The impact resistance of sandwich light weight ferrocement concrete plates

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ABSTRACT: The main objective of this research is to study the impact resistance of sandwich light weight ferrocement concrete plates. They were investigated using the repeated drop-weight impact manual test. Its reinforcing divided to three groups reinforced with skeletal two way steel bars (ø3), and welded metal meshes at the top and the bottom faces. A foam layer with thickness 2.5 cm and density 36% was imbedded between the two faces ferrocement concrete which connected together by steel connector bars (ø3) which pass from the top face to the bottom face throw the foam layer. Fourteen sandwich ferrocement plates with various reinforcing were designed and tested with dimensions of 500 × 500 × 75mm. The test specimens were loaded by 1.90 kg under its height 1.25m at the center of plates. High resistance sandwich light weight ferrocement plates could be developed with high crack resistance and energy absorption properties. The initial cracking impact energy up to failure was extensively determined for all the tested plates. Results of sandwich light weight ferrocement concrete plates emphasized that, increasing the number of the steel mesh layers in the ferrocement composites increases energy at first cracking, energy at up to failure, and energy absorption properties. Employing steel bars 3mm with steel meshes and the foam layer achieved to higher energy absorption compared with those reinforced with steel bars only. This could be attributed to the effect of the sandwich ferrocement concrete with the foam and small diameter of steel bars 3mm in controlling the developed cracks.

INTRODUCTION

Recently sandwich panels have an attention as an important structural shape in the building and construction industry. Sandwich panels have been used in the aerospace industry for many years and these are also being used as load bearing members in naval structures [1] Sandwich panels offer high strength-to-weight ratio causing substantial reduction in the self-weight of the structures. The self-weight of the element with high density (weight) itself accounts for a major portion of the total load of the structure. Thus reduction in the self-weight of the structures by adopting an appropriate approach results in the reduction of element cross-section, size of foundation, cost and also the damages due to earthquake because the earthquake forces that will influence the buildings and other structures are proportional to the mass of the structure[2]. The use of sandwich panels with cores of lightweight concrete is spreading due to their manufacturing efficiency that leads to the industrialization of the building system[3]. Sandwich panels typically consist of two thin, high strength and density outside face sheets known as skin separated by a thick layer made of low strength and density material called as core [4]. Ferrocement laminated composite is also proved to be an effective material to produce skins of sandwich panels [5, 6, 7, 8, 9]. Ferrocement is a type of thin walled reinforced concrete that consists of cement mortar reinforced with closely spaced layers of continuous and relatively small wire mesh [10]. Its advantageous properties such as its versatility of application, strength, toughness, lightness, water tightness, durability, fire resistance and environmental stability cannot be matched by another thin construction material[11, 12]. The impact energy (E imp) depends on the weight of the body (m) used in the impact test, the height from which this body is dropped (h) and the acceleration of gravity is 9.81 m/s2(g). $E\ imp = E\ p = g.\ h.\ m.$ [13,14] When a concrete slab is subjected to a load released from a defined height thereby constituting an impact loading, in general, there is a loss of potential energy which is absorbed and dissipated as strain energy, causing cracks due to stresses developed in the element. The width of crack thus developed is related to the intensity of the energy, the amount of energy absorbed and the properties of the concrete. The energy absorbed is dissipated in the form of crack patterns produced from the impact loading and that the crack pattern is also dependent on the properties of the concrete [15] Over the years researchers have realized that the results obtained from an impact test can depend strongly upon the size and geometry of the specimen and the striker and to a lesser degree on the velocity and energy lost to the testing machine.

REINFORCING STEEL

Galvanized welded metal mesh used was obtained from China. Its properties in the following table 1. **Steel Bars** Normal mild steel bars (nominal diameters 3 mm and 6mm) were used in reinforcing some ferrocement plates, there yield stress was 268.2 N/mm^2 and tension stress was 888N/ mm^2. The impact test can depend strongly upon the size and geometry of the specimen and the striker and to a lesser degree on the velocity and energy lost to the testing machine and elsewhere [16].

EXPERIMENTAL

In this research study the impact resistance of sandwich foam reinforced ferrocement concrete plates, which reinforced with various types of reinforcing materials and its density from 1500-1700 kg/m^3 and 1975kg/m^3 for the control plate it give reduction in the weight by 30%. The test was carried out by dropping the ball (1900gm) from a height (1.25m) repeatedly on the center of the plate which was placed on supported steel frame (fig 2) . The test continued until failure. Fourteen ferrocement plates were designed and cast with dimensions of 500 × 500 × 75 mm its design, mixing and curing the plates tested according Egyptian Code Practices [17] which reinforced with various types of steel reinforcement such as steel bars ø3, welded galvanized steel mesh. The main variables were the number of steel bars and number of steel welded mesh layers at the top and the bottom of plates which have imbedded foam layer (2.5cm). In this program, we tested there in order to study their behavior under impact resistance and measuring the number of blows required to get initial crack and the ultimate failure load . The falling load was kept constant as 1.90 kg from a height equal to 1.25m.

MATERIALS

The cement used was the Ordinary Portland cement, type produced by the Suez cement factory. Its chemical and physical characteristics satisfied the Egyptian Standard Specification [18].

The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the[19].

Super Plasticizer it was a high rang water reducer HRWR. It was used to improve the workability of the mix. The admixture used was produced by Sika Group under the commercial name of ASTM (Sikaviscocrete 20),. It meets the requirements of ASTM (Sikaviscocrete 20), It meets the requirements of ASTM C494 (type A and F). The admixture is a brown liquid having a density of 1.18 kg/litre at room temperature. The amount of HRWR was 2.0 % of the cement weight.

Polypropylene Fibers PP 300-e3 was used. It was available in the Egyptian markets. It was used in concrete mixes to produced fibrous concrete jacket to improve the concrete characteristics. The percentage of addition was chosen as 900g/m3 based on the recommendations of manufacture. The chemical and physical characteristics of Polypropylene Fibers 300-e3 .

Water was used the clean drinking fresh water free from impurities is used for mixing and curing the plates tested according Egyptian Code Practicesmm2 and there tensile strength was 888 N/mm2. .

