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Flexural Behavior of Lightweight Composite Ferrocement Plates

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Abstract

In recent years, producing lightweight structures is considered as one of the most important application of concrete. It has extensive applications in the architect and insulation work. The main objective of this study is to investigate the behavior and the performance of lightweight ferrocement (LWF) composite plates with lightweight materials as filler materials in flexural. Fifteen lightweight ferrocement (LWF) composite plates were investigated by conducting flexural tests. The main variables are (the thickness of plates, the type of filler materials, the type and number of layers of meshes). The behavior of lightweight ferrocement (LWF) composite plates is investigated by conducting flexural tests on fifteen simply supported rectangular plates under three lines loadings. Fifteen plates represented in twelve lightweight ferrocement (LWF) plates and three conventional reinforced concrete (RC) plates. The ferrocement plates were divided into three groups according to the thickness of plates 6cm, 8cm and 10cm. The structural performances of the LWF and RC plates are investigated in terms of crack load, load-deflection curves, stiffness, energy absorption capacity, ductility index, ultimate flexural load-to-weight ratio, load-strain curves, crack patterns, and the failure modes. The test results revealed remarkable enhancement in the flexural behavior and potential application of lightweight ferrocement (LWF) composite plates to produce lightweight structural elements as compared to that of the reinforced concrete (RC) plates, which lead towards the industrialization of building system and meets with innovation and expansible application of concrete construction technology results in better efficiency of developing of lightweight composite ferrocement plates.

Keywords: Ferrocement; Flexural Behaviour; Plates; Composite; Lightweight; Filler Materials.

1. Introduction

Ferrocement as a construction technique is defined by ACI (committee 549) 2008) [1] as follows: "Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and / or small diameter rods completely infiltrated with, or encapsulated in mortar. The most common type of reinforcement is steel mesh other materials such as selected organic, natural of synthetic fibers may be combined with metallic mesh" [2]. The applications of Ferrocement were boat construction, Silos, Roofs, Tanks, Strengthening and Repairing of Reinforced Concrete Tanks, beams, slabs, Columns [3-12].

A Ferrocement sandwich panel is "Two thin skin layers of relatively high strength and modulus of elasticity, separated by a thick layer of a low strength material as a core". Ferrocement sandwich panel is one of the developed applications of ferrocement technology that offer an ideal building material. The advantage of this type of building materials is mainly the light weight of the unit compared to its equivalent volume of the conventional concrete. Such panels could be used as roof elements or as wall bearing elements. This is mainly due to the two thin skin layers at the two faces, which can carry loads, resist impacts, and accommodate architectural acceptance, while in the same time the core material provides thermal and sound insulation [13].

Many of researches studied the behavior of lightweight ferrocement sandwich composite element such as Mahmoud A. W. and Kimio F. [14] studied the flexural behavior of lightweight ferrocement sandwich composite beams. There results refer to the LWF beams revealed the remarkable enhancement in the structural behavior and potential application of lightweight sandwich ferrocement polystyrene foam composite as compared to that of the RC beams. This leads to wards the Industrialization of building system and meets with innovation and responsible application of concrete construction technology which results in better efficiency of the composite.

Noor A. M. *et al.* [15] studied strength and behavior of lightweight ferrocement aerated concrete sandwich blocks. The compressive strength increases with the increase in wire mesh layers, single layer of wire mesh may be considered as optimum in terms of compressive strength, strength and behavior of lightweight ferrocement aerated concrete sandwich blocks. Shaheen *et al.* [16] studied the structural behavior of composite reinforced Ferrocement Plates, The cracking loads slightly increased as the reinforcement volume fraction increased. The cracking loads were independent of the mesh type. The flexural capacity of the composite plates increased with the increase of the specific surface area of the mesh.

2. Experimental Program

The aim of the experimental program was to determine the behavior and performance of the composite ferrocement plates with lightweight materials as filler materials in flexural. The experimental program was divided into two phases, the first phase regarding the filler material, the effect of using different filler material on the behavior of the plates. The filler material was used in this study (lightweight brick, foam, plastic pipes and galvanized steel sheets). The second phase regarding the effect of using different of meshes and its layers on the performance of the composite ferrocement plates in flexural load. This program was studying the initial load, ultimate load, flexural behavior, ductility ratio, energy absorption and mode of failure at collapse of the control plates, which were reinforced with steel and to compare their behavior with those conventional reinforced ferrocement plates reinforced with expanded, welded and Polyethylene meshes.

In this program, fifteen specimens were cast and tested in order to study their behavior under flexural loadings. The dimensions of the plates were 550×1100×100 mm, 550×1100×80 mm and 550×1100×60 mm. Four types of filler materials that are widely used to produce light weight (lightweight brick, foam, plastic pipes and galvanized steel box) were used to construct the test specimens. This study compares the performance of light weight plates with normal weight plates. The main variables of this research were type of filler material, thickness of plates, the type and numbers of layer meshes. Table 1 shows details of the experimental program for all the test specimens while Fig. 1 emphasizes the type of lightweight filler materials (LWFM). Tables 2-5 show the properties and photo of meshes used of all plates, respectively.

2.1. Materials

A. Cement used was the Ordinary Portland cement, type produced by the Suez cement factory. Its chemical and physical characteristics satisfied the Egyptian Standard Specification (ESS 4756-1/2009) [17].

B. Fine aggregate used in the experimental program was natural siliceous sand. Its characteristics satisfy the Egyptian Code of Practices (ECP 203/2007) [18], (ESS 1109/2008) [19]. It was clean and nearly free from impurities with a specific gravity 2.6 t/m3 and a modulus of fineness 2.7.

C. Super Plasticizer used 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 C494 (type A and F) [20]. The admixture is a brown liquid having a density of 1.18 kg/litre at room temperature. The amount of HRWR was 1.0 % of the cement weight.

D. Water was used; clean drinking fresh water free from impurities was used for mixing and curing the tested plates according to (ECP 203/2007) [18].

E. Reinforcing Materials

1. Reinforcing Steel Bars

   a) High Tensile deformed steel bars produced from the Ezz Al Dekhila Steel - Alexandria was employed. Its chemical and physical characteristics satisfy the (ESS 262/2011) [21]. High tensile deformed steel bars of (nominal diameter 10 mm) were used in reinforcing all plates, yield stress was determined as 400 MPa and its tensile strength was 600 MPa.

b) Mild Steel bars of 8 mm diameter were used in the short direction of plate. Its chemical and physical characteristics satisfy (ESS 262/2011) [21]. Its yield strength and its tensile strength were 240 MPa and 350 MPa respectively.

2. Reinforcing Meshes

a) Expanded Metal Meshes: Expanded metal mesh was used as reinforcement for ferrocement plates. Its chemical and physical characteristics satisfy (ESS 262/2011) [21]. Table 2 shows the technical specifications, mechanical properties and photo of expanded metal mesh.

b) Welded Metal Meshes: Galvanized welded metal mesh employed which obtained from China. Its chemical and physical characteristics satisfy (ESS 262/2011) [21]. Table 3 shows the technical specifications, mechanical properties and photo of welded metal mesh.

c) Polyethylene Meshes: Two types of Polyethylene meshes were used, which obtained from Al Shrouk Company of synthetic fibers namely CE121 and CE131. These types of meshes are made from high density polyethylene. "Geogrid" were used. Tables 4-5 show the properties and photos of these meshes.

F. Filler materials:

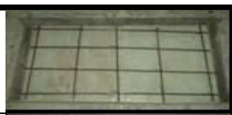
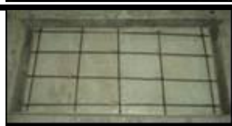
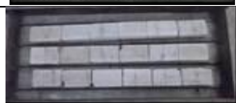
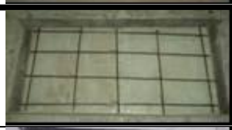
Four types of lightweight materials used as a filler materials in composite ferrocement plates. These types of small density filler materials were used.

1) Plastic Pipes: Plastic Pipes used was obtained from China. Plastic Pipes were used as lightweight filler material for ferrocement plates. Table 6 shows the technical properties and photo of plastic pipes.

2) Lightweight Bricks: Lightweight brick used was obtained from light brick factory at industrial region, Kewesna, Menoufia. Lightweight bricks were used as lightweight materials for ferrocement plates. Table 7 shows the technical Properties and photo of lightweight brick used.

3) Foam: used extruded Polystyrene Thermal Insulation Boards was produced from Chemicals Modern building group, its density is 5.85 Kg/m^3 for thermal insulation boards which produced from high quality extruded polystyrene foam and available in different thicknesses and edge shapes.

TABLE 1: DETAILS OF THE EXPERIMENTAL PROGRAM FOR ALL PLATES.

