"STUDY OF FLEXURAL STRENGTH OF FERROCEMENT SLAB PANELS"

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ABSTRACT

Ferrocement panels are versatile forms of precast concrete consist of cement, wire mesh, sand, and water that is known for high strength. However, the ideal composition of cement mortar, admixture proportions, and thickness of the panels are not well studied. This paper describes the results of numerous experiments conducted on flat ferrocement panels reinforced with different number of wire mesh layer and variation in panel thickness to determine the optimum flexure strength based on the criteria provided below. The main objective of these experimental tests is to determine the ideal combination of wire mesh layers and panel thickness to obtain the optimum flexural strength for flat ferrocement panels and to compare the effect of varying the number of wire mesh layers on the ductility and the ultimate strength of this type of ferrocement elements. In this study, the specimens were divided into eight groups to investigate the strength and behavior of ferrocement flat panels subjected to two-point loading. Two different composition of cement mortar are used to study the strength of element in case of using fly-ash instead of %15 by weight of cement in mortar. Thirty six ferrocement elements were constructed and tested. In addition, two cases of wire mesh layers are tested, which are two-layer case and four-layer case. Also, two cases of panel thicknesses are tested, which are 25mm and 30 mm cases.

Keywords: Accelerated Construction, Concrete - SCC, Lt. Wt., High Performance, etc., Construction, Hollow core, Substructure, Precast, light weight.

1. INTRODUCTION

1.1 General

A big number of civil structures around the world are in a state of serious weakening today due to carbonation, chloride attack, etc. Many civil structures are not considered safe anymore due to increment of load specifications in the codes or due to overloading or due to under design of old structures or due to lack of quality control. To preserve efficient serviceability, older structures must be repaired or make stronger so that they meet the same needs demanded of the structures built today and tomorrow. Ferrocement over the years have gained regards in terms of its superior efficiency and versatility and diversity.

What is ferrocement?

Ferrocement is a type of reinforced concrete family using closely spaced multiple layers of mesh and small diameter rods completely infiltrated with mortar or encapsulated in mortar. Pier Luigi Nervy (an Italian architect and contractor) in 1940 used ferrocement first for the constructing of aircraft hangars, boats and buildings and other structures. It is a cheap, very durable and versatile material.

1.2 Constituents of ferrocement:

Cement: Fresh cement should have uniform consistency and free of any lumps and foreign matter.

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

Water: Potable and clean water is suitable for use as mixing water and also for curing ferrocement panels

Admixture: Chemical admixtures are used in ferrocement for purposes of water reduction, with strength and minimize permeability; air entrainment, which rises resistance to thawing and freezing; and suppression of reaction between cement and galvanized reinforcement.

Ferrocement composites have:

Thickness 6 mm to 50 mm
Steel cover 1.5 mm to 5 mm
Ultimate tensile strength up to 34 MPa
Allowable tensile stress up to 10 MPa
Rupture modulus up to 55 MPa
Compressive strength up to 28 MPa to 69MPa.

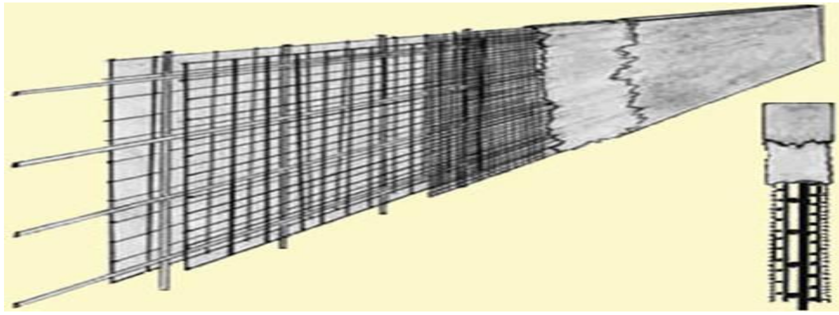


Figure1- 1 Typical cross section of ferrocement structure

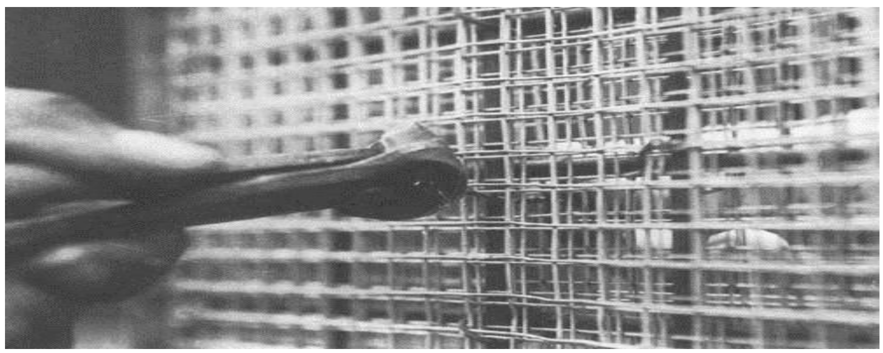


Figure1- 2 Reinforcing mesh

1.3 Historical background –

Italian architect, Pier Luigi Nervi, was first who undertook real research into Ferro-cement technology. He noticed that reinforcing concrete with layers of wire mesh resulted in a material with high impact resistance features. This material is different from reinforced concrete in its elasticity and flexibility. After the Second World War, Pier L. Nervi built a motor sailor with 165-ton. This ship, "Irene", proved to be seaworthy. Similar ships were built in the Australia, U.K. and New Zealand, and one circumnavigated the world without problems. But Pier Luigi Nervi would not have been an architect and structural engineer if he had not also used this material for building construction. He first built a storehouse of Ferrocement in 1947,and then he combined reinforced concrete with the Ferro-cement technique and constructed the famous Turin Exhibition Hall with a roof system with 91 m spans. Nervi's conclusion proved that Ferro-cement is a great quality construction material. The question we may ask, why Ferro-cement is relatively rarely used as a building material in industrial countries? The answer is, in the process of industrialization of construction work, in order to decrease the labor cost, construction works has become more capital-intensive. Therefore, working processes have been mechanized wherever possible. In this context the possibilities for mechanizing Ferro-cement remain limited. A large percentage of labor cost will always characterize this technology. While this is considered to be a disadvantage for industrialized countries, it is an affirmative factor in developing countries where the labor market is characterized by high unemployment and low labor costs. In a result, it has to be emphasized that ferro-cement is by no means a second-class technology, but rather highly proper especially for countries where labor costs are low.