Mortar Matrix**:** The concrete mortar used for casting plates was designed to get an ultimate compressive strength at 28-days age of (350 kg/cm2), The constituent materials were first dry mixed; the mix water was added and the whole patch was re-mixed again in the mixer. The mechanical compaction was applied for all specimens its properties explained in table 2.

The foam layer was used with a thickness 2.5cm and density 36%**.**

Preparation and Casting of Test Specimens: Fig (1, 3) and Tables (3).Is the Description of the ferrocement plates used for the impact resistance test and there reinforcement details before casting. Fig (2) Showing the steel supporting frame which used as a support and the testing device. The wooden forms of plates were coated with thin oil before concrete mortar casting. Fig 1. Showing The top and the bottom reinforcement was fixed up and down of the foam layer with shear connectors (steel bars ø3) then placed in their right position in the forms. The concrete was then placed in the forms and compacted by using the vibrating table to ensure full compaction. After the molds had been filled with concrete, the surface of concrete in molds was leveled by using the trowel. Plates were lifted in the forms and covered with polythene sheets for 24 hours in laboratory conditions. Fig.4. Showing the tension and compression faces after the impact test and the cracks.

Table1. Showing the mechanical properties of mortar

Mix Design	*Mix. Weight (kg/m³)*
Cement	681.82
Sand	1363.64
Water	238.64
S.P.	6.82
Fibers	0.9

Table 2. Explain the mix design weight of the Welded mesh

Dimensions (mm)	12.5 × 12.5 mm
Weight (gm. /m²)	430
Proof Stress (N/mm²)	400
Ultimate Strength (N/mm²)	600
Ultimate Strain × 10-3	1.25 × 1.5 mm
Proof Strain × 10-3	1.17

Table3. Showing the experimental program for all groups of plates

Groups	*The Plates numbers*	*The reinforcing of The plates with Foam layer*	*Type of reinforcing at the top & bottom + foam at the center*
Control pl.	PL1	PL.S 6ø6	steel bars 6ø6 at the center without foam
G1	PL2	PLF+S6ø3	steel bars 6ø3
	PL3	PLF+S8ø3	steel bars 8ø3
	PL4	PLF+S12ø3	steel bars 12ø3
G2	PL5	PLF+L2	2 layers Welded mesh
	PL6	PLF+L3	3 layers Welded mesh
	PL7	PLF+L4	4 layers Welded mesh
	PL8	PLF+L5	5 layers Welded mesh
G3	PL9	PLF+S6ø3+L2	steel bars 6ø3 + 2 layers Welded mesh
	PL10	PLF+S8ø3+L2	steel bars 8ø3 + 2 layers Welded mesh
	PL11	PLF+S12ø3+L2	steel bars12ø3 + 2 layers Welded mesh
	PL12	PLF+S8ø3+L3	steel bars 8ø3 + 3 layers Welded mesh
	PL13	PLF+S12ø3+L3	steel bars 12ø3+ 3 layers Welded mesh
	PL14	PLF+S12ø3+L4	steel bars 12ø3+ 4 layers Welded mesh

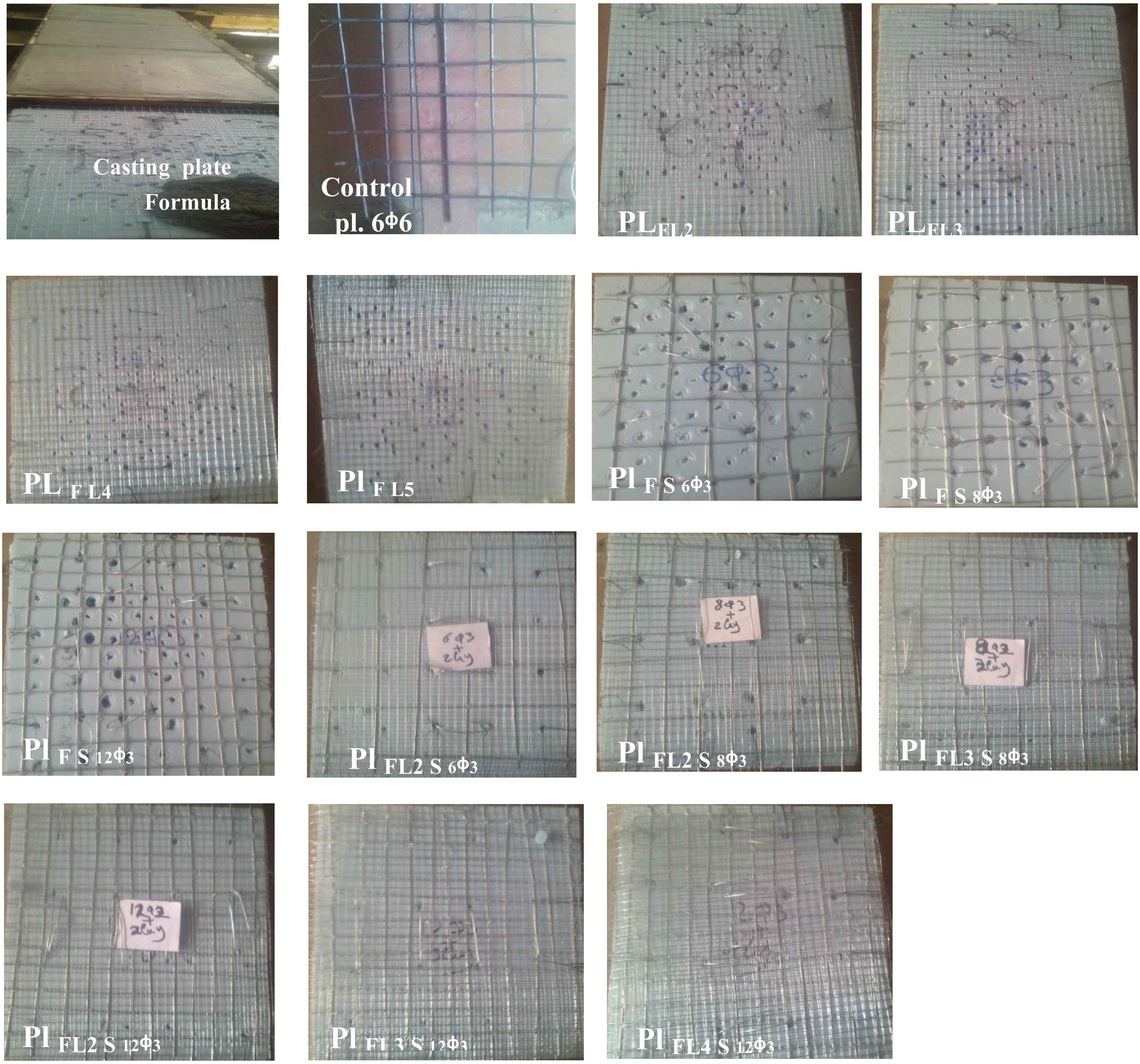


Fig 1.