Group	Code	Thickness (mm)	Steel Bars	Type of meshes	No. of layers meshes	Type of filler materials	Weight of plates (Kg)	Vr %	Plates
Group 1	C 10	100	4Ø10 + 5Ø8	-------------	-------------	-------------	136.9	0.81	
	E3F10	100	4Ø10	Expanded	(3 Lower +1 Welded Upper)	Foam 50 (mm)	120.5732	1.23	
	P1G10	100	4Ø10	Polyethylene meshes CE131	-------------	Galvanized Steel Sheets	118.1	1.90	
	P1P10	100	4Ø10	Polyethylene meshes CE131	-------------	Plastic Pipes	126.877	0.62	
	W2G10	100	4Ø10	Welded	(2 Lower +1 Upper)	Galvanized Steel Sheets	118.24	2.03	
	W2GF10	100	4Ø10	Welded	(2 Lower +1 Upper)	2 Galvanized Steel Sheets +1 Sheet of Foam 5 cm	118.385	2.03	
Group 2	C8	80	4Ø10 + 5Ø8	-------------	------------	----------------	110.28	1.01	
	W2P8	80	4Ø10	Welded	2	Plastic Pipes	100.3981	0.94	
	E2B8	80	4Ø10	Expanded	2	Light Brick +Welded Mesh	85.5	1.9	
	W2B8	80	4Ø10	Welded	2	Light Brick +Welded Mesh	84.45	1.5	
	P1B8	80	4Ø10	Polyethylene meshes CE131		Light Brick +Welded Mesh	84.31	1.3	
	F3B8	80	4Ø10	Polyethylene meshes CE121	3	Light Brick +Welded Mesh	84.25	1.3	
Group 3	C6	60	4Ø10 + 5Ø8	-----	-----	Light Brick +Welded Mesh	84.122	1.52	
	E1P6	60	4Ø10	Expanded	1	Plastic Pipes	74.044	1.39	
	F2P6	60	4Ø10	Polyethylene meshes CE121	2	Plastic Pipes	73.58	1.09	

4) Galvanized Steel Sheet: use was produced from the Ezz Al Dekhila Steel – Alexandria. Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011) [21].

TABLE 2: TECHNICAL SPECIFICATIONS AND MECHANICAL PROPERTIES OF EXPANDED METAL MESH.

Style	1532
Sheet Size	1 × 10 m
Weight (Kg/m^2)	1.3
Diamond size (mm)	16 x 31
Dimensions of strand (mm)	1.25 x1.5
Proof Stress (N/mm^2)	199
Proof Strain × 10^{-3}	9.7
Ultimate Strength (N/mm^2)	320
Ultimate Strain× 10^{-3}	59.2

TABLE 3: TECHNICAL SPECIFICATIONS AND MECHANICAL PROPERTIES OF WELDED METAL MESH.

Dimensions (mm)	12.5 × 12.5
Weight (gm. /m^2)	430
Proof Stress (N/mm^2)	400
Ultimate Strength (N/mm^2)	600
Ultimate Strain × 10^{-3} (mm)	1.25 × 1.5
Proof Strain × 10^{-3}	1.17

TABLE 4: TECHNICAL SPECIFICATION OF POLYETHYLENE MESH (CE121).

Size of opening	12x12 mm
Thickness	3 mm
Weight	529 g/m^2
Tensile Strength	24.7 MPa
Elongation in Longitudinal Direction	21%

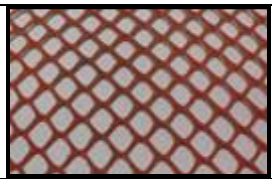


TABLE 5: TECHNICAL SPECIFICATION OF POLYETHYLENE MESH (CE131).

Size of opening	45 x 45mm
Thickness	5mm
Weight	625 g/m^2
Tensile Strength	27.5 MPa
Elongation in Longitudinal Direction	25%

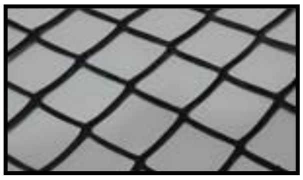


TABLE 6: TECHNICAL SPECIFICATION OF PLASTIC PIPES.

Diameter of opening	35 mm
Thickness	2mm
Weight	40 g/m

TABLE 7: TECHNICAL SPECIFICATION OF LIGHTWEIGHT BRICK.

Size of opening	145×100 mm
Thickness	45mm
Weight	522 Kg/m
Density	500Kg/m^3

2-2 Mortar Matrix:

The concrete mortar used for casting plates was designed to reach compressive strength at 28-days age of (350 kg/cm^2), 35 MPa. The mix properties of mortar matrix were chosen based on the (ACI committee 549 report: 2008) [22] and Egyptian Code Practices (E.C.P. 203/2007) [18]. For all mixes, mechanical mixer in the laboratory used mechanical mixing with capacity of 0.05 m^3, where the volume of the mixed materials was found to be within this range. The constituent materials were first dry mixed; the mix water with super plasticizer was added and the whole batch was re-mixed again in the mixer. The mechanical compaction was applied for all specimens. Mix properties by weight for the different groups are given below in Table 8.

TABLE 8: CONSTITUENTS OF MORTAR.

Cement	Sand /Cement	W/C	S.P*./C
1	2	0.35	1%

* Super plasticizer = (Sikaviscocrete 20)

2-3 Preparation and Casting of Test Specimens:

Description of the lightweight ferrocement plates, their reinforcement details and dimensions of the ferrocement plates are shown in Table 1. The wooden forms of plates were coated with a thin film of oil before concrete mortar casting. The reinforcement was 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 a trowel. Plates were lifted in the forms and covered with polyethylene sheets for 24 hours in laboratory conditions until the sides of the forms were stripped away. Then, plates were remolded and immersed in water for 28 days curing before testing. Then the plates were left for 4 hours in the laboratory conditions before testing.

3. Analysis and Discussion of the Test Results

Table 9 summarizes the experimental results of the test program. While comparisons are conducted for results of different test groups to examine the effectiveness of the test parameters under investigation; existence of the permanent type of filler materials, ferrocement forms, type of mesh reinforcements. The effects of these parameters on the structural responses of the proposed plates in terms of first crack load, serviceability load, ultimate load, ductility ratio and energy absorption properties were investigated and mode of failure extensively.

TABLE 9: STRUCTURAL RESULTS OF ALL THE TESTED PLATES.

Code	Weight (Kg)	Initial Crack Load (KN)	Serviceability Load (KN)	Ultimate Load (KN)	Maximum deflection (mm)	Ductility Ratio	Energy Absorption, (KN mm)
C 10	136.9	10	55	75.6	14.36	27.63	857.63
E3F10	120.57	6	35.5	56.6	15.91	41.67	709
P1G10	118.1	9	38	60.5	12.08	16.51	530.49
P1P10	126.88	6	17.1	33.1	14.41	11.79	344.19
W2G10	118.24	17	51	76.5	15.45	12.2	951.7
W2GF10	118.38	12	47	71.1	14.07	10.49	775.8
C8	110.28	8	40	62.4	15.76	23.95	762
W2P8	100.4	1	14.5	41.8	20.2	53.32	578.9
E2B8	85.5	9	32	52.5	12.02	12.12	449.17
W2B8	84.44	9	36.5	57.5	11.55	11.77	480.3
P1B8	84.3	9	33.5	57.8	16.69	15.05	753
F3B8	84.24	9	27	48.1	14.5	11	522.52
C6	84.12	5	17.5	39.9	16.54	15.39	482.15
E1P6	74	2	12.6	28.4	14.05	16.58	259.7
F2P6	73.58	3	7.2	25.2	17.19	12.75	278.5

3.1 Initial Cracking and Ultimate Loads:

Initial cracking and ultimate loads of all the tested composite plates are presented in Table 9, while Figs 1 and 2 show the first cracking loads (P_{cr}) and ultimate loads ($P_{ult.}$) for all the tested plates. Using lightweight materials as a filler material of plates indicated smaller values of initial crack and ultimate loads. The increasing in (P_{cr}) and ($P_{ult.}$) values may refer to the increase of the section dimensions. The values of decreasing depend on the type of filler materials and reinforcements mesh type.

A) Initial Cracking Loads

Initial cracking loads for control plates using different thicknesses increased by about 100%, 60% for plates **C10** (100 mm thickness) and **C8** (80 mm thickness) respectively compared to that of control plate **C6** (60 mm thickness). This increase could be attributed to increase of cross sectional stiffness compared to the span of tested plates. **In case 100 mm** thickness of plates using welded steel mesh and galvanized steel box, the initial crack load increased by about (70% and 20%) for plates **W2G10** (2 welded mesh, 3galvanized steel b+6ox) , **W2GF10** (2 welded mesh and 2galvanized steel box+ 1 foam) respectively compared to that of control plate C10. This increase could be attributed to increasing the area of steel section and volume fraction, Vr % (2.03%) compared to the controlled plate, uniformly distribution of welded steel meshes along the cross section and using galvanized steel box (in the range of this study). It is interesting to note that the initial crack load decreased by about (40%, 10% and 40%) for plates E3F10 (3 layers of expanded steel meshes and 3 foam), **P1G10** (1 Polyethylene meshes CE131, 3 galvanized steel box), **P1P10** (1 Polyethylene meshes CE131 and 4 Plastic Pipes) respectively compared to that of control plate C10. This increase could be attributed to increasing the area of steel section and volume fraction, Vr % and the increasing of lighter weight of plates located in the core of plates by using plastic pipes and galvanized steel box compared to that of control plate (in the range of this study).

In case of 80 mm thickness of plates using welded &expanded steel meshes, lightweight brick, the initial crack load increased by about(12.5%) for plates **E2B8** (2 layers expanded steel meshes and 3 lightweight brick), **W2B8** (2 welded mesh, 3 lightweight brick), **P1B8** (1 polypropylene mesh, 3lightweight brick) and **F3B8** (3 Polyethylene meshes CE121, 3 lightweight brick) respectively compared to that of control plate C8, while the initial crack load decreased by about (87.5%) for plate **W2P8** (2 welded steel meshes and 4 Plastic Pipes) compared to that of control plate C8. This increase may be referred to the increasing of weight of filler material (lightweight brick) and Vr % of reinforcement compared to that of control plate (in the range of this study). In case of 60 mm thickness of plates using expanded steel meshes and plastic pipes, the initial crack load decreased by about(60% and 40%) for plates **E1P6** (1 expanded mesh and 4 Plastic Pipes), **F2P6** (2 Polyethylene meshes CE121 mesh and 4 Plastic Pipes) compared to that of control plate C6. This decrease could be contributed to decreasing of filler material (Plastic Pipes) compared to that of control plate as shown in Figs. 1 to 3.