1.4 Properties of ferrocement-

The engineering properties of ferro-cement structure are similar to normal concrete, and in some applications it performs even better. The tensile strength of ferrocement is a result of the volume of reinforcement used in the structure. Apart from the reinforcement volume, the direction of its use in line with the tensile stress direction and force direction is also very important. When ferrocement member subjected to upwards tensile stress behaves like linear elastic material until the first crack appears. Beyond this, the ferrocement member will enter the multiple cracking and then continuing to a point where the mesh starts to experience yielding. Once at this stage the number of cracks will continue to grow with the increase in the stress or tensile force. The specific surface area of the ferrocement member or element has been found to influence the first crack in tension, and the width of the cracks. The maximum stress at first crack for ferrocement matrix increases in proportion to the specific area of the element. Ferro concrete has relatively good strength and resistance to impact. When used in house construction in developing countries, it can provide better resistance to earthquake, fire and corrosion than traditional materials, such as stone masonry, adobe and wood. It is suggests a possibility of producing a very thin and light structures. This means it has ability of giving cost saving through the material usage. Apart from the material saving, the overall dead weight of the structure also could be decreased by employing ferrocement; thus it will result in more economical foundation design. Ferro cement has very high tensile strength- to weight ratio and very superior cracking behavior, Low w/c ratio produces an impermeable structures. Ferro cement structures have less shrinkage, high durability, and light weight.

1.5 Comparision between -

Table 1 Comparison between RCC and Ferrocement

R.C.C	FERROCEMENT
Min Thickness – 75 mm	Thin Walled , 25-50 mm
Matrix : Cement Content	Micro-Concrete (Rich Cement Mortar)
R/F – Steel Bars > 6mm dia , spaced apart	Continuous Fine Wire mesh dispersed throughout the body of structure
Strength – Weak in tension , bond & Shear	High tensile strength, superior bond & shear strength.
Strength to Weight Ratio – In tension & Compression, Very Low.	Very High
For casting- Formwork & shuttering are quite essential.	Tightly tied wire meshes act as forms for mortar casting.

1.6 Objective of Proposed Study –

The main objective of these experimental tests is to study the different numbers of wire mesh layers and effect of varying thickness of panels on the flexural strength of flat ferrocement panels, also to compare the effect of varying the number of wire mesh layers and thickness variation on the ductility and ultimate strength of these types of ferrocement structure. In the test also two different composition of cement mortar are used to study the strength of element in case of using fly-ash instead of %15 of cement in mortar.

2. LITERATURE REVIEW:

Flexural Behavior of Flat and Folded Ferrocement Panels by Mohamad N. Mahmood & Sura A. Majeed

Ferrocement is one of the construction materials which may be able to fill the need for building light structures. Ferrocement composite consist of cement-sand mortar and single or multi-layers of steel wire mesh to produce elements of small thickness having high durability, resilience and when properly shaped it has high strength and rigidity. These thin elements can be shaped to produce structural members such as folded plates, flanged beams, wall panels…etc for use in the construction of cheap structures.

Experimental Program

Geometry of the specimens:

The tested ferrocement elements consist of three folded panels and four flat panels. The dimensions of the folded and flat panels are shown in Fig (2-1) which depicts that the horizontal projection of the folded panel is equal to (380x600mm) which is equal to the dimensions of the flat panel. The thickness of all the elements is equal to 20mm. Dimensions of the folded and flat panels (dimensions are in mm).In handling the folded panel without wire mesh, it failed along the longitudinal folds after removing it from the mold so it has been excluded for the test results. The panels are constructed using the conventional ferrocement materials, which is composed of cement mortar and square wire meshes.

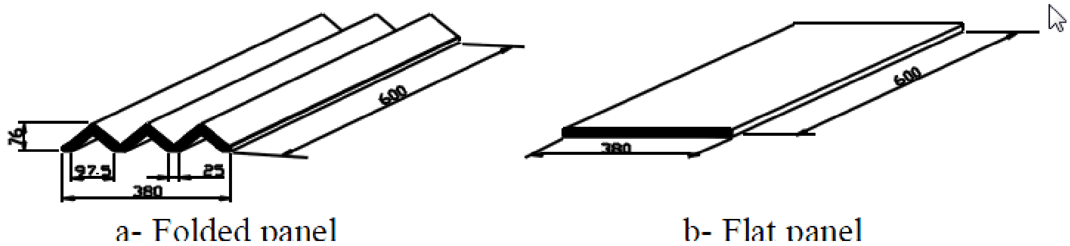


Figure 2- 1 Dimensions of the folded and flat panels (dimensions are in mm).

Table 2 Details of tested panels

Panels number	panel type	Number of mesh layers
A1	Folded panels	1
A2		2
A3		3
B1	Flat panels	0
B2		1
B3		2
B4		3

Wire mesh:

The wire mesh used in the present work is mild steel galvanized welded wires of square grid having wire spacing equal to 12.5mm with a wire diameter equal to (0.65mm). The average values of yield stress (fy), ultimate stress and modulus of elasticity are given in Table (3). The yield stress is determined corresponding to a 0.2% offset according to ASTM standard A370 [8].

Table 3 Properties of the constituent materials

Mortar	
Cement : sand : water (by weight)	1 :2 : 0.45
Cube strength (7 days)	22.5MPa
Cube strength (28 days)	37.4MPa
Modulus of rupture (28 days)	6.3MPa
Wire mesh	
Grid size	12.5x12.5mm
Diameter of wire	0.65mm
Yield stress (0.2% offset)	400MPa
Ultimate tensile strength	500MPa
Modulus of elasticity	63490MPa

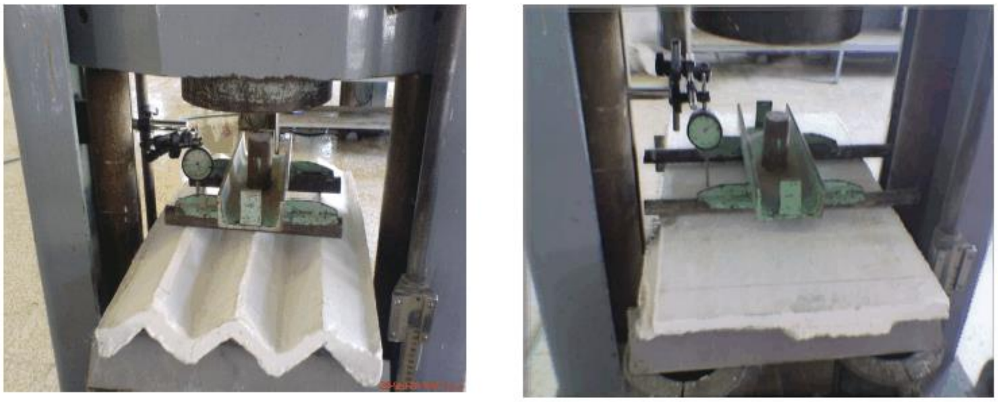


Figure 2- 2 set up of the tested folded and flat panels.

