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Flexural Behaviour of Ferro cement Slab Panels Using Expanded Metal Mesh Incorporating Steel Fibers

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Abstract -.The present study describes the results of testing flat ferrocement panels reinforced with different number of wire mesh layer. The main objective of this work is to study the effect of using different no of wire mesh layers on the flexural strength of flat ferrocement panels and to compare the effect of varying the no of wire mesh layers and use of steel fibers on the ultimate strength and ductility of ferrocement slab panels. The no of layers used are two, three, four and five. Slab panels of size (200*550) with thickness 25 mm are reinforced with expanded metal mesh with varying no of layers of mesh. Panels were casted with mortar of mix proportion (1:1.75) and water cement ratio (0.38) including super plasticizer (Perma PC202) with dosage of 1% of total weight of cement. Some panels were casted with steel fibers (0.5%) of total volume of composite and aspect ratio (l/d) =57.Panels were tested under two point loading system in UTM machine after curing period of 28 days. Test results shows that panels with more no of layers and steel fibers exhibits greater flexural strength and less deflection as that compared with panels having less no of layers of mesh.

Keywords: Ferrocement; wire mesh; effect;, flexural strength; ductility; ultimate strength; plasticizer; steel fibers.

I .INTRODUCTION

The concept of industrialization of the construction technology has emerged as well accepted and preferred option in the field of building construction now a days in order to reduce in-situ construction up to maximum extent. This could be achieved by employing a number of strategies including the application of newly developed cement based composites for structural applications. Cement based composites perform better than conventional plain concrete. The development of new construction materials and technology can partly relieve pressures on the existing building material supply and help to arrest the spiralling rise in cost of these materials and also may reduce in-situ construction activities Ferrocement is one of the relatively new cementitious composite considered as a construction material.

A. Definition-

"Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh" .The mesh may be made of metallic and suitable materials. In the words of Nervi who first used the term ferrocement its notable characteristics is "Greater elasticity and resistance to cracking given to the cement mortar by the extreme subdivision and distribution of the reinforcement"

II. CONSTITUENTS OF FERROCEMENT

The constituents of ferrocement include the hydraulic cement mortar which should be designed according to the standard mix design procedures for mortar and concrete which include cement, water, sand, wire mesh and admixtures.

A. Cement

The cement should be fresh of uniform consistency and free of lumps and foreign matter and of the type or grade depending on the application.

B. Water

Potable water is fit for use as mixing water as well as for curing ferrocement.

C. Fine Aggregates

Normal weight fine aggregate clean, hard, and strong free of organic impurities and deleterious substances and relatively free of silt and clay.

D.Wiremesh

Steel meshes for ferrocement includes square woven or square welded mesh and chicken wire mesh of hexagonal shape and expanded metal mesh. Some mesh filaments are galvanized. Properties of the resulting ferrocement product can be expected to be affected by mesh size, ductility, manufacture and treatment.

E. Admixtures

In numerous admixtures available, chemical admixtures is best suitable for ferrocement because it reduces the reaction between matrix and galvanised reinforcement. Chemical admixtures used in ferrocement cement serve one of the following purposes like water reduction, improvement in impermeablity, air entrainment, which increases resistance to freezing and thawing.

III. PROPERTIES OF FERROCEMENT COMPOSITES

- Wire diameter 0.58 to 2 mm
- Size of mesh opening 6 to 35 mm
- Maximum use of 12 layers of mesh per inch of thickness
- Maximum 8% volume fraction in both directions
- Maximum 10 square inches per cubic inch in both directions.
- Thickness 6 to 50 mm
- Steel cover 1.5 to 5 mm
- Ultimate tensile strength up to 35 MPa
- Allowable tensile stress up to 14 MPa
- Modulus of rupture up to 70MPa
- Compressive strength up to 21 to 96 Mpa