B) Ultimate Loads

The ultimate loads for control plates using different thicknesses increased by about 89.5%, 56.4% for plates **C10** (100 mm thickness) and **C8** (80 mm thickness) respectively compared to the control plate **C6** (60 mm thickness). That increase may refer to the increase of cross sectional stiffness compared to the span of tested plates. **In case 100 mm thickness** of plates using welded mesh and galvanized steel box, the ultimate load increased by about (1.2%) for plate **W2G10** (2 welded mesh and 3galvanized steel box) compared to control **C10**. This increase could be attributed to increasing the area of steel section and volume fraction, Vr % stiffness compared to the controlled plate and the distribution welded meshes and using galvanized steel box (in the range of this study). When the ultimate load decreased by about (6%, 20%, 25% and 56.2%) for plates **W2GF10** (2 welded mesh and 2galvanized steel box+1foam), **P1G10** (1 Polyethylene meshes CE131 and 3 galvanized steel box) **E3F10**, (3 expanded and 3foam), and **P1P10** (1 Polyethylene meshes CE131 and 4 Plastic Pipes) respectively compared to control plate **C10**. This decreasing may refer to the increasing lighter weight of filler materials and decreasing of the area of steel section and Vr % stiffness compared to the controlled plates (in the range of this study).

In case 80 mm thickness of plates using welded &expanded steel meshes and lightweight brick, the ultimate load decreased by about (7.4%, 7.8%, 15.9%, 22.3% and 33%) for plates **P1B8** (1 polypropylene mesh and 3 lightweight brick), **W2B8** (2 welded steel mesh and 3 lightweight brick), **E2B8** (2 expanded mesh and 3 lightweight brick), **F3B8** (3 Polyethylene meshes CE121 and 3 lightweight brick) and **W2P8** (2 welded and 4 Plastic Pipes) compared to control plate **C8**. This decreasing may refer to the increasing the lighter weight of filler material (lightweight brick) and decreasing of Vr % of reinforcement compared to that of control plate (in the range of this study).

In case 60 mm thickness of plates using expanded steel meshes and Plastic Pipes, the initial crack load decreased by about (28.8% and 36.8%) for plates **E1P6** (1 expanded steel mesh and 4 Plastic Pipes) and **F2P6** (2 Polyethylene meshes CE121 and 4 Plastic Pipes) compared to control plate **C6**. This decrease could be attributed to the increasing of lighter weight of filler material (Plastic Pipes) compared to that of control plate and decreasing of the Vr % due to employing of Polyethylene meshes CE121 compared to that of control plate (in the range of this study). See Figs. 1, 2 and 5.

According to the test results, the only increasing was recorded as 1.2% for welded steel mesh and 3 galvanized steel boxes. Based on the test results; it is interesting to note that the filler material, the type of mesh and the layers of meshes used as reinforcement of plates have significant effect on cracking load of the plates. When using longer aspect ratio of steel bars, tend to increase the ultimate load. But using filler materials tend to decrease the initial and ultimate load. Based on discussions mentioned above, using filler materials and the metal meshes have good positive effect on the first cracking loads and their respective ultimate loads. The plates using filler materials had the behavior as the same behavior of control plates.

C) Flexural Serviceability Load

The Flexural serviceability load was calculated from the load-deflection curves. It is defined here as the load corresponding to deflection equal to the span of the plate (900 mm) divided by (constant = 250) according to The Egyptian Code Practices (E.C.P. 203/2007) [18]. Figs. 1 and 4 represent the values for the serviceability load and for all the tested plates. This indicates that pregnancy takes the same initial crack & ultimate load behavior approximately. The grater and the smallest serviceability loads were (**51 KN** and **7.2 KN**) for lightweight plates **(W2G10 & F2P6)** compared to that of control plate. This increasing may refer to the increasing stiffness due to the increasing of the steel area Vr % and due to the distribution of welded steel meshes and using galvanized thin steel box compared to that of control plate, This decrease may refer to the increasing the lighter weight of filler material (Plastic Pipes) compared to that of controlled plate C10 and decreasing of the Vr % due to employing Polyethylene meshes CE121 compared to that of control plate C6 respectively (In the range of this study).

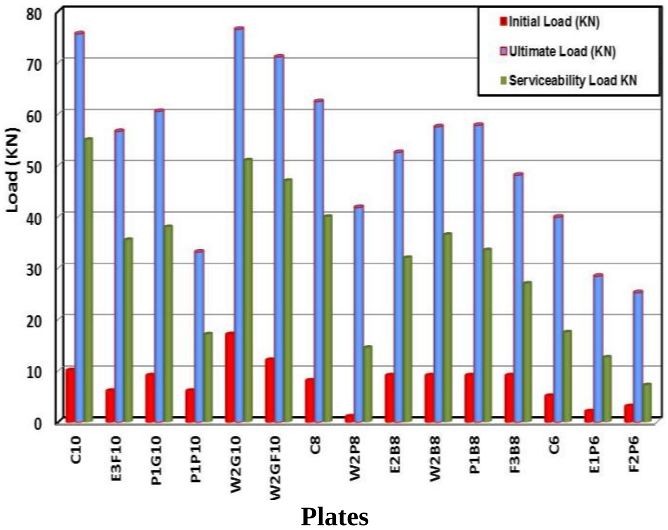


Figure 1: Initial & Serviceability & Ultimate Load for all Plates.

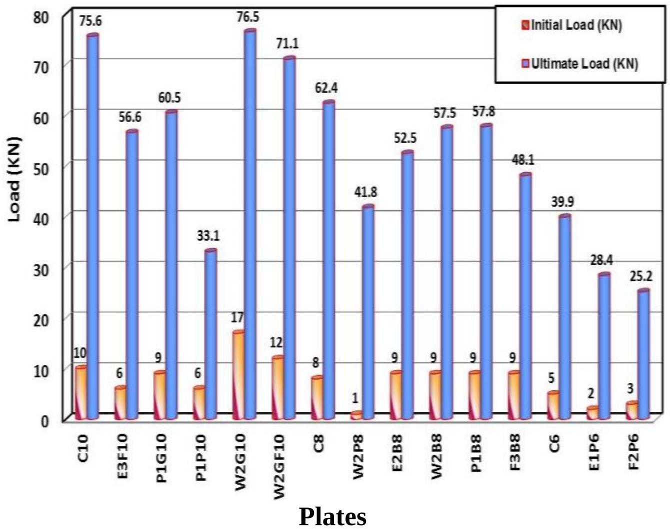


Figure 2: Initial & Ultimate Load for All Plates.

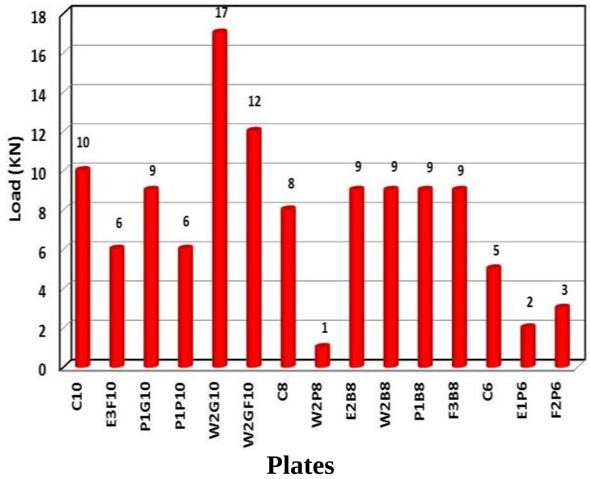


Figure 3: Initial Load for All Plates.

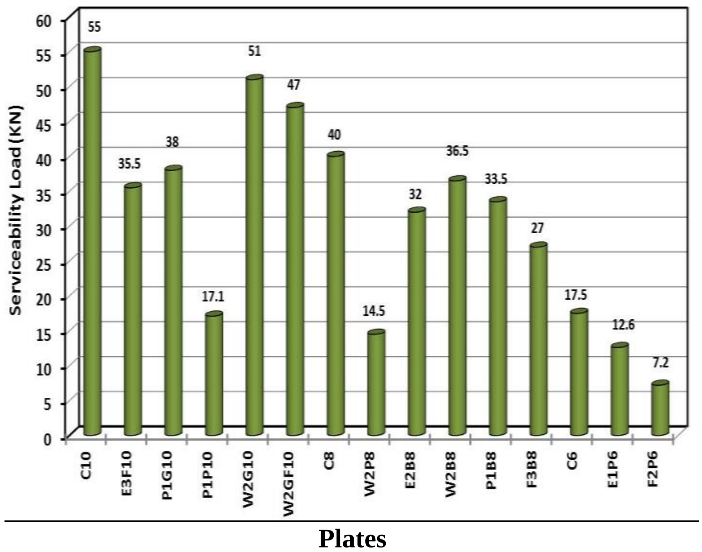


Figure 4: Serviceability Load for all Plates.

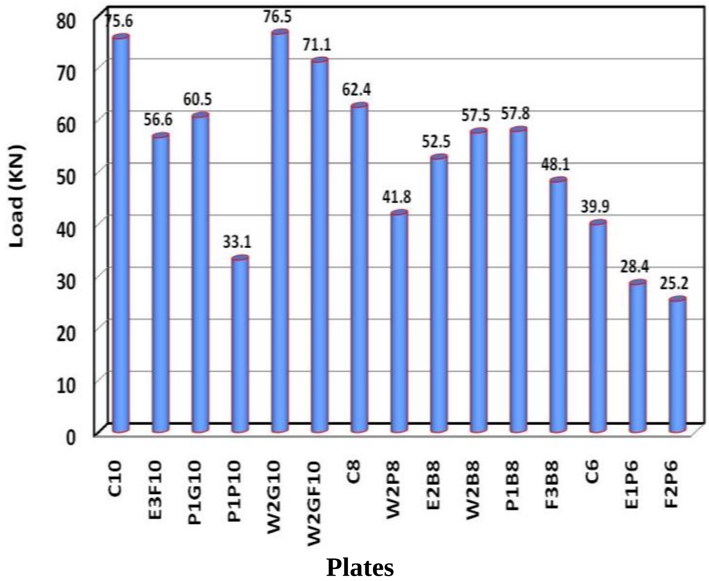


Figure 5: Ultimate load for all plates.