Table 4 Cracking load and ultimate strength of the tested panels

Panel number	Cracking Load (N)	Ultimate Load (N)	Flexural strength (N.mm/mm)
A1	4550	4750	1042.0
A2	4450	6500	1425.0
A3	4450	9000	1975.0
B1	985	1100	241.0
B2	775	1150	252.0
B3	835	1820	400.0
B4	945	1850	406.0

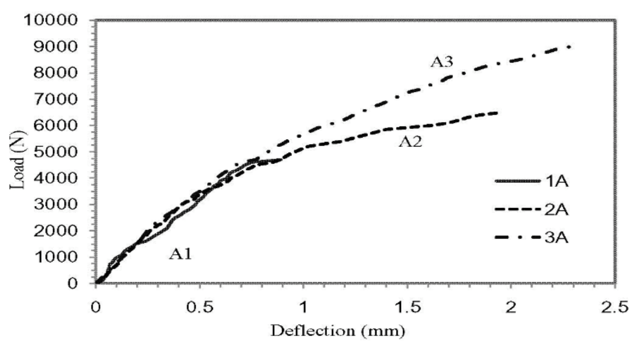


Figure 2.3 Load deflection curves for the folded panels

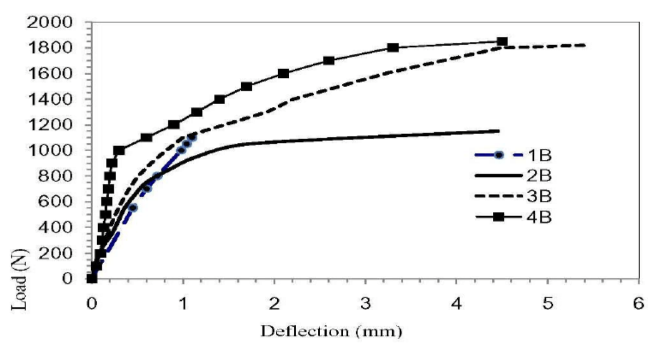
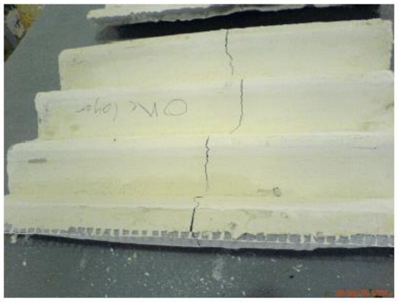
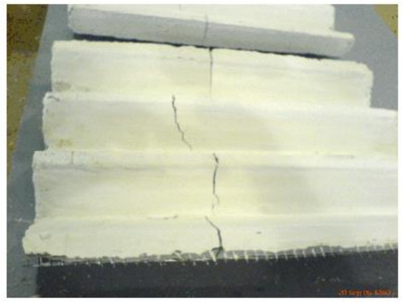


Figure 1.4 Load deflection curves for flat panels


A1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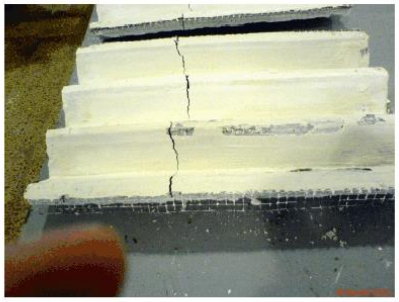
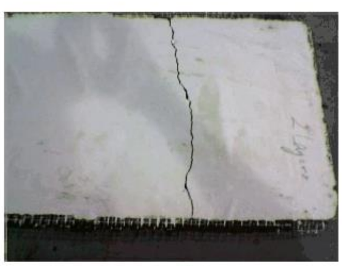

A3

Figure 2.5 Crack pattern at the top face of the folded panels


B1


B2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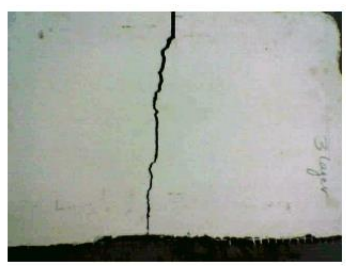

B4

Figure 2.6 Crack pattern at the top face of the flat panels

Concluding Remarks

Based upon the experimental test results of the folded and flat panels the following can be stated:

- The cracking load was not significantly affected by the number of the wire mesh particularly for the folded panels.
- The flexural strength of the folded panel increased by 37 and 90 percent for panels having 2 and 3 wire mesh layers compared with that of single layer; while for the flat panel the percentage increase in the flexural strength using 2 and 3 layers is 65% and 68% compared with that of plain mortar panel. The gain in the flexural strength of the flat panel with single layer, located at mid depth of the section, compared with that of plain mortar is only marginal. But using single layer helps in increasing the ductility of the flat panel.
- The experimental and numerical results show the superiority of the folded to the flat panel in terms of ultimate strength and initiation of cracking.
- Finally increasing the number of layers of wire mesh from 1 to 3 layers significantly increases the ductility and capability to absorb energy of both types of the panel.

3. EXPERIMENTAL PROGRAM

In order to study the strength and structural behavior and ultimate strength of ferrocement slab panels, a series of experiments have been carried out. This chapter includes the properties of the materials used, casting of ferrocement slab panels, and preparation of samples, testing procedure, description of the testing instrument and the geometry of the specimens.

The experimental program includes preparing and testing of thirty six ferrocement slab panels under two-point loading. The primary variables were the thickness of panels, number of layers of meshes and existence of fly ash.

Materials:-

Cement: The cement used in the tests was Ordinary Portland Cement (Grade 43) locally available.

Fine Aggregate (Sand): Locally available clean and good graded fine aggregate was used after passing through I.S sieve 2.36 mm.

Wire Mesh: Galvanized woven square meshes were used with 2 mm diameter and 25 mm spacing used in the specimens as shown in the following figure.

Figure 3.1 Square Woven Meshes

Water: Ordinary drinking water was used for mixing and curing of concrete. The water was clean and free from acids, alkalis and organic impurities.

Moulds: Moulds were made from plywood of 19mm thickness. The moulds were fabricated in college workshop. Also before casting interior surface was oiled.