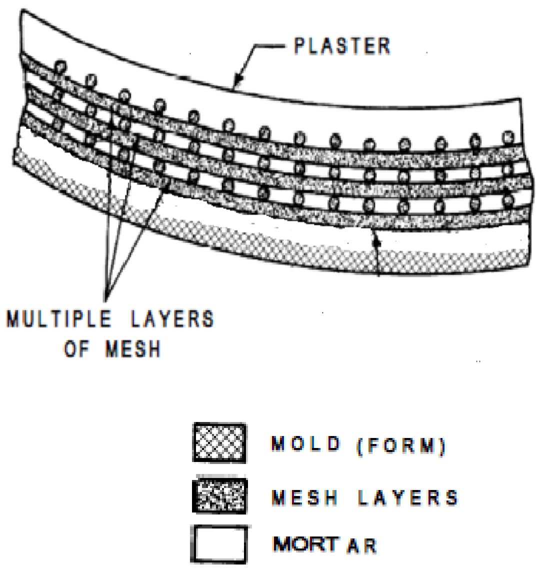


Fig 1.Cross section of ferrocement laminate

IV. HISTORY OF FERROCEMENT

Joseph Louis Lambot a horticulturist experimented with plant pots, seats and tubs made of meshes and plastered with sand and cement mortar replaced his rotting rowing boat. He called this material as “Ferciment” in a patent which he took in 1852. There was very little application of true ferrocement construction between 1888 &1942 when Pier Luigi Nervi began a series of experiments on ferrocement. He observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogeneous material capable of resisting high impact. In 1945 Nervi built the 165 ton Motor Yatch “Prune”on a supporting frame of 6.35mm diameter rods spaced 106mm apart with 4 layers of wire mesh on each side of rods with total thickness of 35mm.It weighed 5% less than a comparable wooden hull &cost 40% less at that time. In 1948 Nervi used ferrocement in first public structure the “Tutrin Exhibition Building”, the central hall of the building which spans 91.4m was built of prefabricated elements connected by reinforced concrete arches at the top &bottom of the undulations. In1974 the American Concrete Institute formed committee 549 on ferrocement. ACI Committee 549 first codified the definition of ferrocement in 1980 which was subsequently revised in 1988, 1993 and 1997(AE Naaman2000)

V. LITERATURE REVIEW

A. “Thin Cementitious Slabs reinforced with Stainless Steel Fibers”- by P.B. Sakthivel et al.

In this research work 18 ferrocement panels were casted using stainless steel fibres of different range and the energy absorbed by the panels under impact load was compared with energy absorbed by panels without stainless steel fibres. Materials include OPC 53 grade with SP-3.14, river sand with specific gravity of 2.74, Stainless Steel (SS) metal reinforcing fibers Grade - AISI 304 in size of 0.45 mm diameter X 12.5 mm long. A total of 18 cementitious slabs (of size 250mm x 250 mm x 25 mm thickness) were cast in wooden moulds .Out of these, 3nos. are "Control Specimens" (cast with plain cement mortar without fibers) and 15 nos. are "Test Specimens"(cast with fibrous cement mortar using SS fibers of 0.5%, 1%, 1.5%, 2% and 2.5%) of volume of specimens with 3 specimens in these 5categories each. Mortar was prepared with sand-cement ratio of 2:1 and water-cement ratio of 0.43. Specimens have been allowed to set for minimum 24 hours and de-moulded and transferred to the curing tank and removed after 28 day for testing. On analyzing this, it can be inferred that the energy absorbed by the cementitious slabs with SS fibers of 0.5%, 1%, 1.5%, 2% and 2.5% is about 2 times, 2.5 times, 4 times, 5.5times and 8.5 times (respectively) of the energy absorbed by plain cementitious slabs (without fibers). It can be concluded that the Stainless Steel reinforcing fibers are capable of increasing the strength parameters of cementitious matrix, and more importantly the energy absorption capacity of cementitious slabs. Also on increasing the fiber percentage from 0.5 to 2.5 the crack width of slabs decreased substantially on subjecting the slabs to impact loading.