Fig 2. The test device

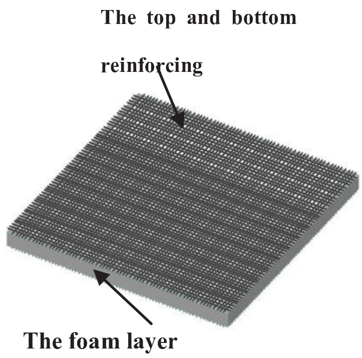
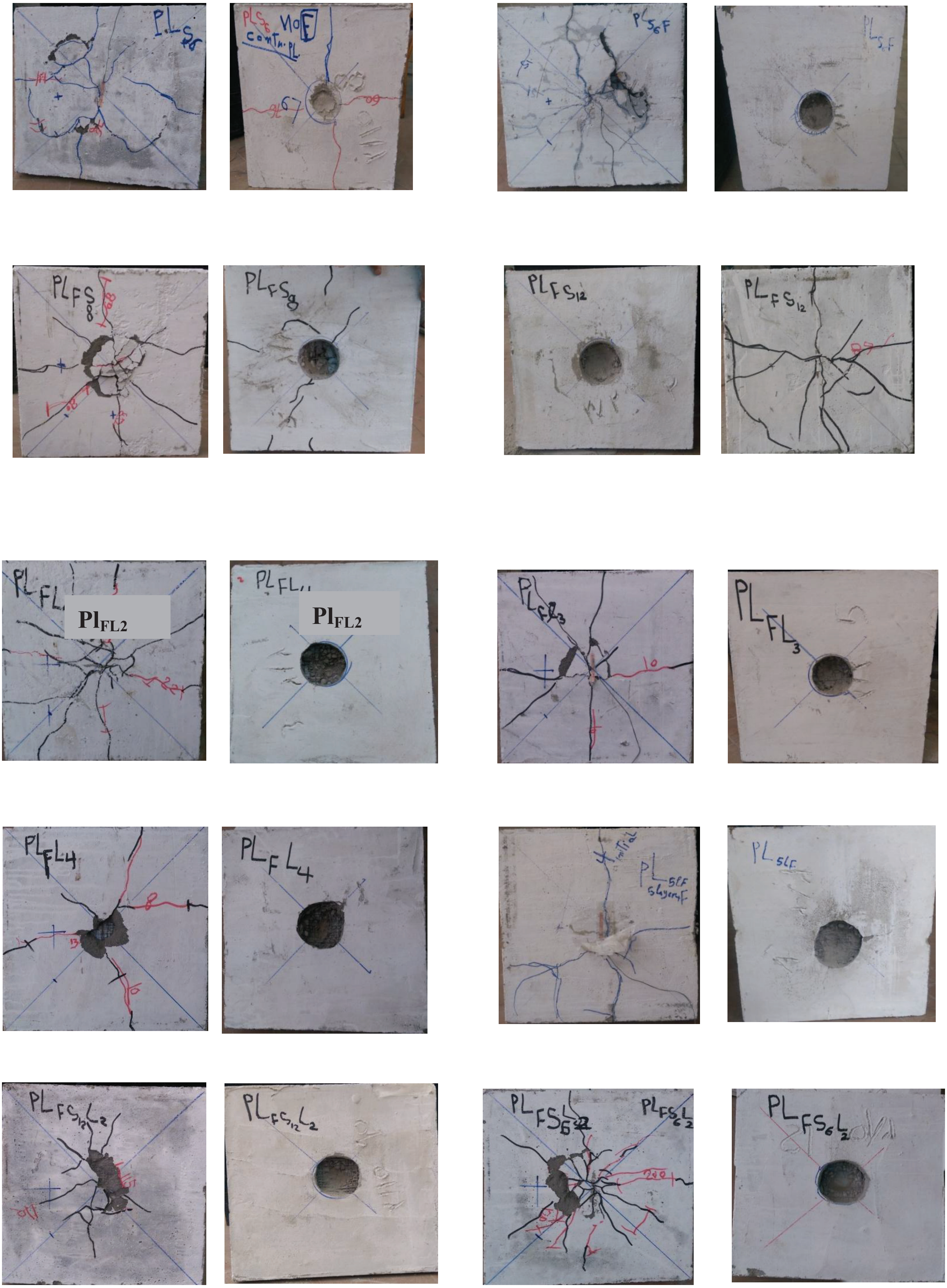