3.2 Deflection Values:

The load-deflection curves of all plates can be seen in Figs. 6 to 22. It can be seen that the load is proportion to the deflection values before cracking of concrete. The mechanical behavior of all beam have three stages. The first stage is elastic stage. The load-deflection relationship is linear (load is proportion to deflection values). It ends once the first crack emerges. The second stage is crack propagation stage. The load-deflection relationship is nonlinear line (curve). The third stage is failure stage.

The maximum deflection values of control plates were the largest deflection values, and the ultimate load of the control plates compared to repaired plates using filler materials technique. The deflection values were affected as the thickness of plate increased, the type of meshes and the type of filler materials.

The maximum deflection values were decreased by about (28.6%, 50%, 31%, 25.8% and 54.4%) for plates **E3F10, P1G10, P1P10, W2G10** and **W2GF10** respectively compared to deflection of control plate **C10** for thickness 100mm.. Using Plastic Pipes as a filler material increased the deflection value and decreased the ultimate load. At thickness 8 cm, the deflection values were increased by about (29.4%, 5% and 8.7%) for plates **W2P8, P1B8** and **F3B8** respectively compared to deflection of control plate **C8**. Where this deflection values were decreased by about (21.4% and 25%) for plates **E2B8** and **P1B8** respectively compared to deflection of control plate **C8**. At thickness 6 cm, the deflection value was increased by about (38.5) for plate **F2P6** compared to deflection of control plate **C6**. While the maximum deflection values decreased by about (10.4%) for plate **E1P6** compared to deflection of control plate **C6**.

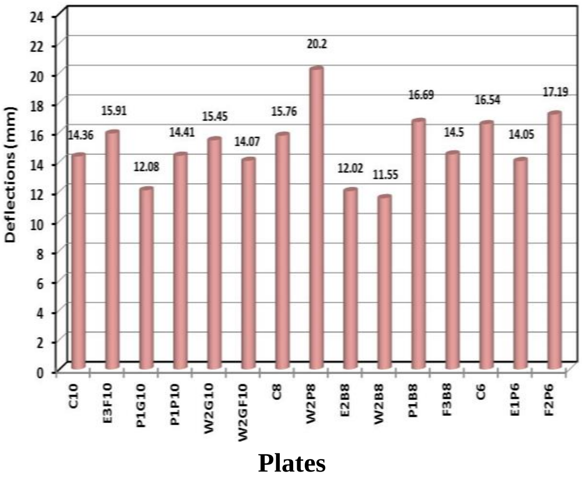


Figure 6: Maximum Deflections for all Plates.

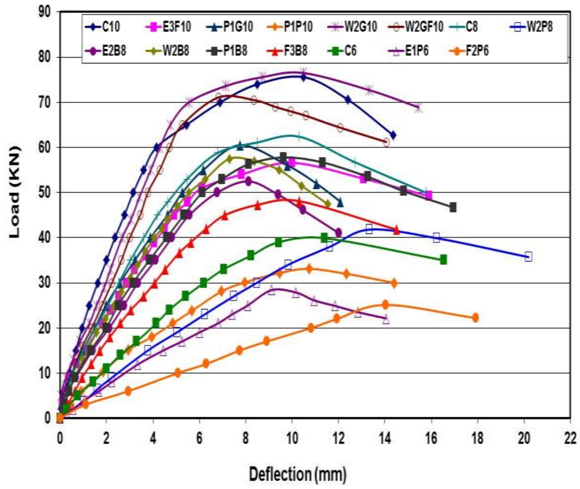


Figure 7: Load Deflection Curve for All Plates.

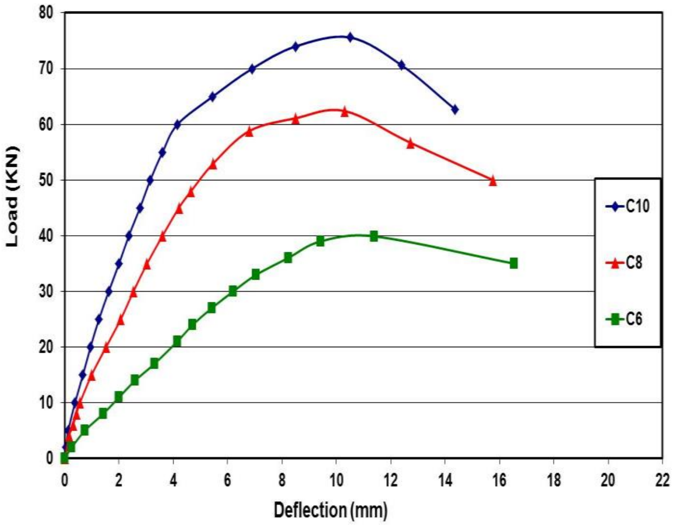


Figure 8: Load Deflection Curve for All Control Plates.

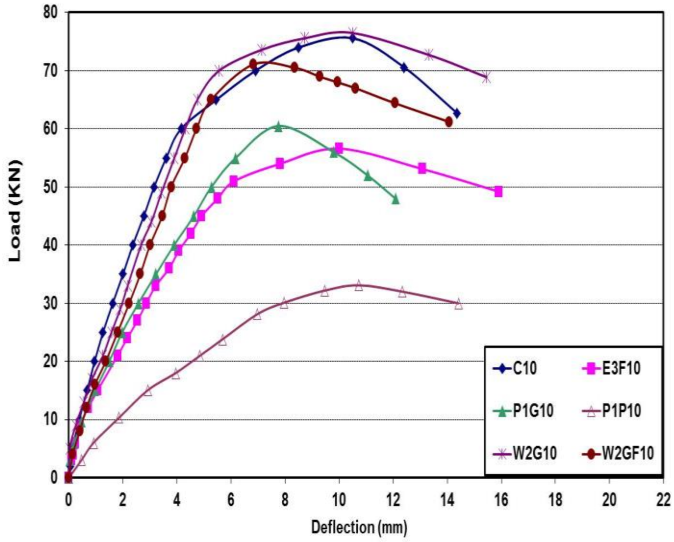


Figure 9: Load Deflection Curve for Plates 10cm thickness.

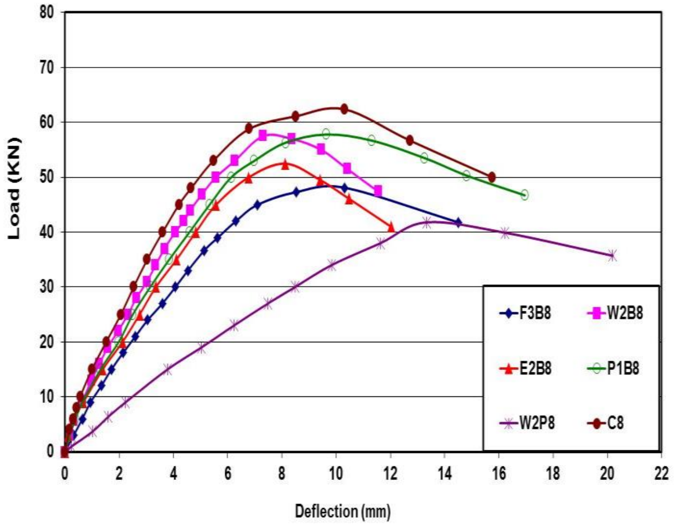


Figure 10: Load Deflection Curve for Plates 8 cm thickness.

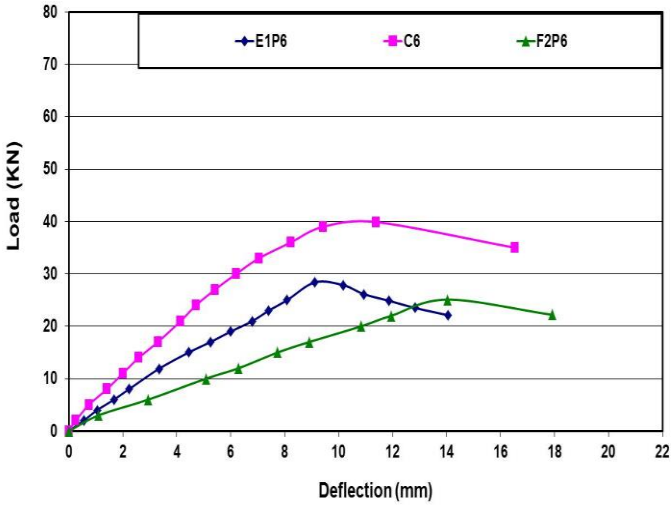


Figure 11: Load Deflection Curve for Plates 6 cm thickness.

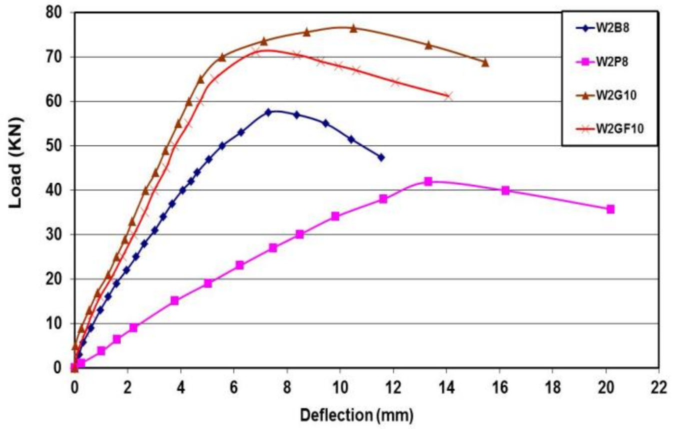


Figure 12: Load Deflection Curve for Plates with Welded Steel Meshes.