B.”Flexural performance of fibre reinforced concrete made with steel and synthetic fibres”- by M.N.Soutsos et al

The experimental project involved casting and testing 66 prisms of size 150*150*550 mm and cubes of size 100 and 150 mm. Cubes were tested for compressive strength using a Tonipact compression testing machine with maximum capacity of 3000 KN. Concrete was mixed in batch sizes of either 73 or 95 l which was sufficient for casting six 100 mm cubes for testing at 3 and 7-days, three 150 mm cubes for testing at 28-days, and six 150*150*550 mm prisms .Load–deflection curves were determined by loading the 28-day prism specimen using a Denison Avery 100 KN test machine in order to load the specimens at a constant deflection rate rather than constant load rate. Materials include CEM I Portland Cement 42.5 N, natural sand and 20–5 mm gravel. The mix proportions used were: 267 kg/m3 of Portland cement, 805 kg/m3 of sand, 1190 kg/m3 of gravel and 189 kg/m3 of water. The total water–cement ratio was 0.71. It appears that the incorporation of steel fibres increased the compressive strength by about 4 and 5 N/mm2 for fibre dosage rates of 30 kg/m3 and 50 kg/m3. The increases in the compressive strength of synthetic fibres is lower, about 2–3 N/mm2 for dosage rates of 4.5–5.3 kg/m3. Incorporation of steel fibres also appeared to increase only slightly the flexural strength, i.e. by about 0.4–0.6 N/mm2 for the plain concrete value of 4.2 N/mm2. The most important parameters for the design of ground supported slabs are the flexural toughness and the equivalent flexural strength ratio. The flexural toughness of concrete increases considerably when steel and synthetic fibres are used.

C. "Mechanical properties of high-strength steel fibers-reinforced concrete"- by P.S. Song et al

In these research work the mechanical properties of high-strength steel fiber -reinforced (HSFRC) concrete such as the compressive and splitting tensile strengths of cylinders were investigated and beams was tested for flexural strength..Materials include cement, silica fume, water, super plasticizer, river sand and crushed basalt of 430, 43, 133, 9, 739 and1052 kg/m3 were used to make the high-strength concrete (HSC). The slump of the concrete was 60 mm. The hooked-end steel fibers made of mild carbon steel with average length of 35 mm, nominal diameter of 0.55 mm and the aspect ratio of 64 were used. A cylinder mould to cast a standard 150*300 mm cylindrical concrete specimen for compressive strength test and splitting tensile test and a 150*150*530 mm beam mould for a flexure strength test were casted with fibre volume fraction from 0.5 to 2%.Compressive strength improvement of HSFRC ranged from 7.1% to 15.3% at the volume fractions of 0.5% to 2.0%, comparable to the improvements of 4.3–10.4% for normal- strength concrete at the same fractions **.**For Split tensile strength the improvement started from 19% at 0.5% fraction and expanded to 98.3% at 2.0% fraction. The compressive strength of HSC improved with additions of steel fibers which was maximum at 1.5% fraction but a slight decrease at 2% fraction compared to 1.5% still remaining 12.9% higher than before the fiber addition. The splitting tensile strength and modulus of rupture of HSFRC both improved with increasing fiber volume fraction. The splitting tensile strength ranged from 19.0% to 98.3% higher for the fractions from 0.5% to 2.0% and the modulus of rupture ranged from 28.1% to 126.6% higher for the fraction from 0.5% to 2.0%.

VI. OBJECTIVE OF EXPERIMENTAL STUDY

The main objective of this experimental work is to study the behaviour of ferrocement panels under flexural loading in which expanded metal mesh of thickness (1.6 mm) has been used as a reinforcement. The various parameters considered in this study are as follows -:

- Effect of number of mesh layers on the flexural strength of slab panels.
- Effect of steel fibers on the flexural strength of slab panels.
- Effect of volume fraction on the flexural strength of panels.

VII. EXPERIMENTAL WORK

The experimental program includes casting and testing of flat ferrocement slab panels under two-point loading. The primary variables were the number of layers of meshes in panels and the use of steel fibers.

A. Materials

Cement Ordinary Portland Cement (Grade 43), Sand -:Passing through 2.36 mm I. S. Sieve, Admixture (Perma PC202) Water – Ordinary Drinking Water, Mesh Used – Expanded Metal Mesh(non galvanized) of 1.6 mm thickness. Steel fibers of corrugated type with aspect ratio (l/d=57).