FIG 3. Reinforcing details



Pl_FL2
Pl_FL2

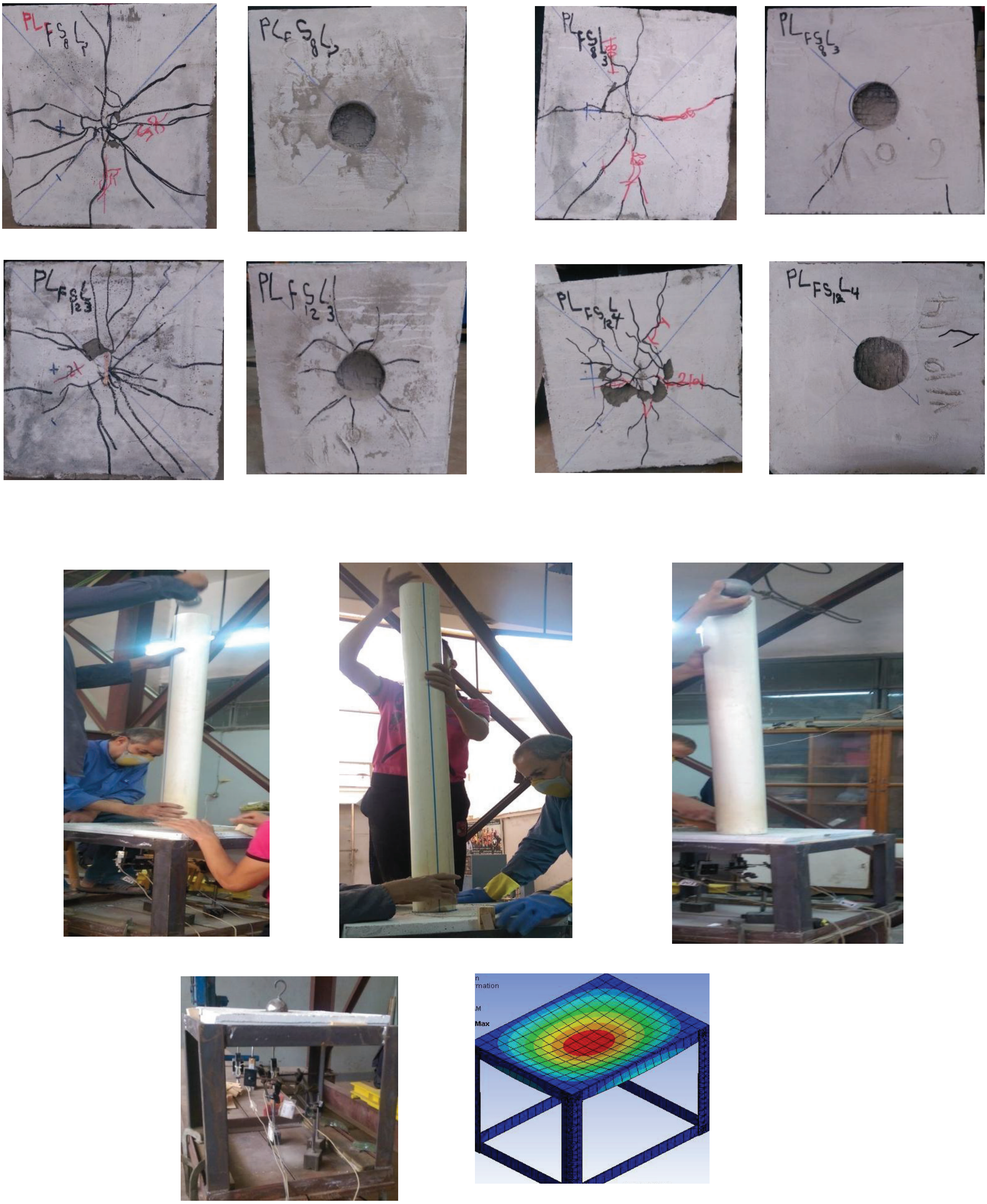
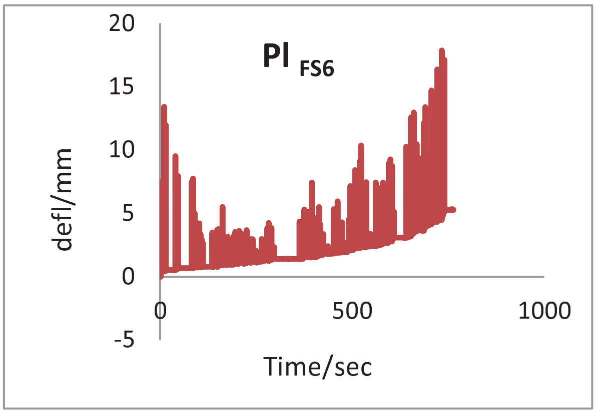
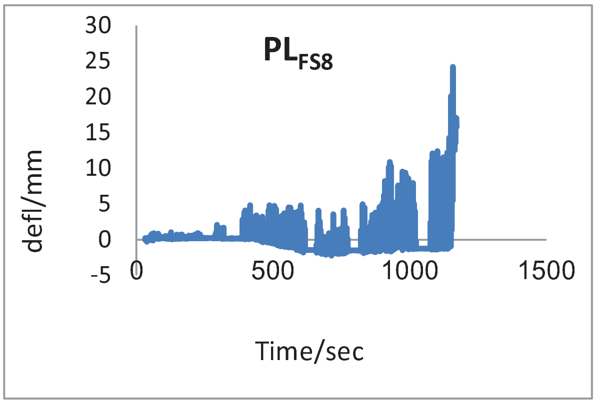
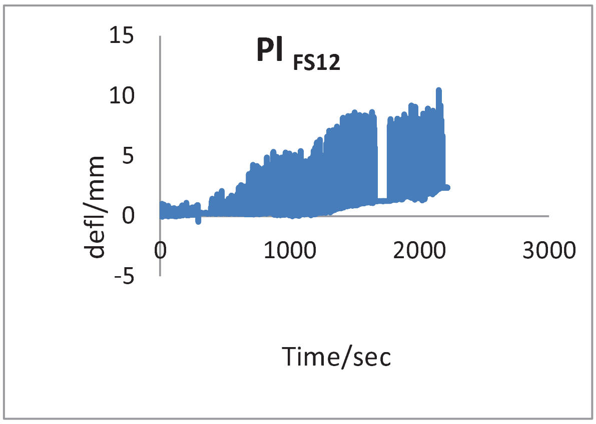
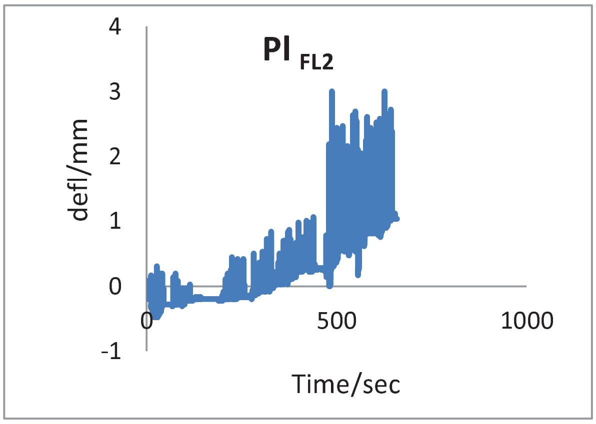