Figure 3.2 Typical Molds of the Tested Specimens

Mixing Details:-

Mixing proportions: Mix proportion was selected from suitable amount of ingredients in such a way to get a workable and homogeneous concrete. After sieving fine aggregates on 2.36 mm, finally a suitable mix proportion by weight was selected from a number of test investigations. The mix proportion was 1:2.5 (Cement: Sand) with water to cement ratio of 0.41. In the trial mixes, crushed stone (passed by 2.36 mm sieve) used as 15% replacement of sand but it resulted in a lower strength as compared to other mixes without crushed stone, hence that proportion has been neglected.

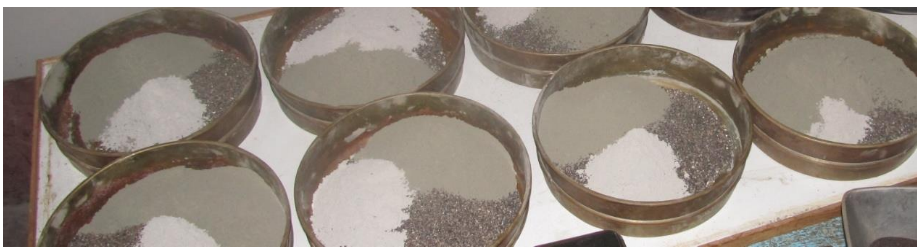


Figure 3.3 Trial Mixes

Mixing operation: The mixing procedure is important for obtaining the required workability. Materials were mixed manually. Fine aggregate and cement were mixed as well as fly ash. Next, the water was added gradually to the mixture, and the operation of mixing was continued until homogeneous concrete mix was obtained.

Casting: The interior faces of the moulds were oiled and then the first layer of cement mortar was poured in moulds. The first layer of mesh was laid with the cover of about 2 to 4 mm from bottom ,then the mortar was placed and the other layers of meshes were also laid. After placing the mesh, pouring of the mixture continued to the level of the mould and smoothened afterwards.

Curing: The test and control specimens were demoulded after 24hours, and cured according to ACI 308.1 . The specimens were cured for about 28days, and then left in air temperature and humidity inside the laboratory until the date of testing.

Concrete Properties:

Compressive strength of Concrete: Six trial mixes were made to find a suitable mixture in the specimens. Different percentage of water to cement ratio, fly ash and crushed stone were employed. The properties of the final mixture, used in the specimens, are shown below:

(W/C: Cement: Sand): (0.41: 1: 2.5)

Nine cubes (70 mm x 70 mm x 70 mm) were tested for specimens to obtain the average compressive strength (f_{cu}). The specimens were cured by immersing in water for about 28days.

- Compression test results for cube: –

Table 5 Cube test results for 28 days

Cube sample	Load taken (7 days) (kg)	Load taken (28 days) (kg)	Compressive Strength (7 days) (N/mm^2)	Compressive Strength (28 days) (N/mm^2)	Average Compressive Strength (7 days) (N/mm^2)	Average Compressive Strength (28 days) (N/mm^2)
F1	14000	21000	28	42		
F2	13500	20000	27.55	40	**27**	**40**
F3	13000	19000	26.5	38		
C1	18500	28000	37.7	56		
C2	18000	27000	36.7	54	**36**	**55**
C3	17500	275000	35.7	55		

Sample calculation –

Compressive Strength (N/mm^2)= Load (N) / Area (mm^2)

-For Cubes which contain fly ash as replacement of 15% by weight of cement

a) 21000 kg = 210 KN = (210*1000 N)/(70*70) = 42 N/mm^2

b) 20000 kg = 200 KN = (200*1000 N)/(70*70) = 40 N/mm^2

c) 19000 kg = 190 KN = (190*1000 N)/ (70*70) = 38 N /mm^2

Average strength of the above cubes =40 N/mm^2

-For Cubes which not contained fly ash

a) 28000 kg = 280 KN = (280*1000 N)/(70*70) = 56 N/mm^2

b) 27000 kg = 270 KN = (270*1000 N)/(70*70) = 54 N/mm^2

c) 27500 kg = 275 KN = (275*1000 N)/(70*70) = 55 N/mm^2

Average strength of the above cubes =55 N/mm^2

Figure 3.4 compressive test cubes

- **Split tensile test results for cylinder –**

Table 6 Load taken in Split strength test

Cylindrical sample	Load taken (KN)	Split tensile strength (N/mm^2)
Sample 1	485	6.86
Sample2	460	6.51
Sample 3	360	5.09

Sample calculation –

$$\textbf{Split tensile strength} = \frac{2P}{\pi D L}$$

where:

P = Failure load, KN

D = Diameter of Cylinder, mm

L = Depth of the cylinder, mm

a) SPLIT TENSILE STRENGTH 1= $(2\times485\times10^3)/(\pi*150*300)$
   = **6.86 N/mm² > min. requirement 3.5 N/mm²**

b) SPLIT TENSILE STRENGTH 2= $(2\times460\times10^3)/(\pi*150*300)$
   = **6.51 N/mm² > min. requirement 3.5 N/mm²**

c) SPLIT TENSILE STRENGTH 3= $(2\times360\times10^3)/(\pi*150*300)$
   = **5.09 N/mm² > min. requirement 3.5 N/mm²**

Figure 3.5 Tensile splitting tests

Geometry of the Specimens:

In this study, the tested ferrocement specimens consists of thirty six flat panels, all the specimens were divided into eight groups to investigate the strength and behavior of ferrocement flat panels subjected to two-point loading at yield stage.

The first group (**F1**) consists of 6 panels of 25 mm thickness with four layers of wire meshes. Also the specimens contained fly ash (15% by weight of cement). Three specimens were tested in the age of seven days and the rest of them were tested at the age of twenty eight days.

The Second group (**F2**) consists of 6 panels of 25 mm thickness with two layers of wire meshes. Also the specimens contained fly ash (15% by weight of cement). Three specimens were tested in the age of seven days and the rest of them were tested at the age of twenty eight days.

Group three (**F3**) consists of 6 panels of 30 mm thickness with four layers of wire meshes. Also the specimens contained fly ash (15% by weight of cement). Three specimens were tested in the age of seven days and the rest of them were tested at the age of twenty eight days.

Group four (**F4**) consists of 6 panels of 30 mm thickness with two layers of wire meshes. Also the specimens contained fly ash (15% by weight of cement). Three specimens were tested in the age of seven days and the rest of them were tested at the age of twenty eight days.

The fifth group (**C1**) consists of 3 panels of 25 mm thickness with four layers of wire meshes but no fly ashes added into the mixture. The panels were tested at the age of twenty eight days.

The sixth group (**C2**) consists of 3 panels of 25 mm thickness with two layers of wire meshes but no fly ashes added into the mixture. The panels were tested at the age of twenty eight days.