B. Mix proportion

Cement sand ratio (1:1.75) 2) Water cement ratio (0.38).
A total of 9 cubes of size (70*70) of above proportion were casted with and without steel fibers to determine strength.
Compressive strength obtained is tabulated below

Table 1.Comp strength of cubes at 28 days

SR.NO	SIZE	Load at failure (kg)	Comp strength (N/mm²)	Average comp strength
Without steel fibers				
1	70*70	22540	46	
2	70*70	25480	52	50
3	70*70	23030	47	
With steel fibers				
4	70*70	26460	54	
5	70*70	23520	48	51
6	70*70	24990	51	

Table 2.Details of panels to be casted

Without steel fibers			
NO	***Size of panel***	***Layers***	***No of panels***
1	200*550*25	2	3
2	200*550*25	3	3
3	200*550*25	4	3
4	200*550*25	5	3
With steel fibers			
NO	Size of panel	Layers	No of panels
1	200*550*25	2	3
2	200*550*25	3	3
3	200*550*25	4	3
4	200*550*25	5	3

C. Preparation of mortar

Mortar was prepared by calculating the exact amount of cement sand and water. At first the cement and sand were mixed dry. Admixture with dosage of (1% of wt of cement) was mixed thoroughly with water and then added to dry mix. Steel fibers with dosage of 0.5% of total volume of composite were added. 50% of steel fibers were added in dry mortar and remaining 50% after mixing of water.

Fig 2-Mixing of steel fibers in mortar

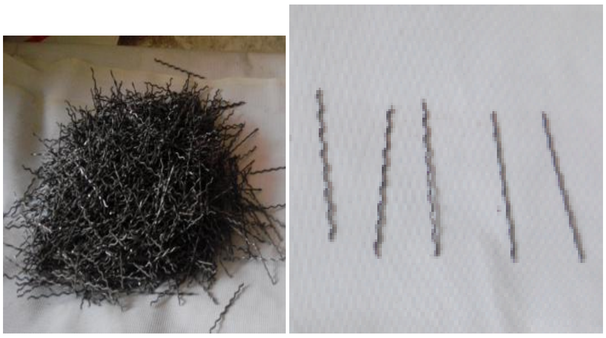


Fig 3-Corrugated type steel fibers with aspect ratio (l/d) =57

Fig 4-Admicture (Perma PC202) after mixing with water used in mix

D. Casting

The steel moulds prepared were properly oiled before casting. At bottom one layer of mortar was applied of thickness 3 mm followed by layer of expanded metal mesh and again followed by layer of mortar. The procedure continues for placing number of layers of mesh in panel**.**

Fig 5-Steel mould oiled before casting of thickness 25 mm

The mesh pieces were cut down according to the size of panel leaving a cover of 3 mm on both sides. Size of mesh pieces were (544*194) mm.

Fig 6-Pieces of expanded metal mesh

Fig 7-Placing of mesh layers in mortar

E. Curing

After casting the panels were removed from mould after a period of 24 hours. After removal the panels were cured in normal water tank for a period of 28 days.

F. Testing

The panels were removed after a period of 28 days from water. White wash was applied to the panels to get clear indications of the cracks due to bending under service load. Panels were tested for flexure test under Universal testing machine. The panels were placed on support leaving a space of 50 mm from both ends. Two point loading system was installed at 150 mm from centre as shown. Dial gauge was placed below the panel to record the deflection in mm at each stage of loading.

Fig 8-(25 mm-2 layers) panel under testing set-up

To calculate the flexural strength the panels were loaded under two point loading and load and deflections were noted down carefully.