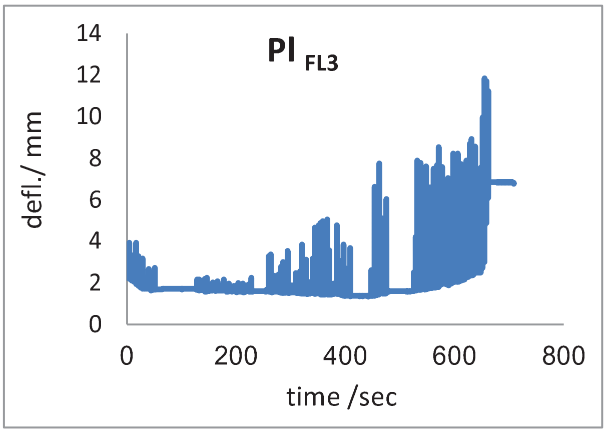
Fig 4. Showing the tension and compression faces for all plates after the impact test and the duration of the test.

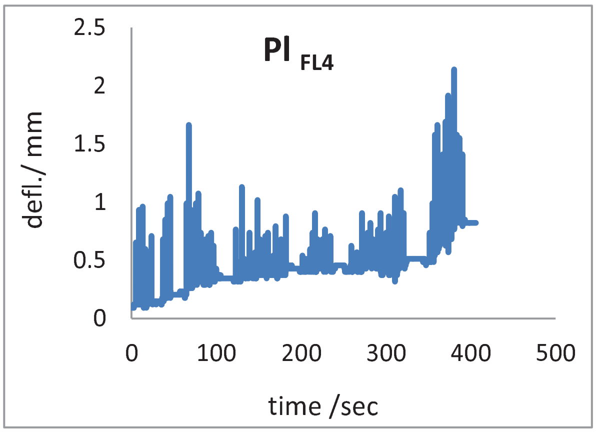

Pl FS6
defl/mm
20
15
10
5
0
-5
0
500
1000
Time/sec

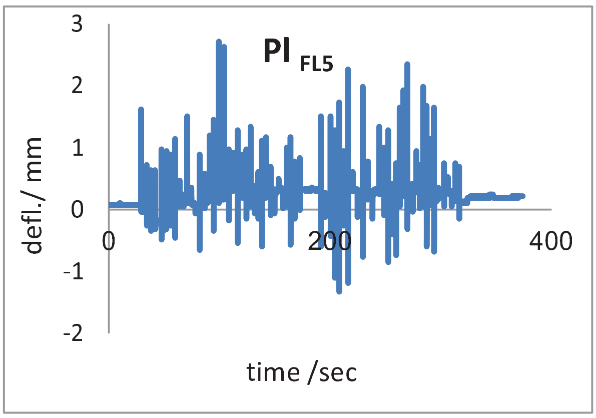

PLFS8
defl/mm
30
25
20
15
10
5
0
-5
0
500
1000
1500
Time/sec

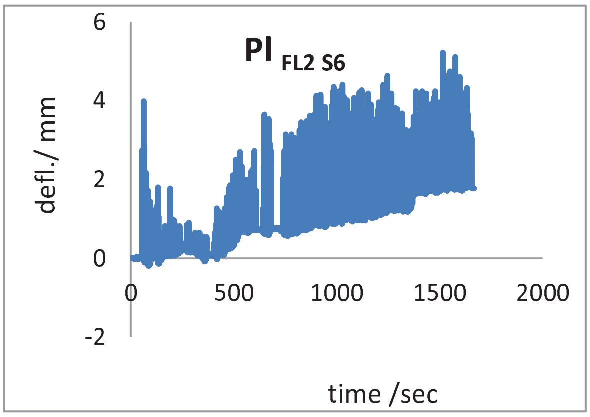

Pl FS12
defl/mm
15
10
5
0
-5
0
1000
2000
3000
Time/sec

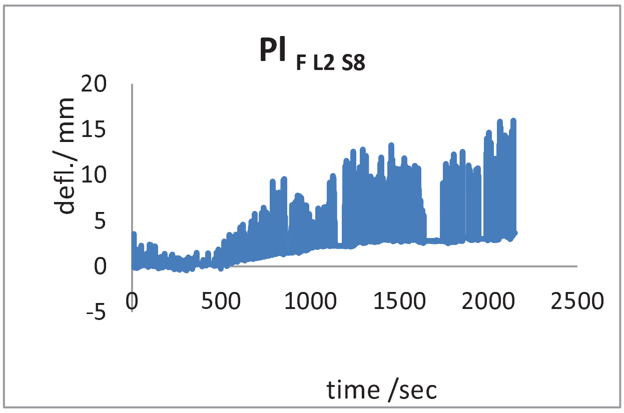

Pl FL2
defl/mm
4
3
2
1
0
-1
0
500
1000
Time/sec

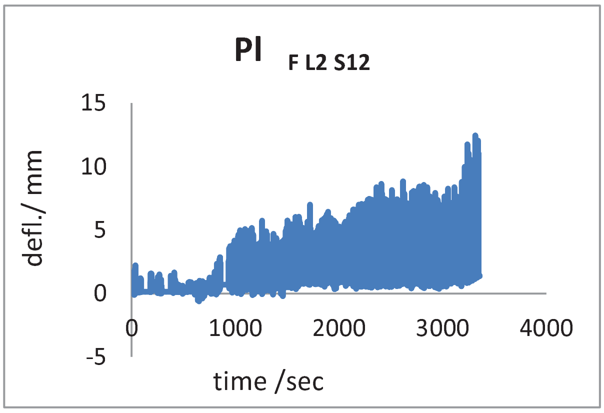

Pl FL3
defl./ mm
14
12
10
8
6
4
2
0
0
200
400
600
800
time /sec

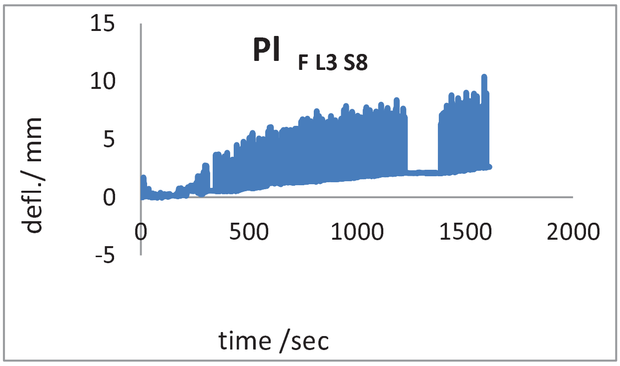

Pl FL4
defl./ mm
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
time /sec

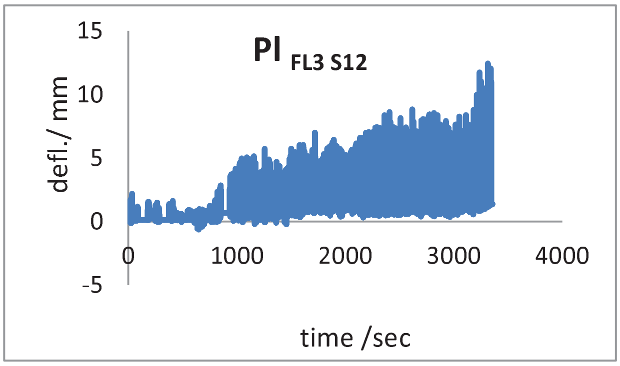

Pl FL5
defl./ mm
3
2
1
0