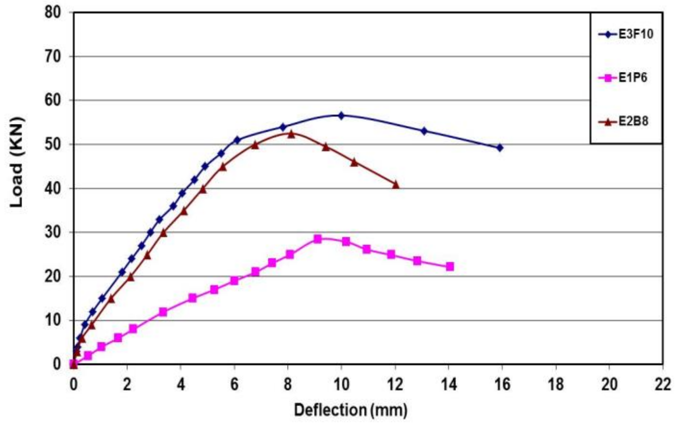


Figure 13: Load Deflection Curve for Plates with Expanded Steel Meshes.

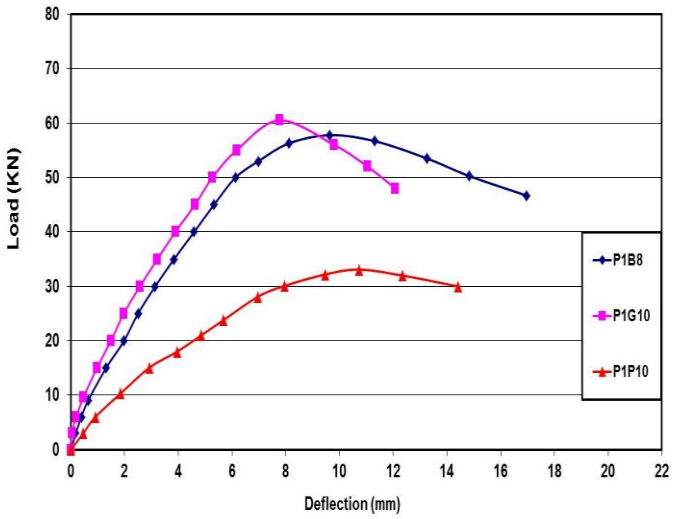


Figure 14: Load Deflection Curve for Plates with Polyethylene CE131 Meshes.

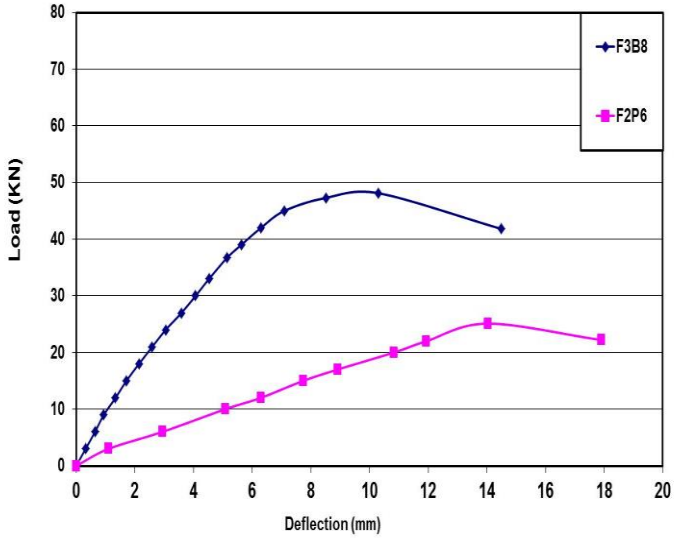


Figure 15): Load Deflection Curve for Plates with Polyethylene CE121 Meshes.

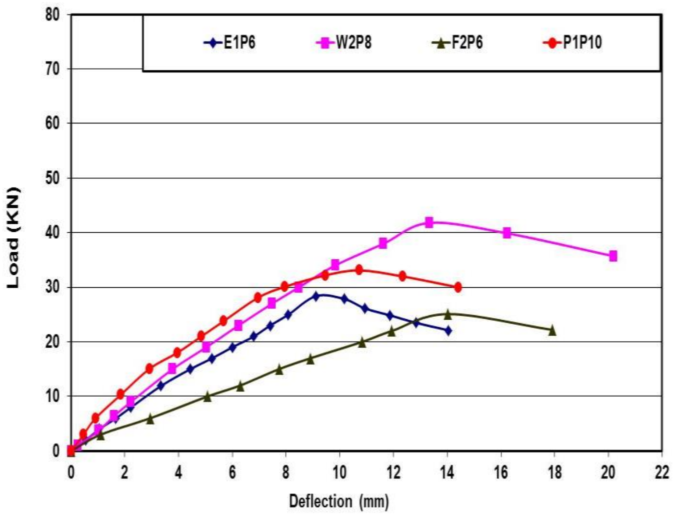


Figure 16: Load Deflection Curve for Plates with Plastic Pipes.

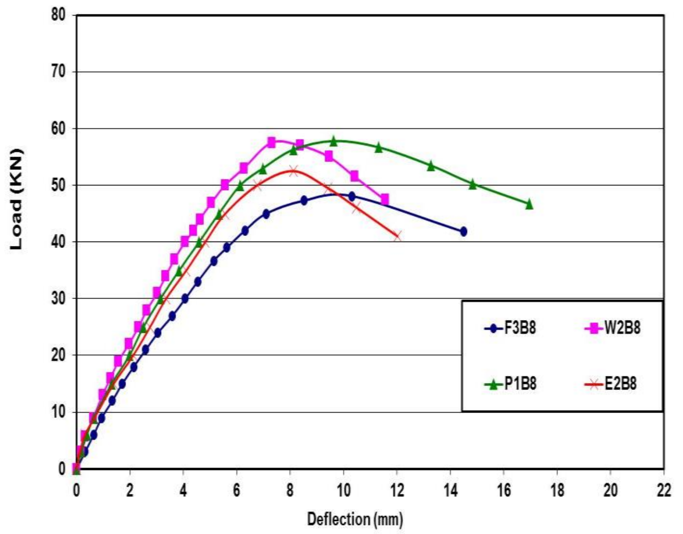


Figure 17: Load Deflection Curve for Plates with Lightweight Brick.

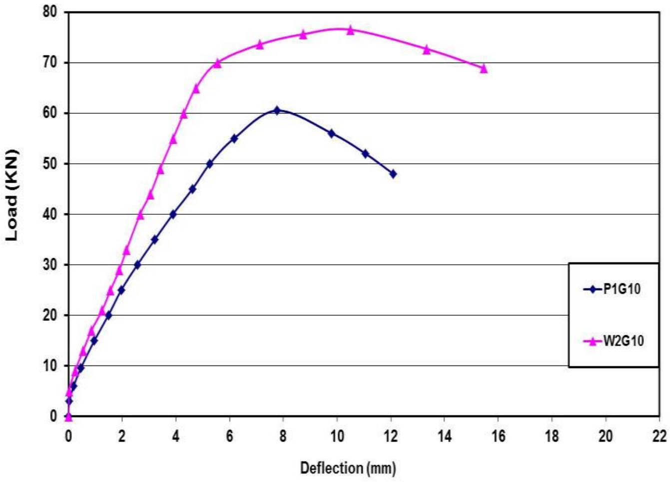


Figure 18: Load Deflection Curve for Plates 10 cm with Galvanized Steel Box.

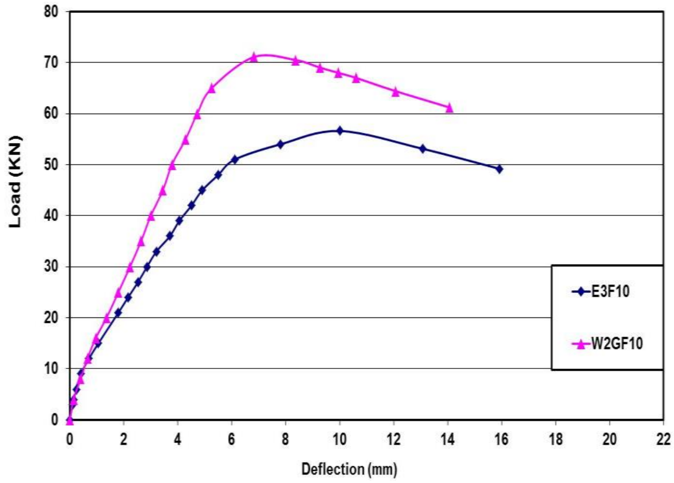


Figure 19: Load Deflection Curve for Plates 10 cm with Galvanized Steel Box & Foam Plates.

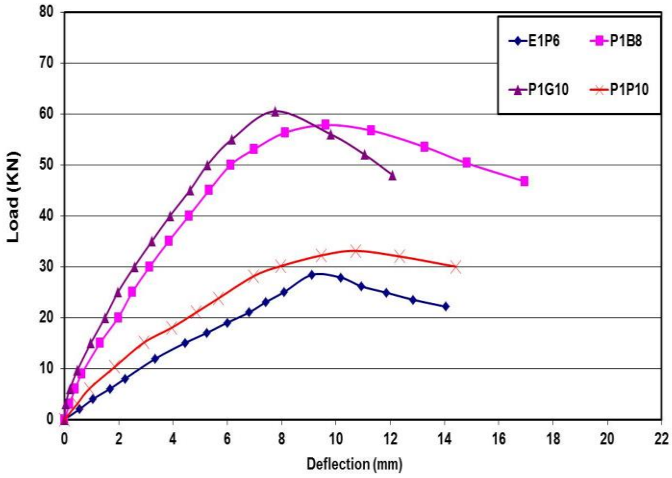


Figure 20: Load Deflection Curve for Plates with One Layer Mesh.