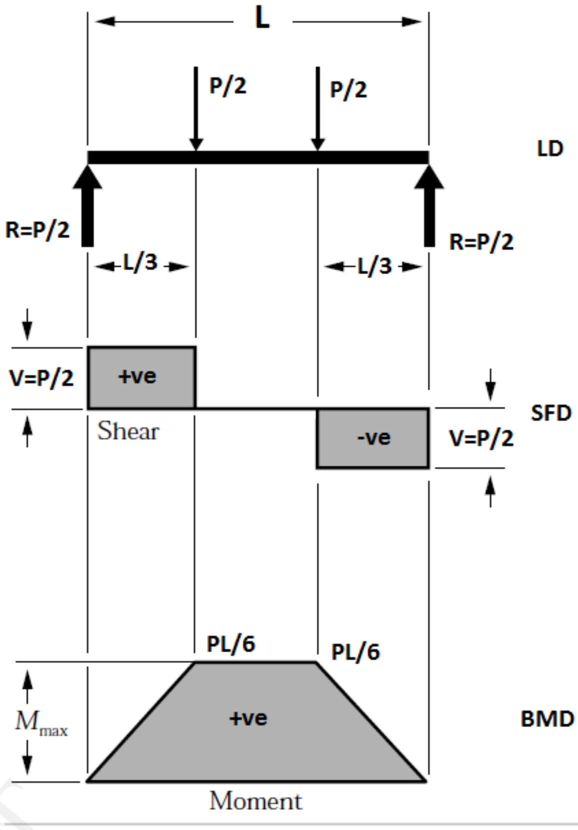


Fig 9-SFD and BMD distribution of panel

The bending strength was calculated using the following formula

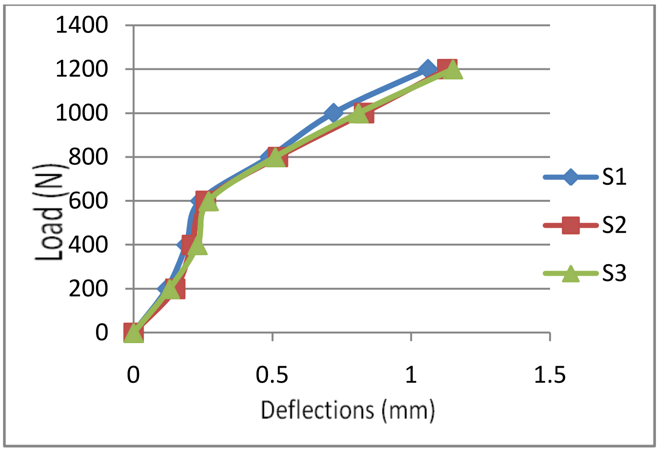
$$M/I=\sigma/y \quad \text{thus } \sigma=M/I * y$$

Where:
M: Bending Moment, (N.mm)
y= D/2, (mm)
I: Moment of Inertia=bd³/12, σ= flexural strength

G. Test Results and graphs

Table 3.Panel thickness-25mm, Layers-2 (without steel fibers)

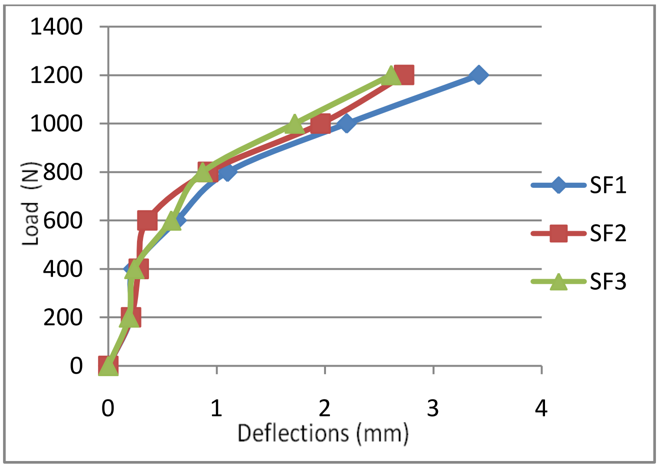
Load (N)	Deflections (mm)		
	S1	***S2***	***S3***
0	0	0	0
200	0.12	0.15	0.13
400	0.19	0.21	0.23
600	0.24	0.26	0.27
800	0.49	0.52	0.51
1000	0.72	0.83	0.81
1200	1.06	1.13	1.15
1st crack	0.24	0.52	0.27
max load	1200	1200	1200



Graph1. Load v/s deflection (25mm-2layers) without steel fibers

Table 4.Panel thickness-25mm, Layers-2 (with steel fibers)