-1
-2
0
200
400
time /sec

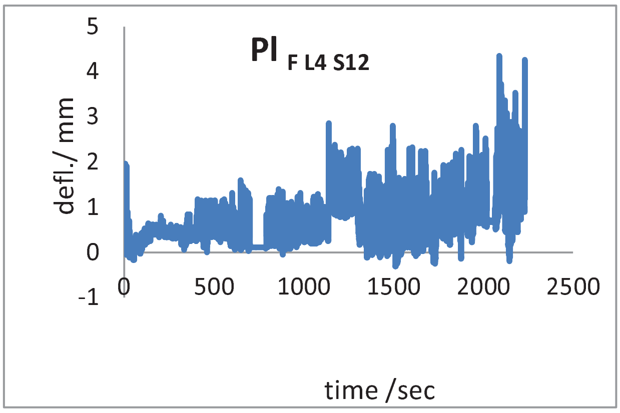

Pl FL2 S6
defl./ mm
6
4
2
0
-2
0
500
1000
1500
2000
time /sec

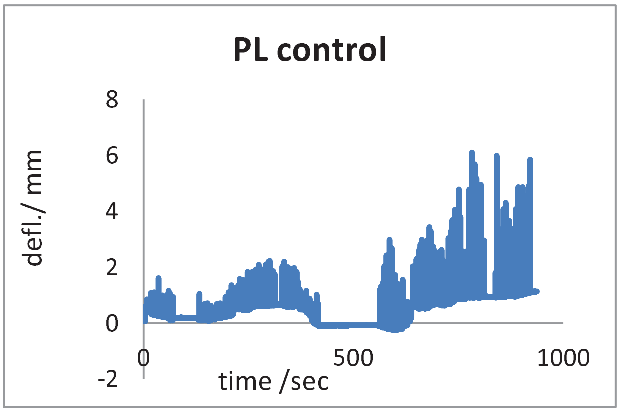

Pl F L2 S8
defl./ mm
20
15
10
5
0
-5
0
500
1000
1500
2000
2500
time /sec


Pl F L2 S12
defl./ mm
15
10
5
0
-5
0
1000
2000
3000
4000
time /sec


Pl F L3 S8
defl./ mm
15
10
5
0
-5
0
500
1000
1500
2000
time /sec


Pl FL3 S12
defl./ mm
15
10
5
0
-5
0
1000
2000
3000
4000
time /sec


Pl F L4 S12
defl./ mm
5
4
3
2
1
0
-1
0
500
1000
1500
2000
2500
time /sec


PL control
defl./ mm
8
6
4
2
0
-2
0
500
1000
time /sec

plates No	%volu. Frac.
cont. pl..S6ø6	1.36
PL.F.S6ø3	0.34
PL.F.S8ø3	0.45
PL.F.S12ø3	0.68
PL.F.L.2	0.44
PL.F.L.3	0.66
PL.F.L.4	0.88
PL.F.L.5	1.1
PL.F.L2S6ø3	0.78
PL.F.L2S8ø3	0.89
PL.F.L2S12ø3	1.12
PL.F.L3S8ø3	1.11
PL.F.L3S12ø3	1.34
PL.F.L4S12ø3	1.56

Table 4.