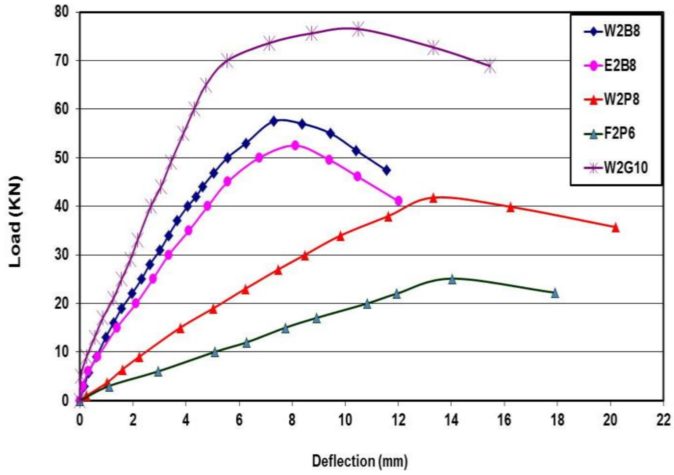


Figure 21: Load Deflection Curve for Plates with Two Layer Meshes.

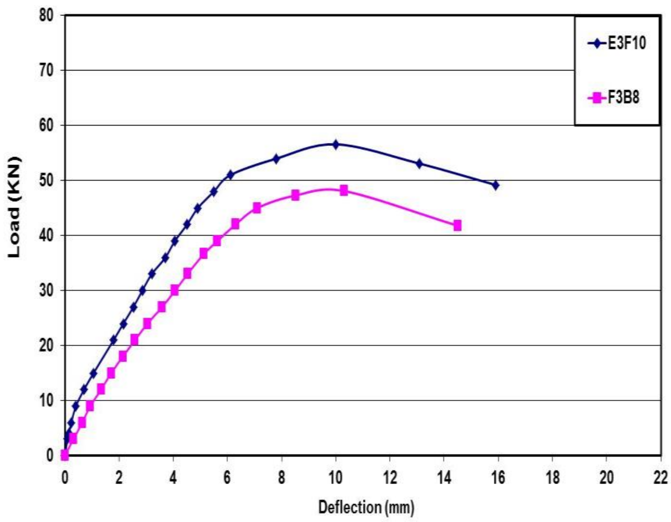


Figure 22: Load Deflection Curve for Plates with Three Layer Meshes.

3.3 Ductility Ratio:

The ductility of the beam can be expressed based on deflection of the plate. According to ACI Committee 363 [21], the ductility ratio was defined it as the ratio of mid span deflection at the ultimate load to that of the first cracking load.

U=μ/yo (Where: μ = beam deflection at failure load & yo = beam deflection at the first cracking load). In thickness 100mm, the largest and lower ductility ratio was recorded (46.29 and 10.92) for plates **(E3F10** and **W2GF10)** This increasing may refer to the increasing stiffness due to the increasing of the steel area and Vr %, due to the distribution of expanded steel meshes and their higher stiffness, this decreasing may refer to the increasing the core of the plate by using galvanized thin steel box and the lower stiffness due to the lower of mesh layers compared to the control plate **C10** respectively.

In thickness 80mm, the largest and lower ductility ratio was recorded (53.32 and 11.92) for plates **(W2P8** and **F3B8).** This increasing may refer to the increasing stiffness due to the increasing of the steel area and Vr %, as result of distribution welded steel meshes, their higher stiffness and lighter weight by employing plastic pipes. This decrease could be attributed to decreasing of the steel area and Vr %. As a result of distribution of polypropylene CE121 meshes, their lower stiffness and lighter weight of plate compared to that of control plate **C8** respectively.

In 60mm plate thickness, the ductility ratios were (18.58 and 14.35) for plates **(E1P6** and **F2P6)** This increasing may refer to the increasing stiffness due to the increasing of the steel area and Vr %, as result of distribution of expanded steel meshes and their higher stiffness. This decrease could be attributed to the lower stiffness and decreasing of Vr % as result of employing Polyethylene meshes CE121 compared to that of control plate **C6** (in the range of this study) respectively**.**

Plates reinforced with welded steel mesh gave lower ductility ratio than that of control plate. Plates reinforced with welded metal mesh gave lower ductility ratio than those of plates reinforced with expanded steel mesh or fiberglass mesh, Fig. 23. The ductility ratios of all plates are presented in Table 9.

3.4 Energy Absorption:

The energy absorption of the beam can be expressed based on deflection of the plate. According to ACI Committee 363 [21], the energy absorption was defined it as the toughness of mid span deflection, this may be calculated as the entire area under the load deflection curve from the origin to rupture.

For plates having thickness of 100mm, the largest and lower energy absorption was recorded (951.7 KN.mm and 344.19 KN.mm) for plates **W2G10 and P1P10 respectively.** This increasing may refer to the increasing stiffness due to the increasing of the steel area and Vr %, due to the distribution of welded steel meshes with using galvanized thin steel box and their higher stiffness, this decreasing may refer to the increasing the core of the plate by employing plastic pipes and their lower stiffness due to the lower of mesh layers Polyethylene meshes CE131 and compared to that of control plate C10 respectively. For plates having thickness of 80mm, the decreasing ratios of energy absorption were 1.1% and 41% for plates P1P8 and E2B8 respectively compared to that of control plate C8. For plates having thickness of 60mm, the energy absorption was decreased to 278.5 KN.mm and 259.7KN.mm for plates F2P6 and E1P6 respectively. This decreasing could be attributed to the lower stiffness and decreasing of loads with deflections compared to that of control plate C6. The energy absorption of all plates is presented in Table 9 and Fig. 24.

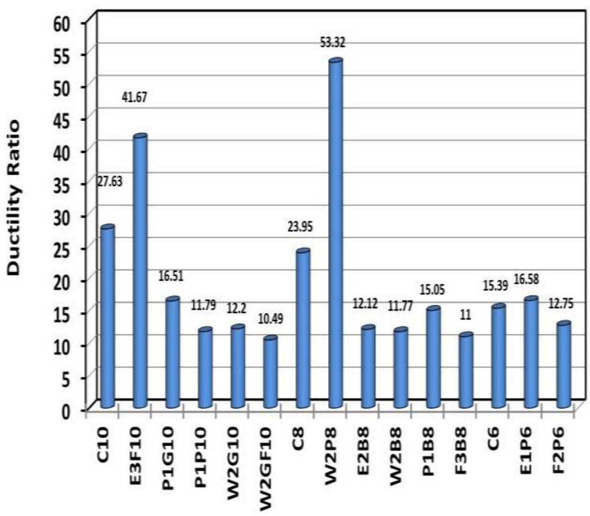


Figure 23: Ductility Ratio for all Plates.

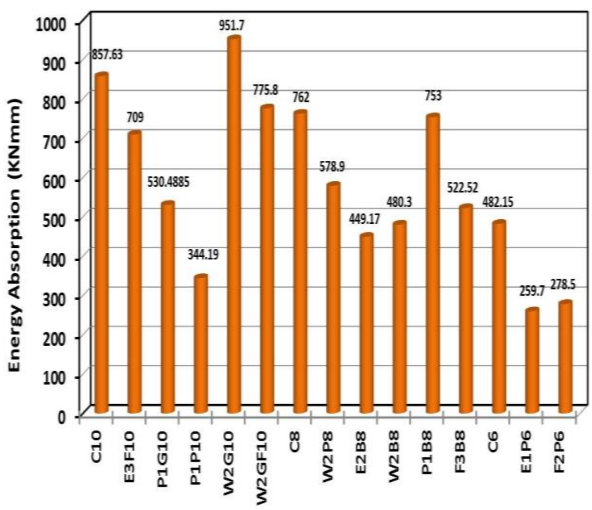


Figure 24: Energy Absorption for all Plates.

3.5 Strain Values:

Figs. 25 to 39 show the measured compressive-strains and tensile-strains values of tested plates. Test results indicated that the values were affected by the thickness of the plate, the type of filler materials and type of meshes used. Results indicated also that the values of strains decreased by noticed values due to the increasing of the stiffness values of plates.

In 100 mm thickness, the lowest and higher strains were recorded for plates (**W2G10** and **P1P10**). This increasing may refer to the increasing stiffness due to the increasing of the steel area and Vr %. As a result of distribution of welded steel meshes and using galvanized thin steel box compared to that of control plate. This decrease may refer to increasing the lighter weight of filler material (Plastic Pipes) and decreasing its stiffness compared to that of control plate **C10** respectively. In 80mm thickness, the lowest and higher strains were recorded in plates (**W2B8** and **F3B8**). This increasing could be attributed increasing its stiffness as result of increasing of the steel area and Vr %. Therefore, as a result of uniformly distribution of galvanized welded steel meshes compared to that of control plate. This decrease may refer to the decreasing its stiffness and increasing resulting from employing Polyethylene CE121 Meshes compared to that of controlled plate **C8** respectively. In 60mm plate thickness, the lowest and higher strains were recorded in plates (**E2P6** and **F2P6**). This increasing may refer to the increasing stiffness due to the increasing of the steel area and Vr % and due to the distribution expanded meshes compared to the controlled plate. This decrease may refer to the decreasing stiffness increasing due to using the Polyethylene CE121 Meshes compared to the controlled plate **C6** respectively (In the range of this study).