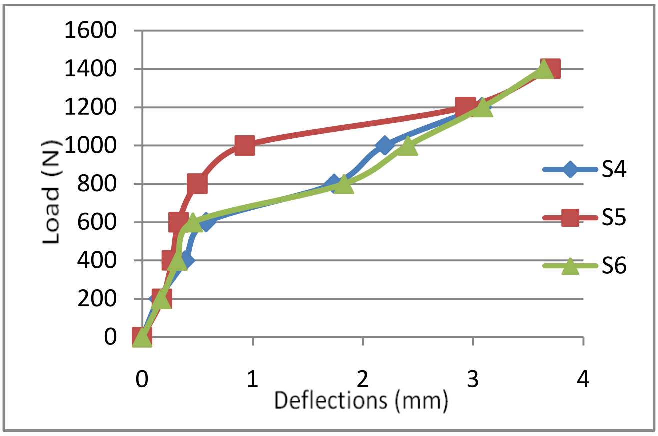
Load (N)	Deflections (mm)		
	SF1	*SF2*	*SF3*
0	0	0	0
200	0.21	0.21	0.19
400	0.23	0.28	0.24
600	0.63	0.36	0.58
800	1.1	0.92	0.87
1000	2.2	1.96	1.72
1200	3.42	2.73	2.61
1st crack	1.1	0.92	0.87
max load	1200	1200	1200



Graph2. Load v/s deflection (25 mm-2 layers) with steel fibers

Table 5-Panel thickness-25mm, Layers-3 (without steel fibers)

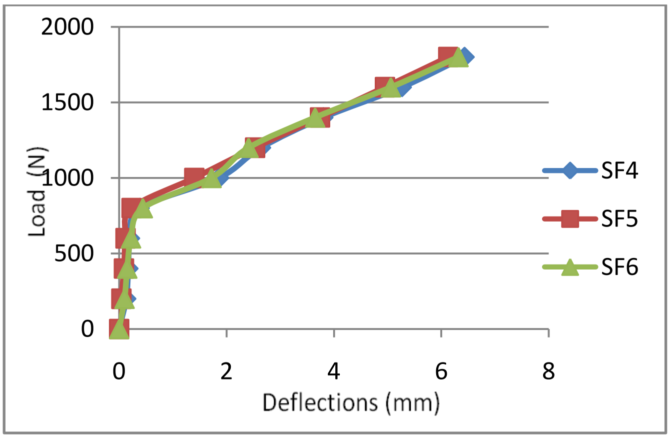
Load (N)	Deflections (mm)		
	S4	*S5*	*S6*
0	0	0	0
200	0.15	0.18	0.17
400	0.39	0.27	0.32
600	0.58	0.33	0.46
800	1.74	0.5	1.83
1000	2.2	0.93	2.41
1200	3.08	2.93	3.09
1400	3.72	3.7	3.64
1st crack	1.74	0.93	1.83
max load	1400	1400	1400



Graph 3.Load v/s deflection (25 mm – 3 layers) without steel fibers

Table 6.Panel thickness-25mm, Layers-3 (with steel fibers)

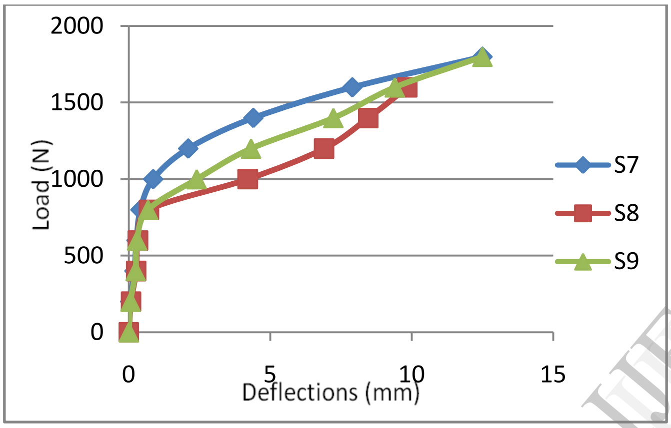
Load (N)	Deflections (mm)		
	SF4	***SF5***	***SF6***
0	0	0	0
200	0.13	0.04	0.1
400	0.17	0.09	0.15
600	0.2	0.12	0.22
800	0.38	0.23	0.44
1000	1.86	1.4	1.72
1200	2.64	2.53	2.41
1400	3.8	3.74	3.65
1600	5.26	4.95	5.06
1800	6.43	6.13	6.32
1st crack	1.86	2.53	2.41
max load	1800	1800	1800