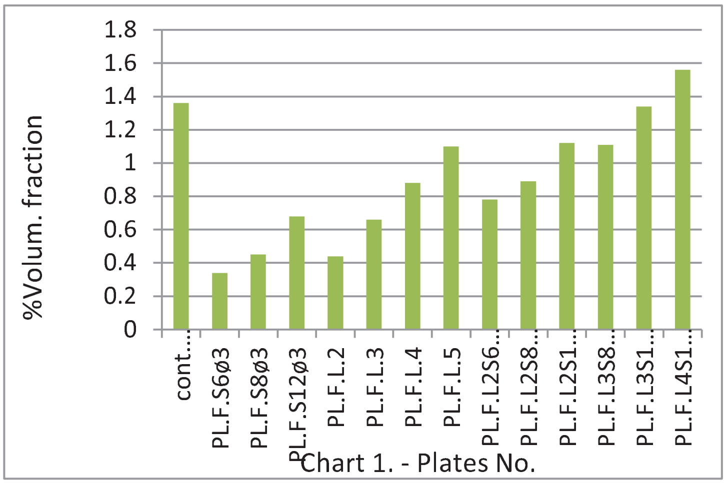
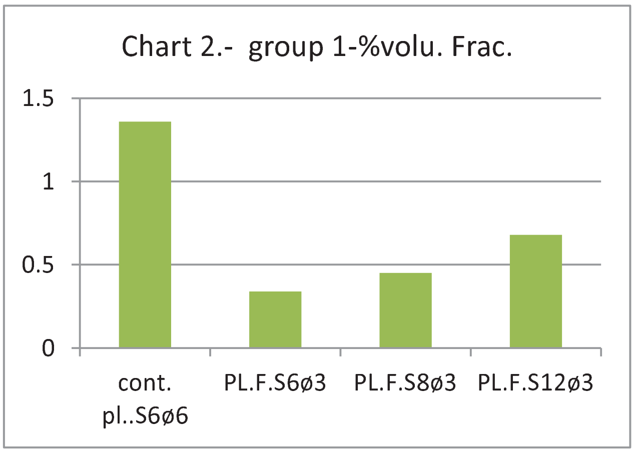
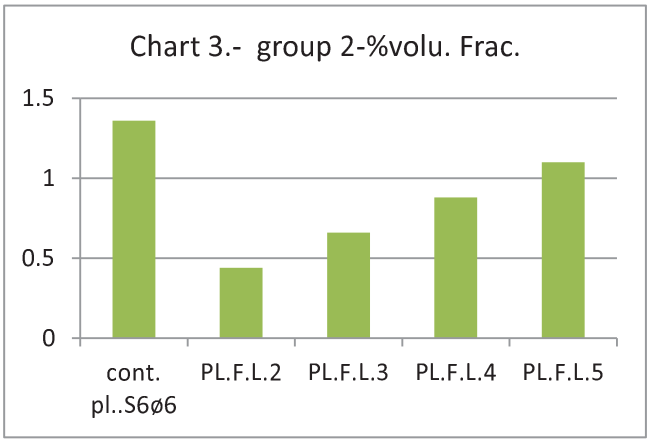
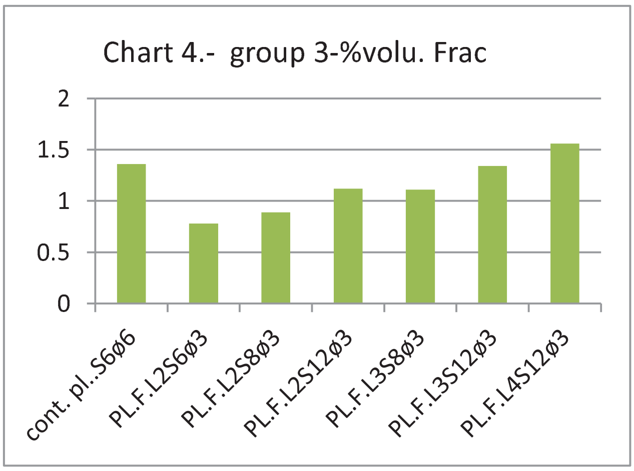


Chart 1. - Plates No.







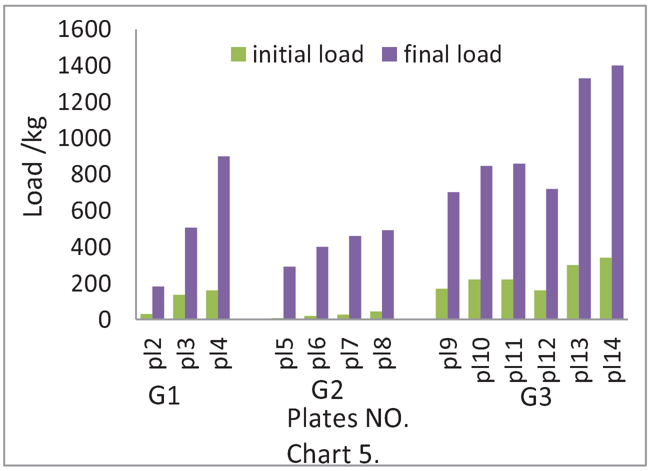
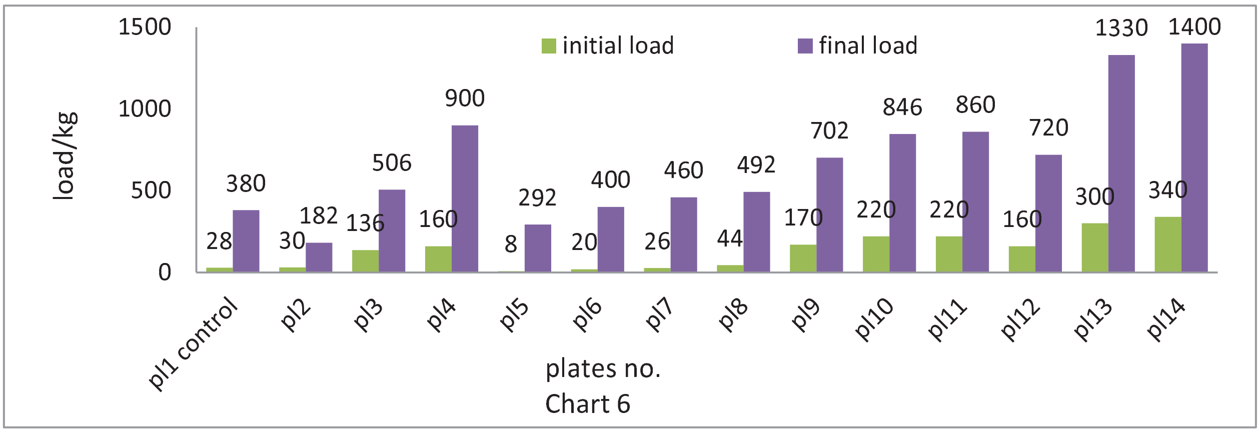
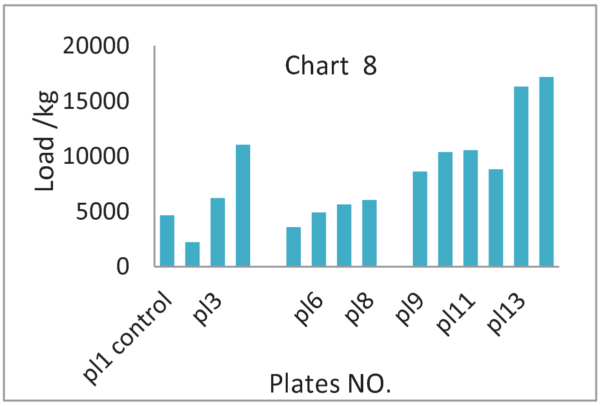
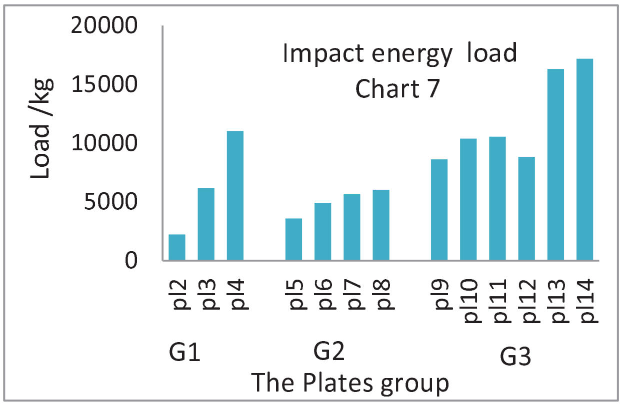