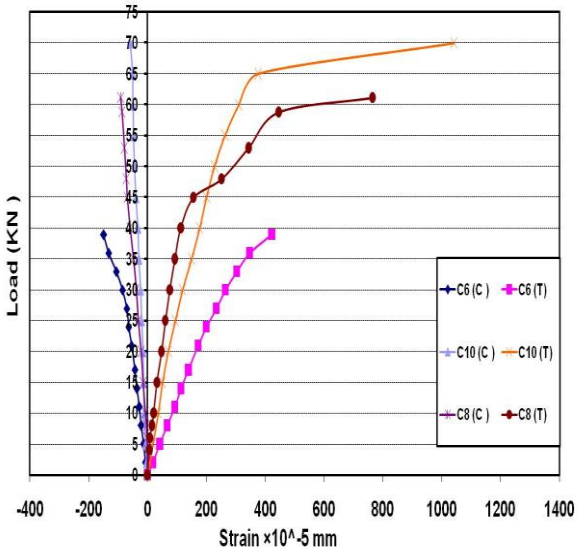


Figure 25: Load Strain Curve for Control Slabs.

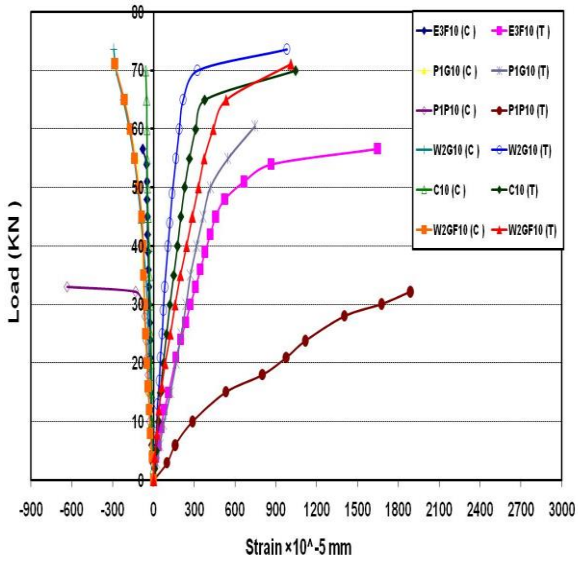


Figure 26: Load Strain Curve for Plates 10cm Thickness.

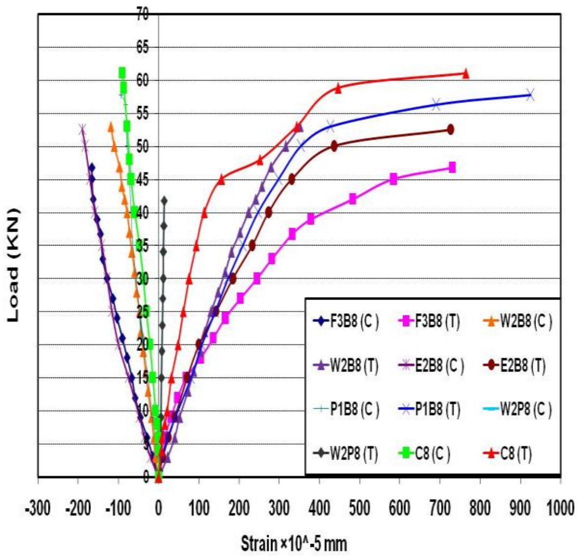


Figure 27: Load Strain Curve for Plates 8cm Thickness.

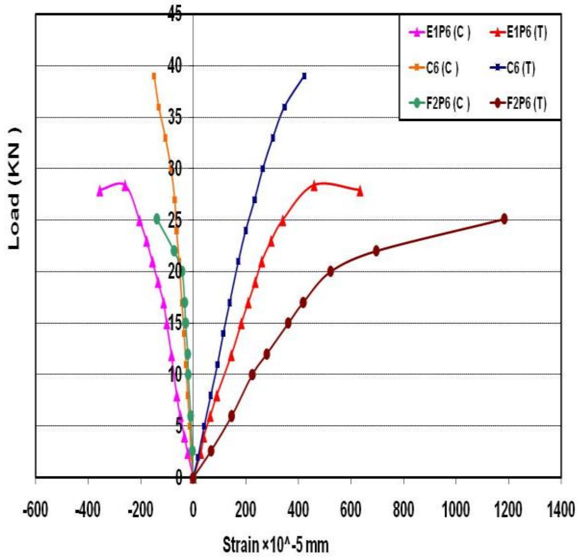


Figure 28: Load Strain Curve for Plates 6cm Thickness.

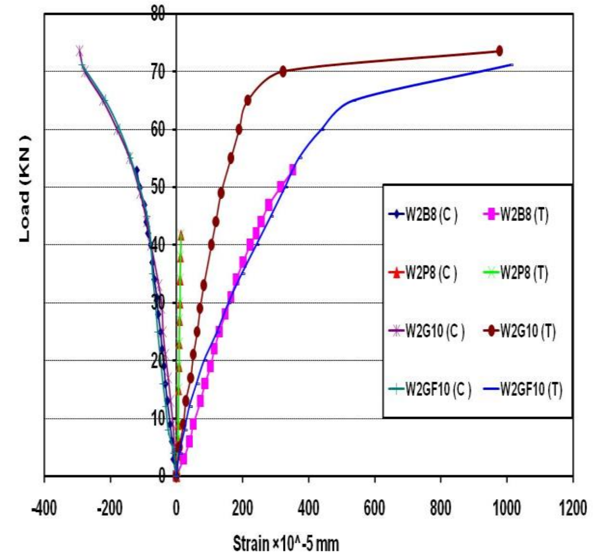


Figure 29: Load Strain Curve for Plates with Welded Steel Meshes.

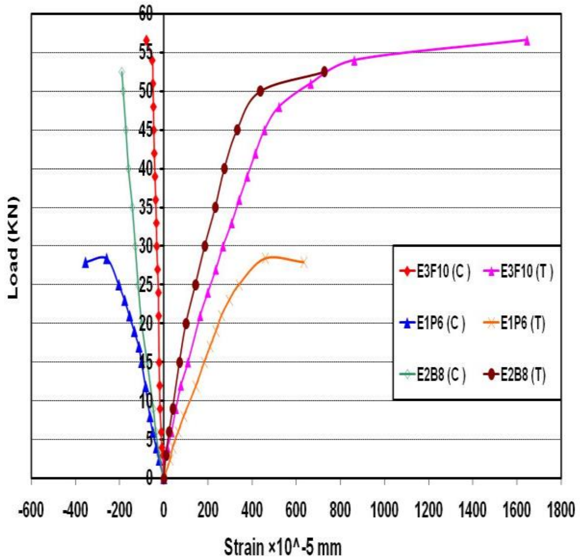


Figure 30: Load Strain Curve for Plates with Expanded Steel Meshes.

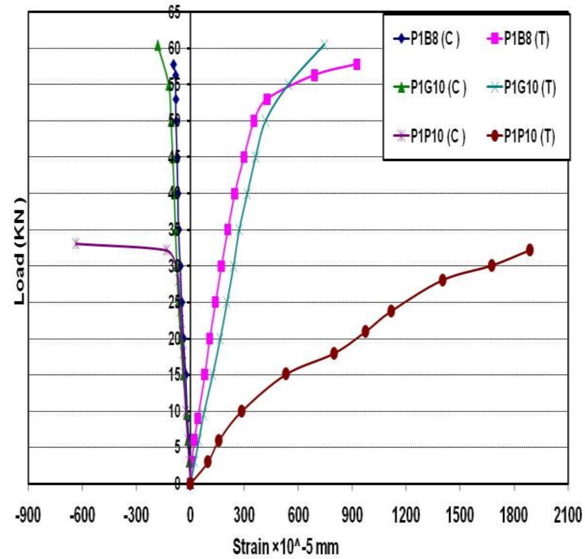


Figure 31: Load Strain Curve for Plates with Polyethylene CE131 Meshes.

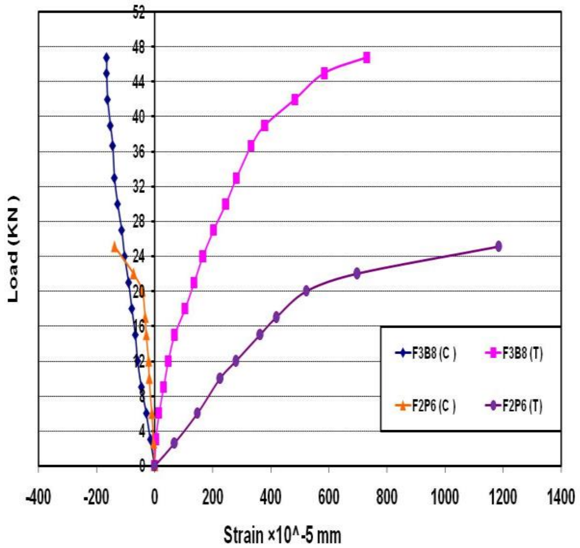


Figure 32: Load Strain Curve for Plates with Polyethylene CE121 Meshes.