The seventh group (**C3**) consists of 3 panels of 30 mm thickness with four layers of wire meshes but no fly ashes added into the mixture. The panels were tested at the age of twenty eight days.

The eighth group (**C4**) consists of 3 panels of 30 mm thickness with two layers of wire meshes but no fly ashes added into the mixture. The panels were tested at the age of twenty eight days.

The number of mesh layers, thickness of panels, material used in specimens and designation of tested elements are given in table 1.

Table 1 Tested panel details

Test Group	**Number of panels**	**Fly ash**	**Number of Mesh layers**	**dimension(mm)**
F1	3+3	Contained	4	550 x 200 x25
F2	3+3	Contained	2	550 x 200 x 25
F3	3+3	Contained	4	550 x 200 x 30
F4	3+3	Contained	2	550 x 200 x 30
C1	3	Not contained	4	550 x 200 x 25
C2	3	Not contained	2	550 x 200 x 25
C3	3	Not contained	4	550 x 200 x 30
C4	3	Not contained	2	550 x 200 x 30

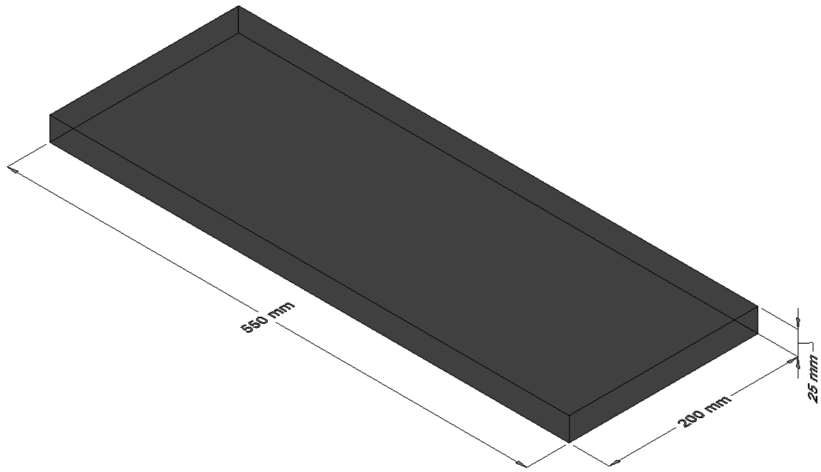


Figure 3- 1 Dimensions of the specimen with 25 mm thickness

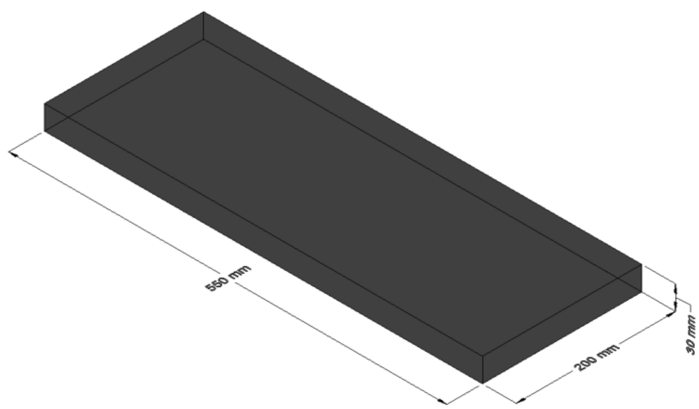


Figure 3- 2 Dimensions of the specimen with 30 mm thickness

4. Instrumentation and set up:

The specimens were white colored in order to observe the cracks easily and they were placed on a simply supported base and each support was 50 mm apart from the edge of the specimen. The load was distributed on a two line load at one-third of clear span of the specimen. A dial gauge was placed at the bottom in the mid span to observe the deflection of the slab panels at each load increment. Cracking was carefully checked throughout the loading process and the corresponding cracking load is also noted

Figure 4.1 Universal Testing Machine

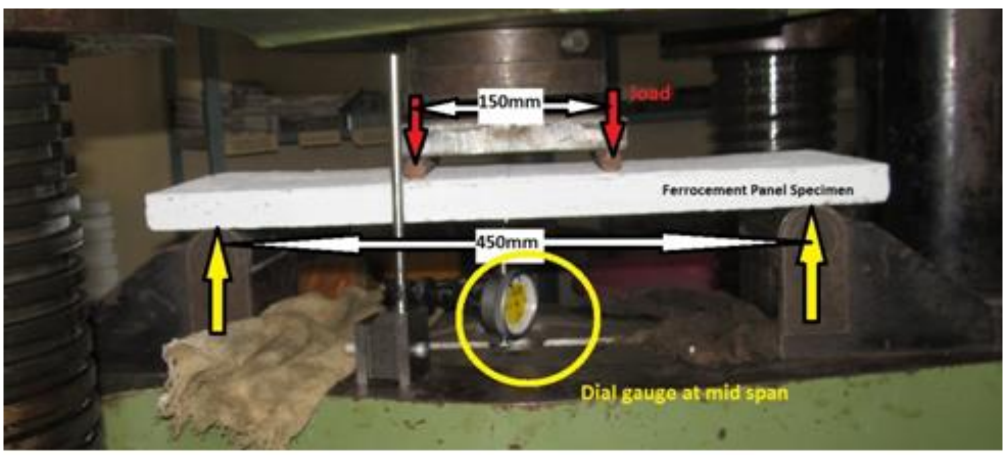


Figure 4.2 Specimen set up under two point loads

Figure 4.3 Specimen under the load

5. RESULTS AND CONCLUSIONS

Results and Discussion: The parameters that had been investigated in this study are the effect of the thickness of the panels and number of wire mesh layers on the cracking load and ultimate flexural strength and to plot the load deflection curve for each panel.