Chart 5.







EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Initial cracking Impact Load and Ultimate load

Charts (5 - 6) show the comparison of the first crack load and ultimate load where the first crack load is defined as the load which cause the first crack of tested plates, where the ultimate load (Final load) is defined as the load which causes failure for the plates, there were measured and obtained from the equations:

Initial Impact Load = No. of blow at the First crack × M

Final Impact Load = No. of blow at the Final crack × M

Where M: weight of ball = 1.90 Kg

Initial crack blows and first crack load plates using steel bars top and bottom (Group 1) for reinforcement plates increased by (1.11, 4.8 and 5.2 %) for plates pl2 (6 Ø3), pl3 (8 Ø 3) and pl4 (12 Ø 3 in plate) respectively compared to the control plate pl1 (6 Ø 6 in plate) one layer without foam. In case of plates reinforcement with welded mesh (group 2) the first crack blow and first crack load increased by (1.6 , 6.1 %) , for plate (4,5 layers mesh top & bottom) . In case of group 3which reinforced with (2,3,4,) layers of welded mesh and steel bars (6,8,12 Ø 3) in plates (11,12,13,14) they increased by (6.1,7.9,5.7,10.7,12.14%).

Maximum blows and ultimate load were increased by (1.3 - 2.4%) for group 1,and (1.1-1.3%) for group2, but group 3, increased by (1.8-3.6%) .

B. Impact energy

The impact energy is defined as the energy equals the potential energy before the body starts its movement, it were measured and Obtained from the equation:

Impact energy (J) = $E_{imp} = E_p = I_f \times M \times H \times g$ = Final Impact Load ×H× g

Where: E_{imp}: is the impact energy of the test (kinetic energy), in J, E_p: is the potential energy (energy stored within the body due to its position that has the potential to be converted in others forms of energy, kinetic energy in this context), If: is No. of blow at the final crack , M: is the

mass of the body (1900 g), H: is the drop height of the body (1.25 m) And g: is the acceleration of gravity (9.81 m/s^2).
Charts (7-8) show the comparison of the impact energy between all of the groups. It is clearly that group (1) increased by (1.2 - 2 %) respect to the control plate, but group (2) which reinforced by welded layers give (0 .4-1.2%) small increase, at the same time group (3) get the higher values (1.6-3.3%).

C. Volume Fraction of Reinforcement (Vr %)

Charts (1-4) and tabl 4. show the comparison of the volume fraction of all reinforcement groups, where it is defined as Volume Fraction of Reinforcement is the total volume of reinforcement per unit volume of ferrocement plate. For a composite reinforced with meshes with square openings, (Vr) is equally divided into (Vrt) and (Vri) for the longitudinal and transverse directions, respectively. The tests given that plates reinforced with welded metal mesh with steel bars were given higher Vr% than control plates reinforced with reinforcing steel only.

D. The relation between time period and the deflection

Fig 5. It is clear that group3. had a longest period time (1500-3000sec.) and give deflection (6-15 mm), group2 had small period time (400-600 sec.) and small deflection (3mm), but group1 had higher deflection (20-30mm) and medium period time (2000 sec.) .

CONCLUSIONS

The following conclusions are derived based on the conducted experiments:

(1) Irrespective of the type of reinforcing meshes in the ferrocement laminates, the existence of the synthetic fibers in the mortar mix resulted in an increase in the first crack load, ultimate load, and impact energy absorption.

(2) The existence of the synthetic fibers resulted in retarding the occurrence of the first crack and better crack distribution in the ferrocement composites. This led to a higher stiffness of the test specimen.

(3) Regardless of the presence of the sandwich foam, specimens incorporating ferrocement permanent forms reinforced with welded wire meshes with steel bars achieved higher first crack load, Vr % and ultimate load and energy absorption in comparison to those reinforced with welded steel mesh.

(4) Using welded steel meshes with mild steel bars in sandwich foam and shear connectors in reinforcing ferrocement plate's results in markedly higher energy absorption than that obtained when using mild steel bars only. This could be attributed to the effect of welded steel mesh in controlling the developed cracks.

(5) Increasing the number of steel bars with welded steel mesh layers and the foam at the Medill in the ferrocement forms decreases the first crack load as result of increasing the specific surface area of welded steel meshes, which leading to higher bond area.

(6) The percentages loss of weight for plates reinforced with steel bars 2.4 %, while it reached to 1.4% with sandwich foam light weight plates this is predominant.

(7) Thin sandwich light weight foam ferrocement concrete plates with shea connectors were developed with high strength, crack resistance, high ductility and energy absorption properties very useful for dynamic applications with great economic and advantages.

(8) In fact, the structural behavior of the sandwich panel depends greatly on the strength of and stiffness of the two face the way they are connected and partially on the strength of the core.

(9) The sandwich elements produced are high performance in compressive strength, flexural strength and ductility whereas the water absorption is very low. These composites have the potential to be applied in earthquake borne areas and also may lead to the industrialization of the building system.

(10) the existing of the foam layer and the small diameter of steel bars 3mm increased the initial load by 5.7% and the ultimate load by 2.4% also get better cracks because the bars distributed on the all area of the faces which do as a mesh.

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