Graph4. Load v/s deflection (25 mm-3 layers) with steel fibers

Table 7.Panel thickness-25mm, Layers-4 (without steel fibers)

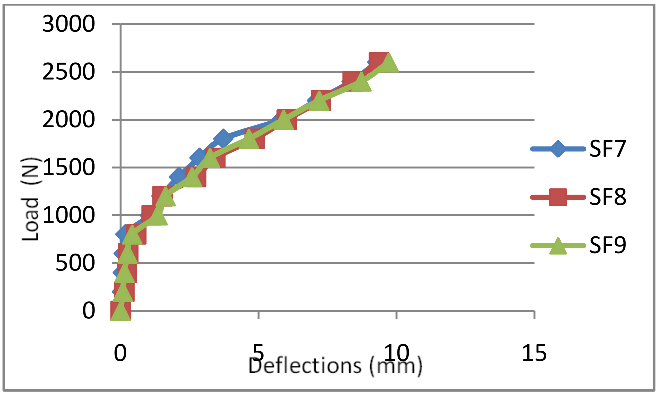
Load (N)	**Deflections (mm)**		
	S7	**S8**	**S9**
0	0	0	0
200	0.05	0.08	0.06
400	0.2	0.26	0.24
600	0.27	0.32	0.29
800	0.41	0.71	0.68
1000	0.86	4.2	2.4
1200	2.1	6.9	4.32
1400	4.4	8.46	7.23
1600	7.9	9.84	9.4
1800	12.5	11.93	12.5
1st crack	2.1	4.2	4.32
max load	1800	1800	1800



Graph5. Load v/s deflection (25 mm-4 layers) without steel fibers

Table 8.Panel thickness-25mm, Layers-4 (with steel fibers)

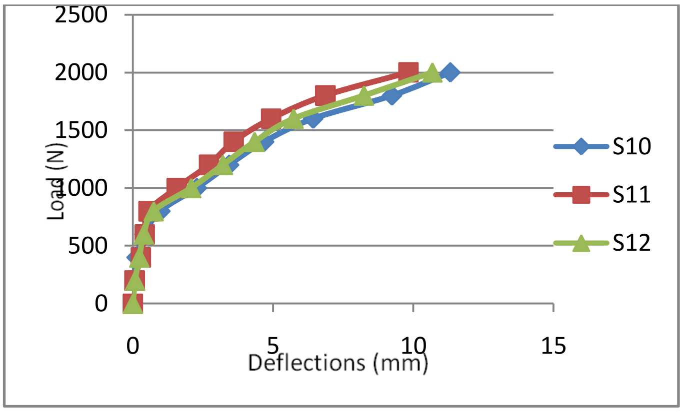
Load (N)	**Deflections (mm)**		
	SF7	*SF8*	*SF9*
0	0	0	0
200	0.05	0.13	0.08
400	0.08	0.23	0.14
600	0.11	0.28	0.25
800	0.17	0.57	0.42
1000	1.06	1.12	1.34
1200	1.48	1.52	1.63
1400	2.11	2.73	2.59
1600	2.86	3.43	3.24
1800	3.72	4.86	4.65
2000	5.83	6.02	5.91
2200	7.12	7.26	7.2
2400	8.37	8.41	8.73
2600	9.3	9.36	9.72
1st crack	2.11	2.73	1.63
max load	2600	2600	2600



Graph6. Load v/s deflection (25 mm-4 layers) with steel fibers

Table 9.Panel thickness-25mm, Layers-5 (without steel fibers)

Load (N)	**DEFLECTIONS (mm)**		
	S10	***S11***	***S12***
0	0	0	0
200	0.06	0.06	0.08
400	0.13	0.28	0.23
600	0.41	0.42	0.39
800	0.98	0.56	0.74
1000	2.28	1.56	2.08
1200	3.43	2.71	3.21
1400	4.68	3.59	4.34
1600	6.43	4.93	5.73
1800	9.24	6.86	8.24
2000	11.32	9.82	10.68
1st crack	3.43	3.59	4.34
max load	2000	2000	2000