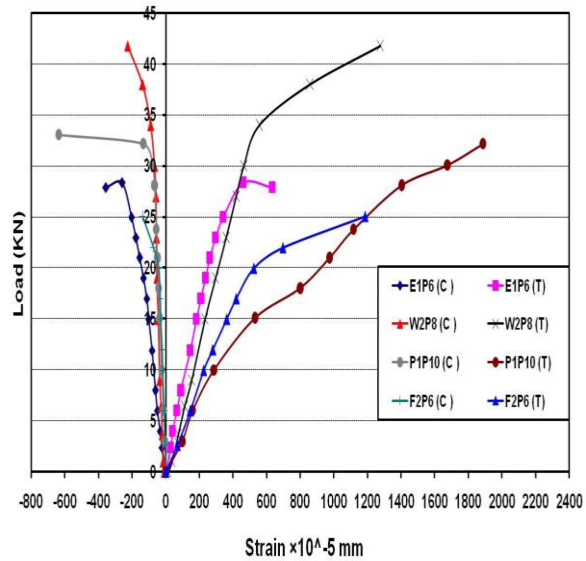


Figure 33: Load Strain Curve for Plates with Plastic Pipes.

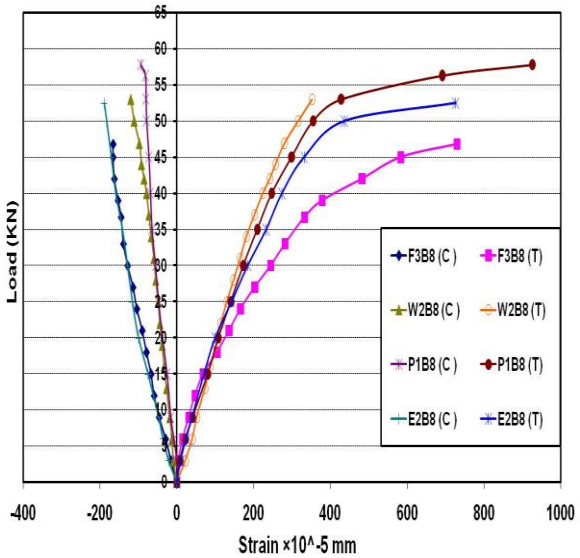


Figure 34: Load Strain Curve for Plates with Lightweight Brick.

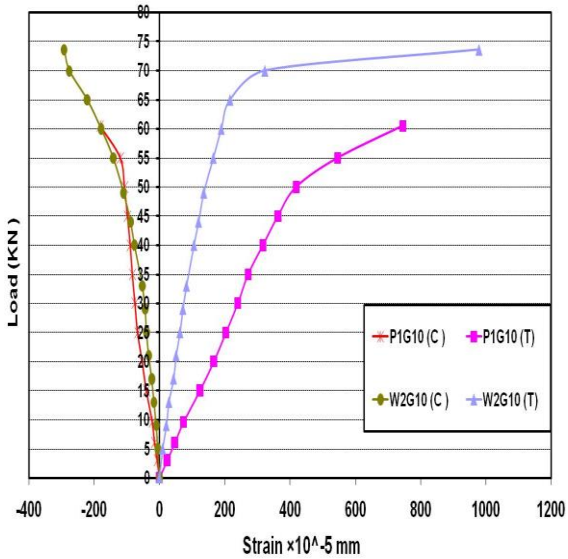


Figure 35: Load Strain Curve for Plates 10 cm with Galvanized Steel Box.

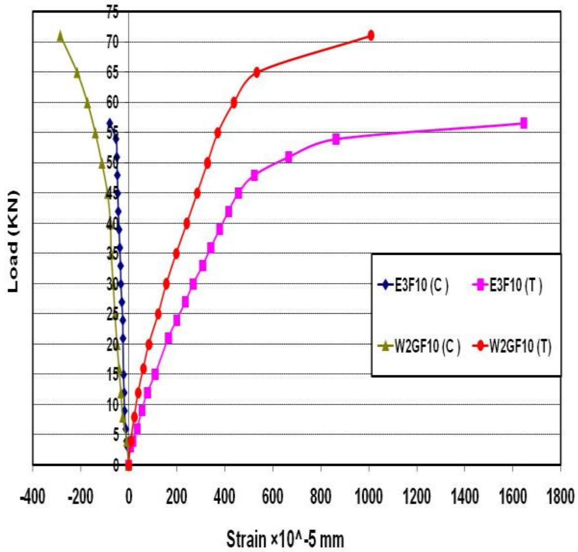


Figure 36: Load Strain Curve for Plates 10 cm with Galvanized Steel Box & Foam Plates.

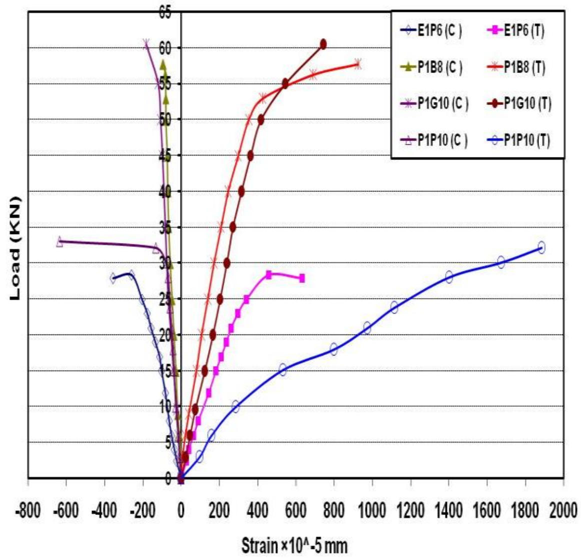


Figure 37: Load Strain Curve for Plates with One Mesh Layer.

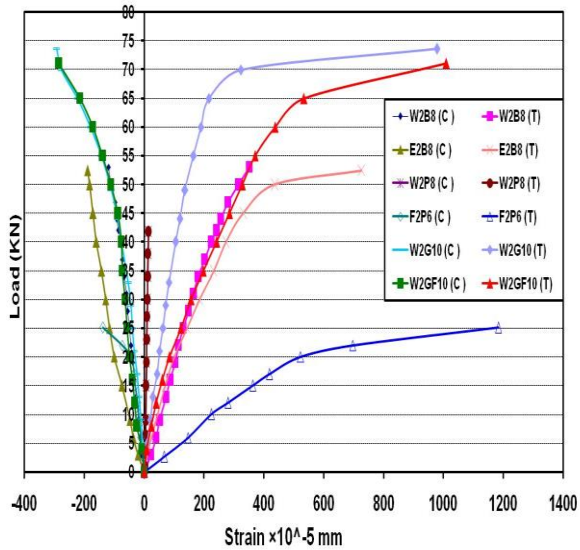


Figure 38: Load Strain Curve for Plates with Two Mesh Layers.

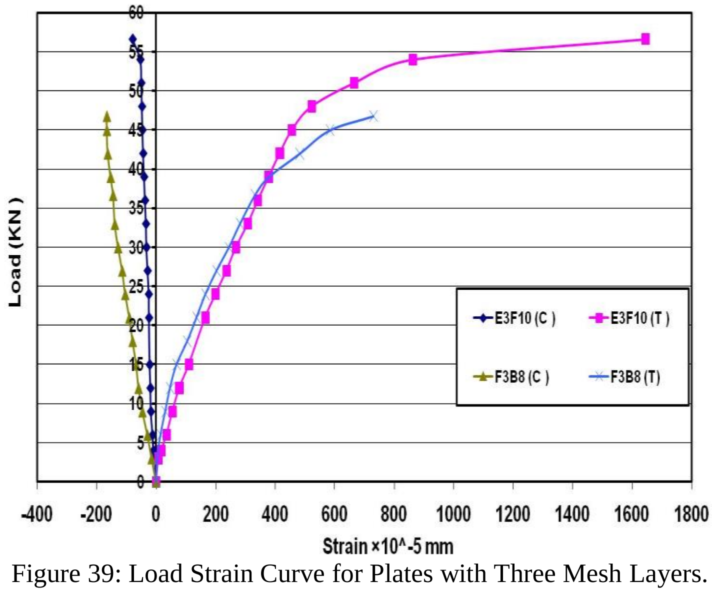


Figure 39: Load Strain Curve for Plates with Three Mesh Layers.

3.6. Crack pattern:

Fig. 40 illustrates an example for crack pattern of the tested plates. Flexural crack and flexural-shear cracks are emerged after plates collapsed. The number of cracks decreased as the thickness plates increased. The distribution of cracks was more evenly due to the addition of filler materials into plates.

Figure 40: Crack Pattern for Slabs with Thickness 10 cm.

Crack Pattern for Slabs with Thickness 8 cm

Upper Face Side Face Lower Face

Figure 40: Crack Pattern for Slabs with Thickness 10 cm (Cont’d).

4. Conclusions:

Based on the reached experimental results in this research the following conclusions could be drawn as follows:

1) The initial first cracking loads, ultimate loads and the deflections were affected with the type of filler materials, thickness of plates, type of reinforcement and the numbers of employed layers meshes.
2) Using filler materials decreased the initial and ultimate loads and increased the deflections.
3) Increasing the thickness of the developed lightweight ferrocement composite plates increased the initial and ultimate load such as concrete plates.
4) The type of mesh used has a great influence on initial cracking and ultimate loads of the tested plates.
5) Employing galvanized welded steel meshes as reinforcing materials in lightweight ferrocement composite plates was found to be more better compared with those reinforced with expanded metal mesh, this could be attributed to the uniform distributed in both directions of welded steel meshes.
6) Using expanded metal meshes in reinforcing lightweight ferrocement plates were significant as result of their higher mechanical properties compared to those reinforced with polyethylene meshes for durability reason.
7) Irrespective of the type of reinforcing materials, the reached strengths at all stages of loading were found to increase with number of layers meshes employed.
8) Composite ferrocement plates with different thicknesses and various types of filler materials were developed with better deformation characteristics, high strength, high ductility, energy absorption properties, lighter in weight with great saving could be useful for developed and developing countries alike.
9) The higher ductility ratio recorded (53.32) for plate W2P8 and the higher energy absorption recorded (958.54KN.mm) for plate W2G10 compared to lightweight ferrocement plates.

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