Simultaneous:

Table 5.17 Test results of panels

Load (kg)	**Deflection (mm)**							
	F1	**F2**	**F3**	**F4**	**C1**	**C2**	**C3**	**C4**
0	0	0	0	0	0	0	0	0
100	0.3	0.3	0.13	0.18	0.24	0.3	0.2	0.14
200	0.63	0.65	0.3	0.36	0.79	1.43	0.28	0.24
300	1.24	1.59	0.55	0.57	1.46	2.49	0.59	0.47
400	1.97	2.59	0.95	1.58	2.27	4.61	1.21	1.35

500	3.17	4.64	1.65	2.52	3.39		1.88	2.48
600	4.4		2.13	6	4.7		2.53	5.83
700	8.19		2.82		7.48		3.48	
800			3.39		9.4		4.93	
900			4.35					
1000			5.86					

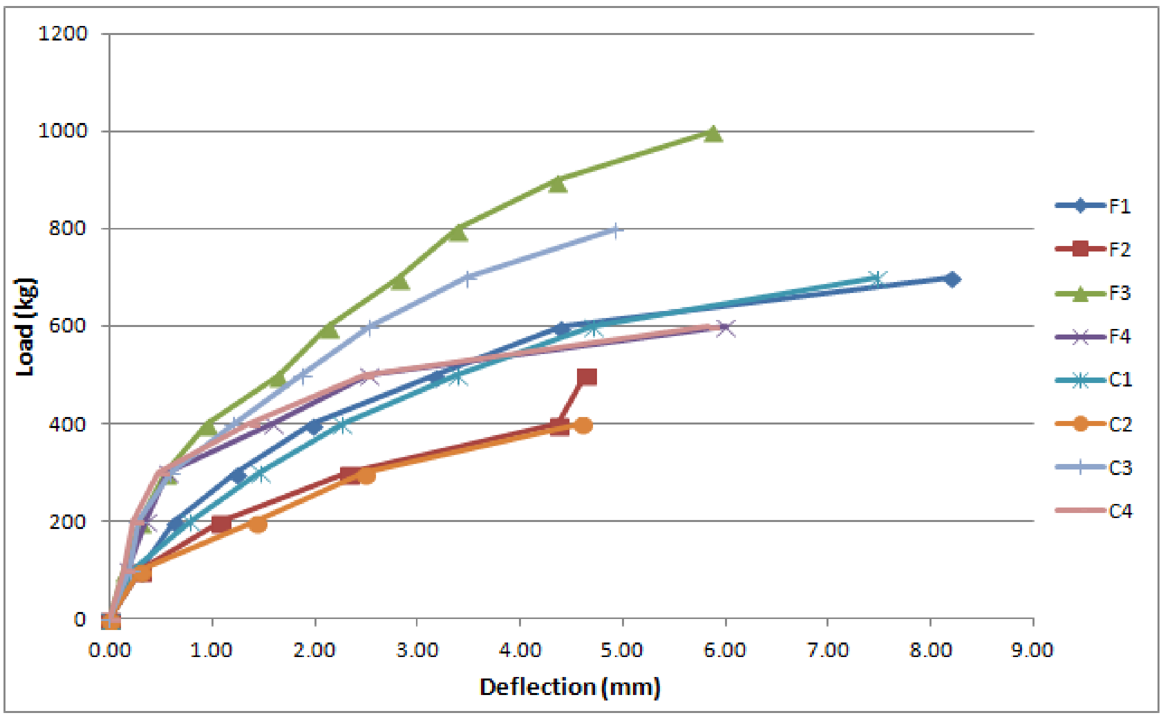
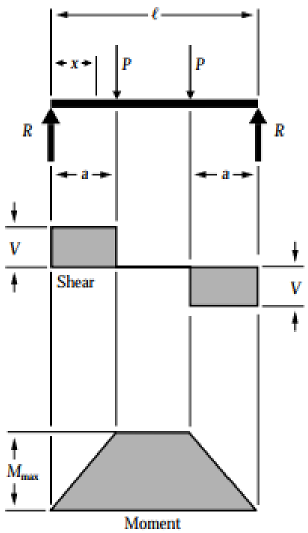


Figure 5.1 Load-Deflection curves for all Panels

Linear Elastic Modulus (E_1) and Nonlinear Elastic Modulus (E_2) calculation:



$$R = V \; \ldots\ldots\ldots\ldots \; = P$$

$$M_{max} \text{ (between loads)} \; \ldots\ldots \; = Pa$$

$$M_x \text{ (when } x < a) \; \ldots\ldots \; = Px$$

$$\boxed{\Delta_{max} \text{ (at center)} \; \ldots\ldots \; = \frac{Pa}{24EI}(3\ell^2 - 4a^2)}$$

$$\Delta_x \text{ (when } x < a) \; \ldots\ldots \; = \frac{Px}{6EI}(3\ell a - 3a^2 - x^2)$$

$$\Delta_x \left(\text{when } x > a \text{ and } < (\ell - a)\right) \; \ldots \; = \frac{Pa}{6EI}(3\ell x - 3x^2 - a^2)$$

$$\boldsymbol{\delta = Pa(3L^2 - 4a^2)/24EI}$$

Therefore: $\boldsymbol{E = Pa(3L^2 - 4a^2)/24\delta I}$

Where:

E: modulus of Elasticity, N/mm^2

I: Moment of Inertia, mm^4

a)Moment of Inertia for 25 mm thickness panels

$\mathbf{I_1} = 200 \times 25^3/12 = 2.6 \times 10^5$ mm^4

b) Moment of Inertia for 30 mm thickness panels

$\mathbf{I_2} = 200 \times 30^3/12 = 4.5 \times 10^5$ mm^4

L : span length of the bending member, mm = 450 mm

a : distance from load to support, mm = 150 mm

P: applied load, N

δ: Deflection at mid span, mm

$$\boldsymbol{E_1 = [P_1 a(3L^2 - 4a^2)]/[24\delta_1 I]} \quad \textbf{(Linear Elastic Modulus)}$$

$$E_2 = [P2\ a\ (3L^2 - 4\ a^2)] / [24\ \delta_2\ I] \quad \textbf{(Non Linear Elastic Modulus)}$$

-Calculation sample for finding flexural strength (σ) at Cracking and Ultimate loads stages:-

For Specimen F11:- $\sigma = \frac{M}{I} . y$

M_{cr}=6278.4/2 × 150 = 470 × 10^3 N.mm ,y= 25/2=12.5 mm , I= 200 × 25^3 /12= 2.6 × 10^5 mm^4

σ_{cr} = (470 × 10^3)× (12.5)/ (2.6×10^3) = 22.6 N/mm^2

$M_{ult=}$ 6965/2 × 150 = 522 × 10^3 N.mm

σ_{ult} = (522 × 10^3)× (12.5)/ (2.6×10^3) = 25.07 N/mm^2

The test results of the samples and structural properties of specimens at the age of 28 days from the day of casting are presented in Table (23) and Table (24).