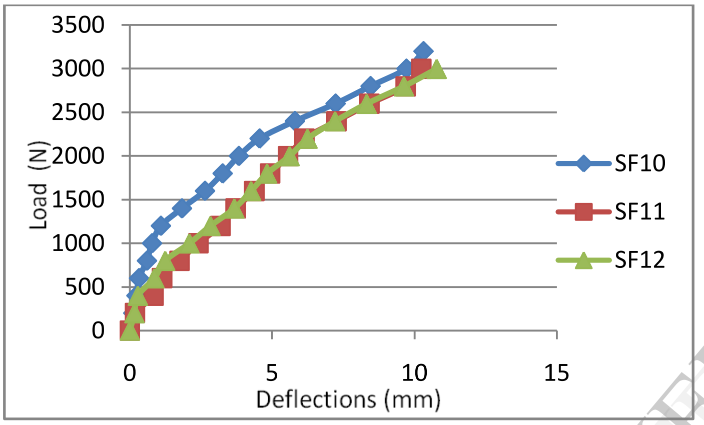


Graph7. Load v/s deflection (25 mm-5 layers) without steel fibers

Table 10.Panel thickness-25mm, Layers-5 (with steel fibers)

Load (N)	**Deflections (mm)**		
	SF10	***SF11***	***SF12***
0	0	0	0
200	0.12	0.18	0.16
400	0.23	0.83	0.28
600	0.32	1.13	0.86
800	0.6	1.74	1.24
1000	0.78	2.41	2.09

1200	1.09	3.18	2.83
1400	1.83	3.72	3.67
1600	2.64	4.37	4.26
1800	3.26	4.93	4.82
2000	3.83	5.56	5.61
2200	4.56	6.13	6.24
2400	5.8	7.26	7.21
2600	7.23	8.42	8.32
2800	8.46	9.69	9.63
3000	9.72	10.24	10.78
3200	10.32		
1st crack	3.83	4.93	4.82
max load	3200	3200	3200



Graph8. Load v/s deflection (25 mm-5 layers) with steel fibers

Table 11.Flexural strength of ferrocement panels without steel fibers.

Panel no	Cracking Load (N)	Ultimate Load (N)	Flexural strength (σcr) at cracking load (N/mm²)	Flexural strength (σult) at ultimate load (N/mm²)
S1	600	1200	2.16	4.33
S2	800	1200	2.88	4.33
S3	600	1200	2.16	4.33
S4	800	1400	2.88	5.04
S5	1000	1400	3.60	5.04
S6	800	1400	2.88	5.04
S7	1200	1800	4.32	7.57
S8	1000	1800	3.60	7.57
S9	1200	1800	4.32	7.57
S10	1200	2000	4.32	6.49
S11	1400	2000	5.04	6.49
S12	1400	2000	5.04	6.49

Table 12 Flexural strength of ferrocement panels with steel fibers.

Panel no	Cracking Load (N)	Ultimate Load (N)	Flexural strength (σcr) at cracking load (N/mm²)	Flexural strength (σult) at ultimate load (N/mm²)
SF1	800	1200	2.88	4.33
SF2	800	1200	2.88	4.33
SF3	800	1200	2.88	4.33
SF4	1000	1800	3.60	7.57
SF5	1200	1800	4.32	7.57
SF6	1200	1800	4.32	7.57
SF7	1400	2600	5.04	9.38
SF8	1400	2600	5.04	9.38
SF9	1200	2600	4.32	9.38
SF10	2000	3200	7.21	11.53
SF11	1800	3000	6.49	10.82
SF12	1800	3000	6.49	10.82

Fig 10.Showing (25 mm-2 layer) panel failure

Fig 11.Showing (25mm- 3 layer) panel failure

VIII. CONLUSION

Based on experimental test results the following conclusions can be made**.**

1. The flexural loads at first crack and ultimate loads depend on number of reinforcing mesh layers used in ferrocement panel.
2. Increasing the number of layers of wire mesh from 2 to 5 layers significantly increases the ductility and capability to absorb energy of the panels.
3. Steel fibers are capable of increasing the strength parameters like the flexural strength of panels as compared to those without fibers.
4. Steel fibers also increases the ductility of panels and decreases the central deflection tendency as compared to others without steel fibers.
5. Result shows that incorporation of steel fibers along with increment in no of layers leads to 40% increase in load carrying capacity and 35% decrease in deflection

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