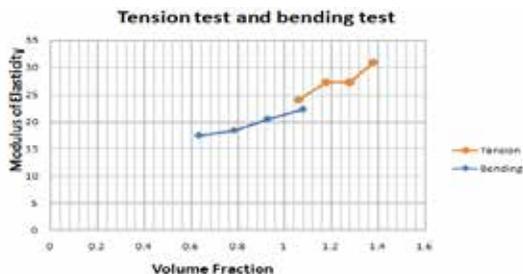
The ductility of FC elements under flexure is higher than that under tension.

References

1. Zachariah Husain .Md. and Inoue Shoji (2003), "Young' s Modulus and Bearing Capacity of Thin Panels Reinforced with Georgic and Hexagonal Meshes", Rural and Environmental Engineering No.44, August 2003, pp. 13- 26.
2. Wail N. Al-Rifaie and Muyasser M. Jomaàh (2010), "Structural Behaviour of Ferrocement System for Roofing", First Engineering Scientific Conference College of Engineering –University of Diyala 22-23 , December 2010, pp. 237-248.
3. Azad A. Mohammed and Dunyazad K. Assi (2012), " Tensile Stress-Strain Relationship For Ferrocement Structures", A1-Rafidian Engineering , Cov.20, N0.2,
4. Youstry B I Shaheen I, Mohamed A Safan 2, Abdalla M A3, Sep 2012, "Structural Behavior of Composite Reinforced Ferrocement Plates", Concrete Research Letters.
5. Howlader M.K , Rashid. M.H, and Zahangir Alam, (2013) , "Effect of Saline Water on the Flexural Performance of Ferrocement Wall Panel" , International Journal of Advanced Structures and Geotechnical Engineering, Vol. 02, No. 03, July 2013,Pg 2319-5347.
6. Shaheen. Y.B.I Eltaly.B and Kameel.M (2013), "Experimental and analytical investigation of ferrocement water pipe "Journal of Civil Engineering and Construction Technology, Vol. 4(4), May 2013, pg. 157-167.
7. Gangadharappa B.M, Prakash K E, Suresh G.S. and Shesha Prakash M N (2013) " Studies on Light Weight Ferrocement Subjected to Axial Tension" International Journal of Emerging Technologies in computational and Applied Sciences , p.p 239-245.
8. Randhir J. Phalke, Darshan G. Gaidhankar (2014), " Flexural Behaviour of Ferrocement Slab Panels Using Welded Square Mesh by Incorporating Steel Fibres", International Journal of Research in Engineering and Technology , Vol-03, Issue-05.



(a)



(b)

Fig 14. Flexural and tension test results of volume fraction verses modulus of elasticity

8. Conclusions

Ferrocement elements of sizes convenient for flexure test and tension test were tested respectively under flexure and tension and the load-deflection behaviour, modulus of elasticity and ductility are determined. The results obtained lead to the following conclusions.

The load-deflection behaviour of Ferrocement elements under