Table Flexural strength at Cracking load and ultimate load of the tested panels

Test Group	Panel number	Cracking load (N)	Ultimate load (N)	Flexural Strength at Cracking load σ_{cr} (N/mm²)	Flexural Strength at ultimate load σ_{ult} (N/mm²)
F1	F11	6278.4	6965	22.60	25.07
	F12	5689.8	7063	20.48	25.43
	F13	5886	7259.4	21.19	26.13
F2	F21	5003	5395.5	18.01	19.42
	F22	5101	5297.4	18.36	19.07
	F23	4905	5493.6	17.66	19.78
F3	F31	8436.6	9613.8	21.09	24.03
	F32	9417.6	10398.6	23.54	26.00
	F33	9417.6	10594.8	23.54	26.49
F4	F41	4905	5493.6	12.26	13.73
	F42	5297.4	6082	13.24	15.21
	F43	4905	6082	12.26	15.21

C1	C11	7848	8044	28.25	28.96
	C12	5886	7063	21.19	25.43
	C13	6867	7553.7	24.72	27.19
C2	C21	3924	4512.6	14.13	16.25
	C22	3924	4120	14.13	14.83
	C23	3826	4218	13.77	15.18
C3	C31	7651.8	10398.6	19.13	26.00
	C32	7259.4	8632.8	18.15	21.58
	C33	7455	9221	18.64	23.05
C4	C41	5297.4	6082	13.24	15.21
	C42	5493.6	6180	13.73	15.45
	C43	5395	6180	13.49	15.45

After recording the results, the data were interpreted. The results for 25 mm thick specimens (28 days) show that using a higher number of mesh layers increases the flexural strength (comparing group F1 and F2. For 25 mm thick slabs using four layers gave approximately 30% increase in flexural strength as compared to two layered slab specimen. Also the cracking load delayed by about 18% for the four layer meshes slab.

Deformations of different specimens were compared at 400 kg applied load in order to observe the stiffness of the slab samples at the same load. For a 25mm thick slab, the deflection of four layered slab was 1.97mm while it was 2.58mm for two layers of meshes slab specimen, that shows using more mesh layers decreases the deformation about 30%.

The results for slab panels with 30 mm thickness also shows increasing layers of meshes increases the flexural strength (comparing group F3 and F4Bending strength increased by about 70% for slabs with four layers of meshes and the cracking load delayed by approximately 80%. Also the deflection decreased by about 65%.

The existence of fly ash also satisfies the conclusion above regarding the number of mesh layers (comparing groups C1 and C2 as well as C3 and C4). On the other hand it affects the strength and decreases the bending strength of the slab panels accordingly.).

Increasing the thickness also affected the final breaking load for slab panels. They show that slab panels with 30 mm thickness gave 43% increase in final breaking load in comparison to slab panels with 25mm thickness. Also first cracking load increased 52%.

Slab panels with smaller thicknesses deflected more, for a 400 kg applied load slabs with 30 mm thickness deflected to about 0.95 mm but for 25mm thick slab panels the deflection was 1.97mm at the same applied load.

The final breaking load in slab panel with 30 mm thickness increased by about 10% of slab panel with 30 mm thickness, also deflection for 30 mm thick slab gave 43% decrease in deflection as compared to 25mm thickness at the 400 kg applied load.

For slab panels without fly ash similar conclusions as in slab panels containing fly ash were achieved for thickness study.

Using fly ash, as 15% replacement by weight of cement, caused a slight decrease in the flexural strength for some of them and a slight increase for the others. It shows that this amount of fly ash does not considerably affect the flexural strength of the slab panels.

All groups of panels with 30mm thickness (with 4 and 2 layers of meshes) behaved in the same rate up to about 300 kg applied load. Then slabs with only two layers of meshes deflected in higher rate (lower slope) while slabs having four layers of meshes deflected in lower rate (higher slope). That means it requires a higher applied load for four layered slab panels to reach the same deflection as two layered slab panels. Also it implies that up to about 300 kg applied load (pre-cracking stage) the variation in the number of layers of meshes does not affect the behavior of panels.

Comparing groups F1and C1 with groups F4 and C4 illustrates that having a greater thickness results in increase in modulus of elasticity up to certain limit of elasto-plastic. In other words for loads less than about 500 kg, in this case, it is beneficiary to use thicker members and lower number of mesh layers. But if the load is higher than that, then it is more ductile and showing higher value of E to use higher number of meshes instead of increasing the thickness of the member.

Compressive strength test results for two groups of cubes show that using fly ash (15% by weight of cement) decreases 37% of compressive strength of cubes as compared to cubes without fly ash.

Difference of cracking loads taken on the test and elasticity limits observed from graphs indicates the ductility amount of panels.

Crack pattern

Regarding the crack pattern of the specimens, it can be concluded that all the samples were failed in bending because the cracks are vertical. The cracks started from the extreme fiber at the bottom and continued vertically upward until the failure reached. Most of the samples failed under the line load and a number of them failed at the mid span.

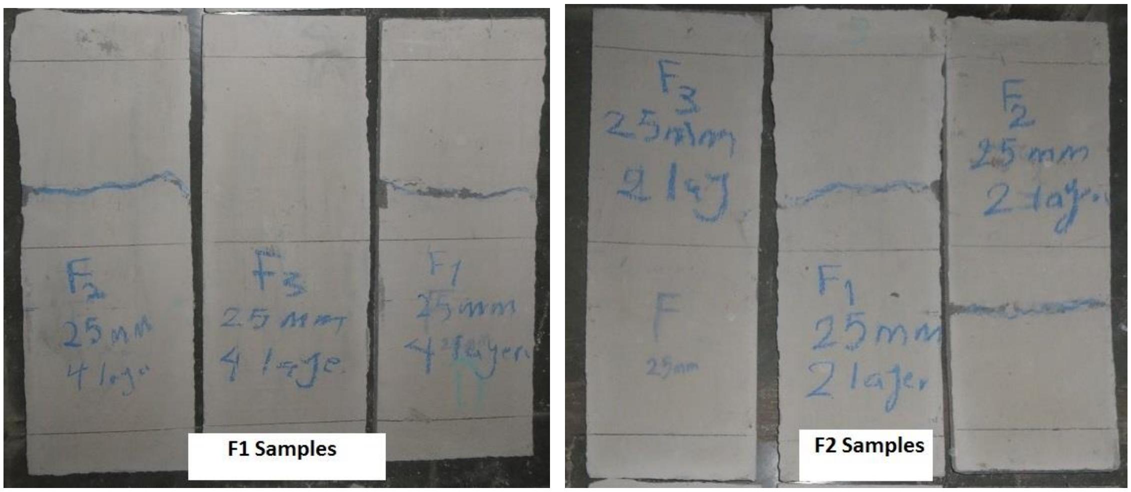


Figure 5.2 Top view of panel crack pattern for F1 & F2 Samples

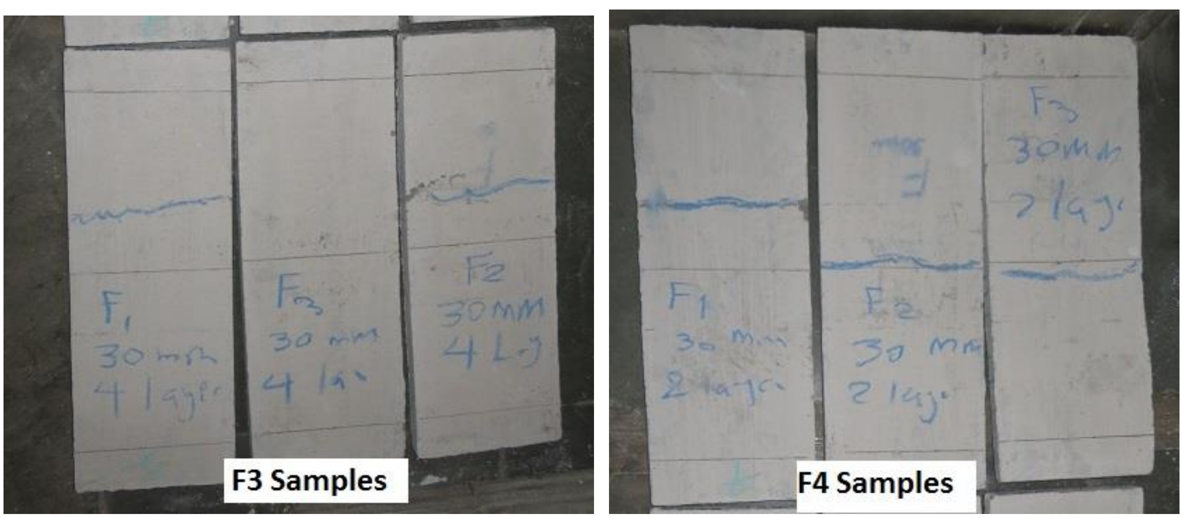


Figure 5.3 Top view of panel crack pattern for F3 & F4 Samples

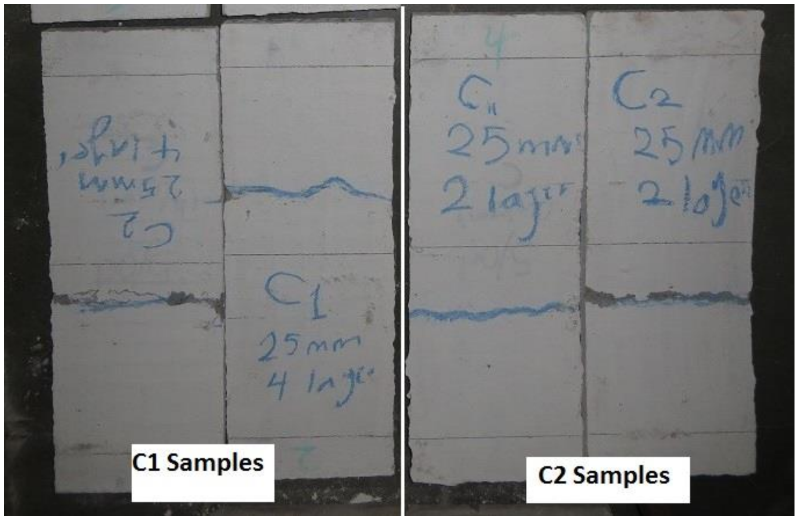


Figure 5.4 Top view of panel crack patterns for C1 and C2 Samples

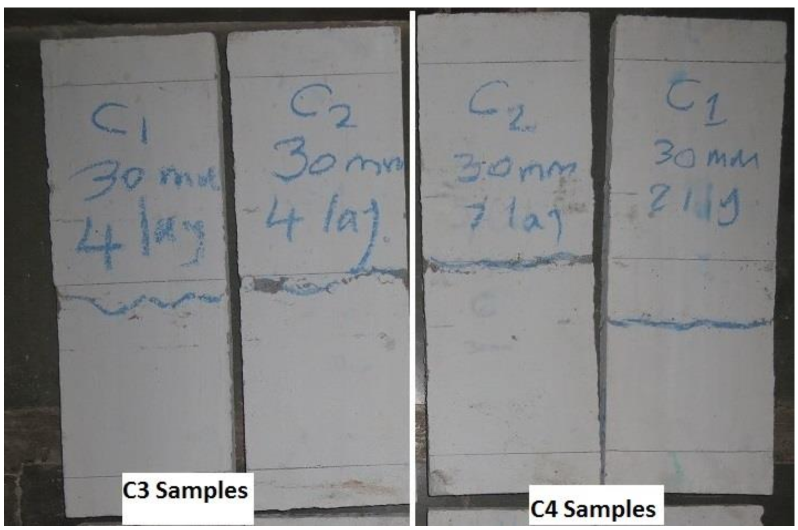


Figure 5.5 Top views of panel crack patterns for C3 and C4 samples

Figure 5.6 Top view of panel crack patterns of samples

Figure 5.7 Front view of panel crack pattern for a sample of F4 group

Figure 5.8 Front view of panel crack pattern for a sample of F2 group

Figure 5.9 Front crack patterns of Samples

4.3 Concluding Remarks

Based upon the experimental test results of the ferrocement panels the following conclusions can be stated:

- The flexural loads at first crack and ultimate loads depend on number of reinforcing mesh layers used in ferrocement.

- For 25 mm thick slabs using four layers gave approximately 30% increase in flexural strength as compared to two layered slab specimen. Also the cracking load delayed by about 18% for the four layer meshes slab as compared to two layered slab specimen. For 30 mm thick slabs bending strength increased by about 70% for slabs with four layers of meshes and the cracking load delayed by approximately 80% as compared to two layered slab specimen. Also the deflection decreased by about 65%. Therefore increasing the number of layers of wire mesh from 2 to 4 layers significantly increases the ductility and capability to absorb energy of both of the panels. Increase in number of mesh layers improves the ductile behavior of ferrocement slabs.

- Increasing the thickness also affected the final breaking load for slab panels. They show that slab panels with 30 mm thickness gave 43% increase in final breaking load in comparison to slab panels with 25mm thickness. also first cracking load increased 52%. Therefore increasing the thickness of ferrocement panels from 25 mm to 30 mm significantly increases the ductility and capability to absorb energy of both of the panels.

- Using fly ash, as 15% replacement by weight of cement, caused a slight decrease in the flexural strength for some of the and a slight increase for the others. it shows that this amount of fly ash does not considerably affect the flexural strength of the slab panels.

- Compressive strength test results for two groups of cubes show that using fly ash (15% by weight of cement) decreases 37% of compressive strength of cubes as compared to cubes without fly ash.

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